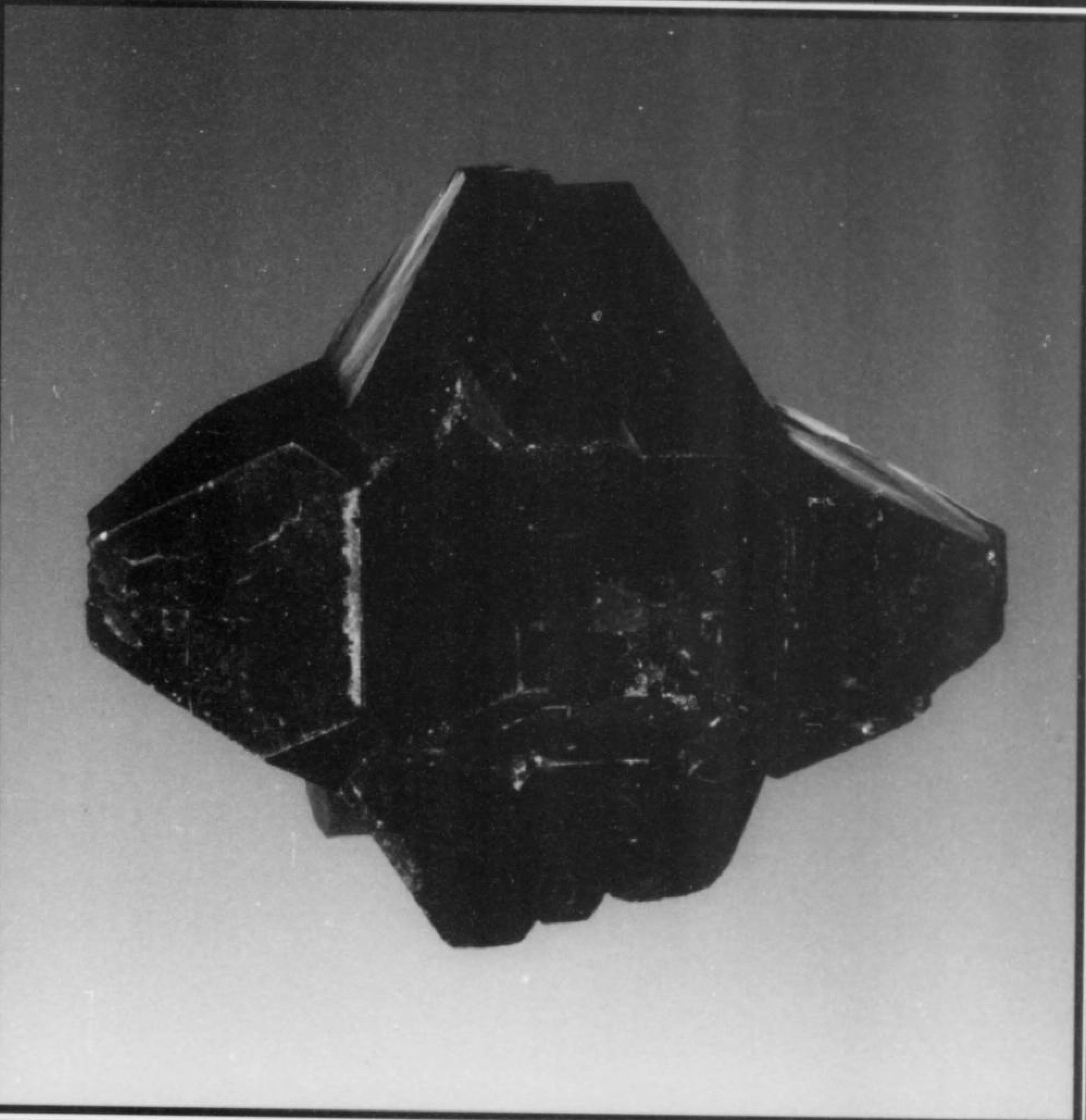
Mexico



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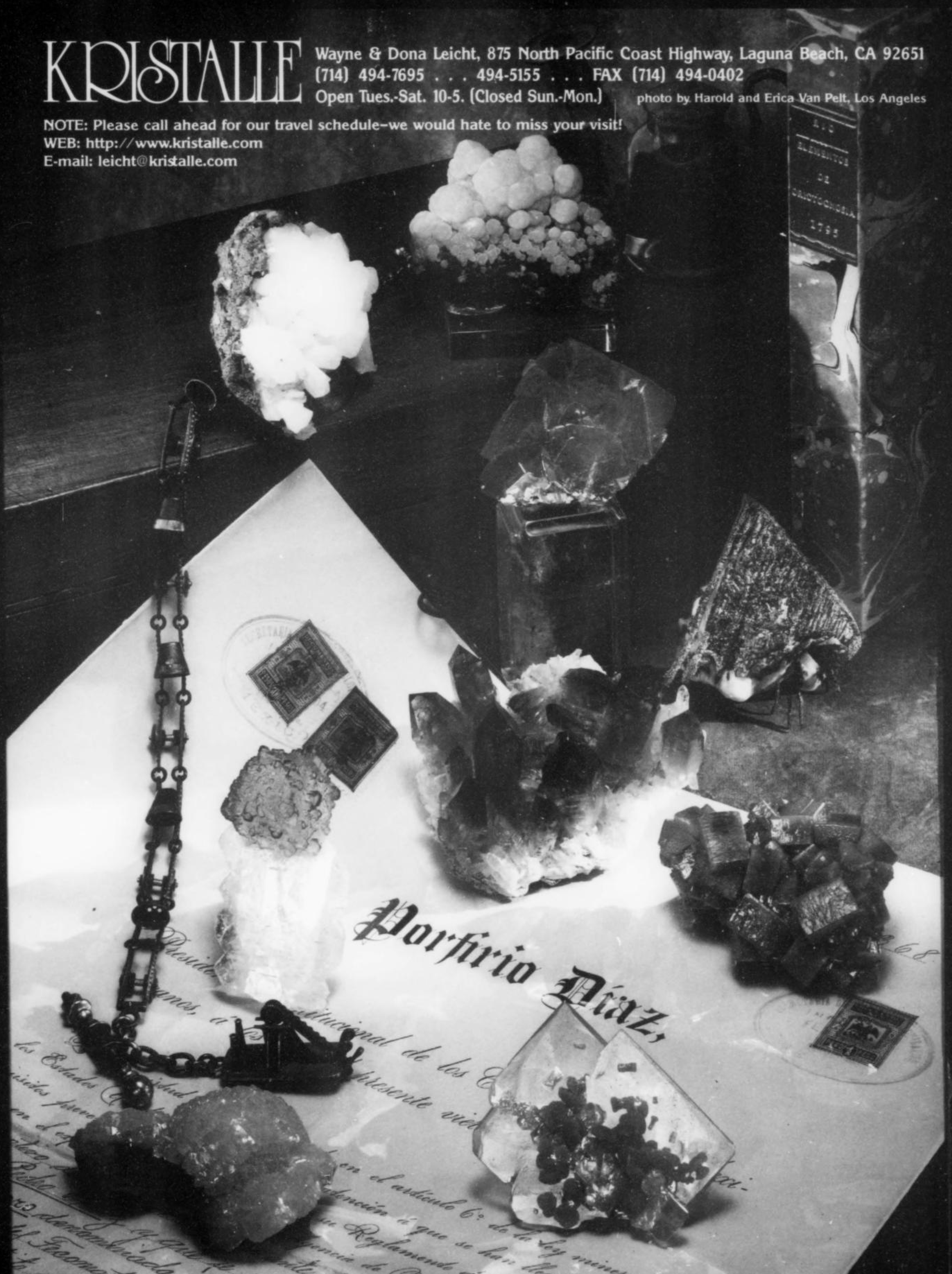

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Mexico

Special Issue I

Boléo

◆ Famous mineral localities: Boléo, Baja California, Mexico

by P. Bariand, J. C. Boulliard,
I. Chancelier-Dumielle & V. Tournis

Boléo

◆ Boléo, A Classic Locality Reworked

by E. Swoboda

The Mineralogical Record

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FRONT COVER: ("The Great") CUMENGITE, in the Sorbonne Collection, Paris. The specimen, collected around 1920, measures 3.5 cm. Photo by Nelly Bariand.

Mexico

Since the time of the Spanish Conquistadors, Mexico has been famous as a land of mineral wealth. Silver and gold were the first to be sought, and, although gold is now dwindling a bit, silver continues to come from the ground as the native metal and as a fascinating variety of other argentiferous species. Today, of course, many other metals are recovered as well, including copper, iron, lead, zinc, molybdenum and vanadium. The heavily mineralized mountain ranges extending almost the full length of the country, the widespread mining activity and the centuries of exploitation have yielded a treasurehouse of mineral specimens for the collector. This good fortune continues as still-active mining operations, large and small, and a seemingly unlimited number of abandoned mines and prospects continue to produce more fine minerals.

Although the geological and economic literature on Mexican mining is extensive, the writings specifically on mineralogy are far less so. What exists is often brief, commonly in Spanish, and frequently in obscure journals not readily available to the collector, even in a large university library. A surprising amount is in French, the legacy of the brief French colonial war and occupation in the late 19th century. All in all, however, the collector-accessible literature on Mexican mineralogy is remarkably scarce considering the tremendous importance of the region and its adjacency to the United States.

The lack of writing on Mexican minerals is clearly reflected in the 28 years of publication of the *Mineralogical Record.* Locality articles published during all that time number only four, two of which had to be written by the editor, owing to the lack of other available authors.

To remedy this great gap in the collector literature, the *Mineralogical Record* inaugurates with this current number the ***Mexico Series*** of special issues. Like the Arizona Series published some years ago, it is planned to continue for at least five issues, maybe more, spread out over the next few years. An invaluable resource during the preparation of these issues will be the Miguel Romero collection of Mexican minerals now held by the University of Arizona Mineral Museum in Tucson; literally thousands of specimens in that incredible collection are suitable for photography. Another important resource will be the Peter Megaw library, also here in Tucson, an extensive archive of obscure literature on deposits throughout Mexico; Peter has also agreed to assist as guest co-editor during the writing and review of articles for the series.

In view of the above preparation, we are now officially issuing a ***Call for Papers*** on mineralogically significant Mexican localities, and on other aspects of related interest. Collecting memoirs and stories will also be considered. So, if you have a favorite locality that you would like to write up, or if you have a story to tell about Mexico and its minerals, please be sure to contact the editor. We need the help of knowledgeable authors; and you will enjoy being a special part of this beautiful and informative series destined to become a prominent collector reference for countless decades to come.

One last thing to mention to our subscribers: There is no telling how long we will be able to keep each issue in the series in print. Readers wishing to put away a few extra copies of each Mexico issue should mail or fax in the special ***Reply Card*** which has been inserted into this issue. You will be mailed and billed for your extra copies of this issue, and later will be *automatically* mailed and billed for the *same number* of extra copies of each succeeding issue in the series when published. We used this system for the Arizona series and it worked well. And by the way, with the card order you get the *wholesale* price!

So sit back now in that comfortable leather chair, prop your silver-studded boots up on the mesquite coffee table, sip your margarita and enjoy issue #1, on the minerals of Boléo. As the red sun sinks slowly behind the Sierra Madre Occidental, you can relax secure in the knowledge that we are already busy at work on the next installment. *Adelante!*

Wendell E. Wilson

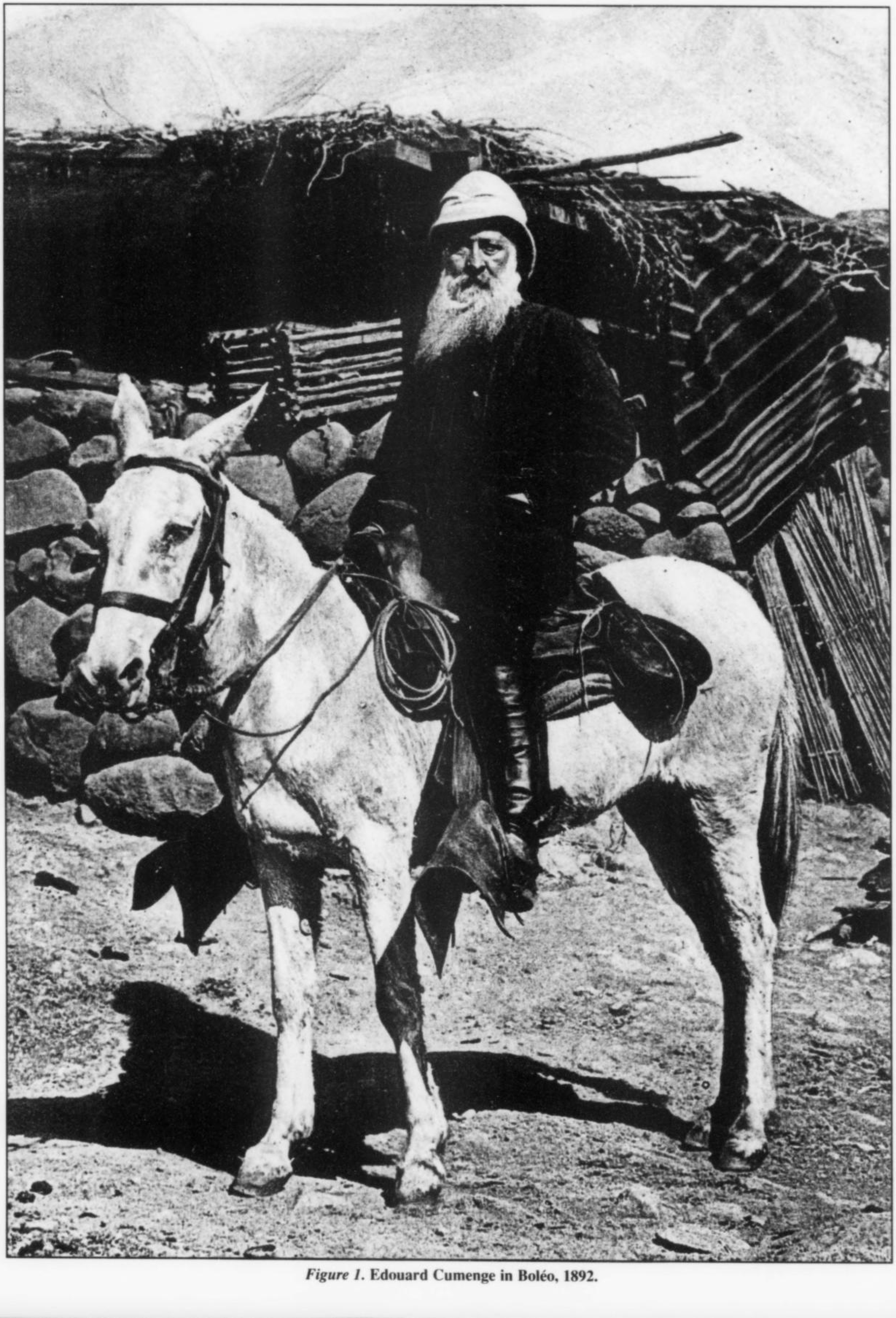

Figure 1. **Edouard Cumenge in Boléo, 1892.**

famous mineral localities:

Boléo

Baja California, Mexico

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Boléo is famous as the type locality for the lead-copper oxychlorides cumengite and pseudoboleite, and the lead-silver copper oxychloride boleite. Attractive specimens of these lustrous, deep blue minerals, in cubes and characteristic star-shaped growths, are the pride of fine private and public collections around the world.

**Location and History* by I. Chancelier-Dumielle; *Edouard Cumenge* by P. Bariand; *History of Investigations* by J. D. Boulliard; *Introduction, Geology,* and *Mineralogy* by J. C. Boulliard and V. Tournis. English translation by Winifred Guershon.

Figure 2. **Boléo, ca. 1911.**

Introduction

The Boléo deposit owes its celebrity to three minerals that were discovered there for the first time—*boleite*, *pseudoboleite* and *cumengite*.

These minerals belong to what has come to be called the "boleite group," to which are added *percylite* (doubtful species) and *paraboleite* (discredited). Let us also note that a mineral found in the Mendip Hills (England) was given the name *diaboleite* by Spencer (1923), based on its external resemblance to boleite and on its chemical formula, which places it in the same family. The minerals in this group are (hydrated?) oxychlorides of lead, copper, and, secondarily, silver. They have been the subject of a large number of scientific works, which reveal a certain lack of consistency on a number of points (see the mineralogy section). *Boleite* (often associated with pseudoboleite) has been found at 20 or more localities throughout the world, while *cumengite*, on the other hand, has only been found in the Boléo deposit, in the Laurium scorias, and in the Ruhr (Winchell and Rouse, 1974). These are secondary minerals that occur in the oxidized zones of hydrothermal sulfide deposits. They were formed during the reaction of primary lead and copper sulfides with supergene solutions charged with chlorides. The primary source of lead (and secondarily, silver) is galena, and the source of copper is chalcopyrite and/or copper sulfides (chalcocite) (Cumenge, 1893). The vast majority of these deposits are located in arid zones where chlorinated salts present in the soil invade the supergene solutions.

Humphreys *et al.* (1980) determined the conditions for stability in an aqueous solution at 298.2°K for cumengite and other oxychlorides (chloroxiphite, diaboleite, mendipite), and described their associations with other oxidized lead minerals (cotunnite, paralaurionite, litharge). Similar works pertaining to boleite and pseudoboleite were published shortly thereafter (e.g. Abdul-Samad *et al.*, 1981). They are in agreement with the associations found in nature, and show, among other things, that boleite must be formed before any pseudoboleite is deposited.

On the basis of their unusual color and habits, the specimens in the boleite group collected in the Boléo mining district can be classified among the mineral world's most curious and remarkable products. The specimens collected during the early days at Boléo remain the best known after almost a century. They make this locality one of the world's classic mineralogical sites.

It is to the geologist and consultant Edouard Cumenge that we owe the first scientific research on and the first collection of these indigo-blue minerals. Later, he reported on his discoveries and explained their formation, as follows (Cumenge, 1893):

> Boleite and cumengite were discovered in the same region, in a part of the great Boléo copper deposit, which has been exploited on a vast scale for six years now by the Boléo Company, near the port of Santa Rosalia in Baja California (Mexico). This immense deposit is made up of a series of cupreous layers intercalated with tuffs and conglomerates. Of the four cupreous layers, superposed at an average distance of about 50 meters, the third layer—the only one exploited to date—revealed, at a very few points, some plumbeous *irrup-*

Figure 3. **The picking table at Boléo, ca. 1910.**

tions that allowed the formation of the *plumbocupreous* mineral species with which we are concerned. The *boleite* discovered in the region exploited by the *Cumenge shaft* in the Soledad Valley appears in the form of cubic crystals of a beautiful indigo-blue scattered throughout an argillaceous gangue called soapstone (*jaboncillo*, in Spanish), sometimes grayish, sometimes reddish, sometimes greenish, found on top of the cupreous layer proper. Some crystals within the cupreous layer itself are implanted on crystalline gypsum, on atacamite, on anglesite in deformed crystals, or on phosgenite in little clustered crystals.

Cumenge was not the only person to collect these minerals. The miners rapidly become aware of the interest the minerals aroused in the French management personnel who had included mineral collecting among their infrequent leisure activities; thus, miners acquired the habit of cashing in on specimens that they found by trading them for certain goods or services.

The history of the discoveries of pockets rich in exceptional minerals, and the frequency of such pockets, is little known. In the last decade of the 20th century, the majority of the fine specimens known remain those that came directly from Cumenge himself. The first years of collecting yielded rather rich finds of large (up to 2 cm) cubes of boleite, cumengite, and pseudoboleite. In 1898, Lacroix reported that cumengite and pseudoboleite were hardly to be found in the deposit any longer, and that the large boleite cubes were being encountered more rarely (the cuboctahedrons more often). It was in 1920, however, that the giant cumengites were discovered. The source appears to have been a single miner, who gave the crystals to the mine physician in payment for his services.

After several visits in 1959 and 1969, Edward Swoboda joined forces with William Larson, and the company they founded, Pala Properties International, undertook in 1973 to search for more specimens of the quality of those collected before the beginning of our century. The prospecting site chosen, naturally, was the portion of the mining district described by Cumenge, that is to say the Amelia mine, near Curuglu Canyon. It was in this canyon that, thanks to the skill and the labor of the older miners who had worked in this district, a shaft angling downward for 175 meters at an angle of 32° toward the Cumenge shaft and the old galleries was dug. This project required a little more than ten months of continuous digging, and was rewarded with boleites up to 2 cm (sometimes accompanied by balls of paratacamite and anglesite crystals) and cumengites measuring 1 cm (Swoboda, 1976).

In the last few years, all specimens collected have come from excavations where (following the infrequent rainfall) blue crystals, which certain residents of the region hasten to gather up, are revealed.

The precise locality for boleite and associated minerals still appears to be the Amelia mine, since subsequent prospecting efforts in the district have failed to reveal these minerals elsewhere (Wilson, 1955).

The supply of minerals from the Boléo deposit is extremely modest at the present time, although some lots of specimens brought back by the French engineers sometimes provide surprises. For example, a few years ago, a mineralogist and collector found a batch of specimens containing several dozen boleites, pseudoboleites, and cumengites of good quality at the flea market in Paris. The seller saw no value in these curiosities and was asking a laughably low price for them.

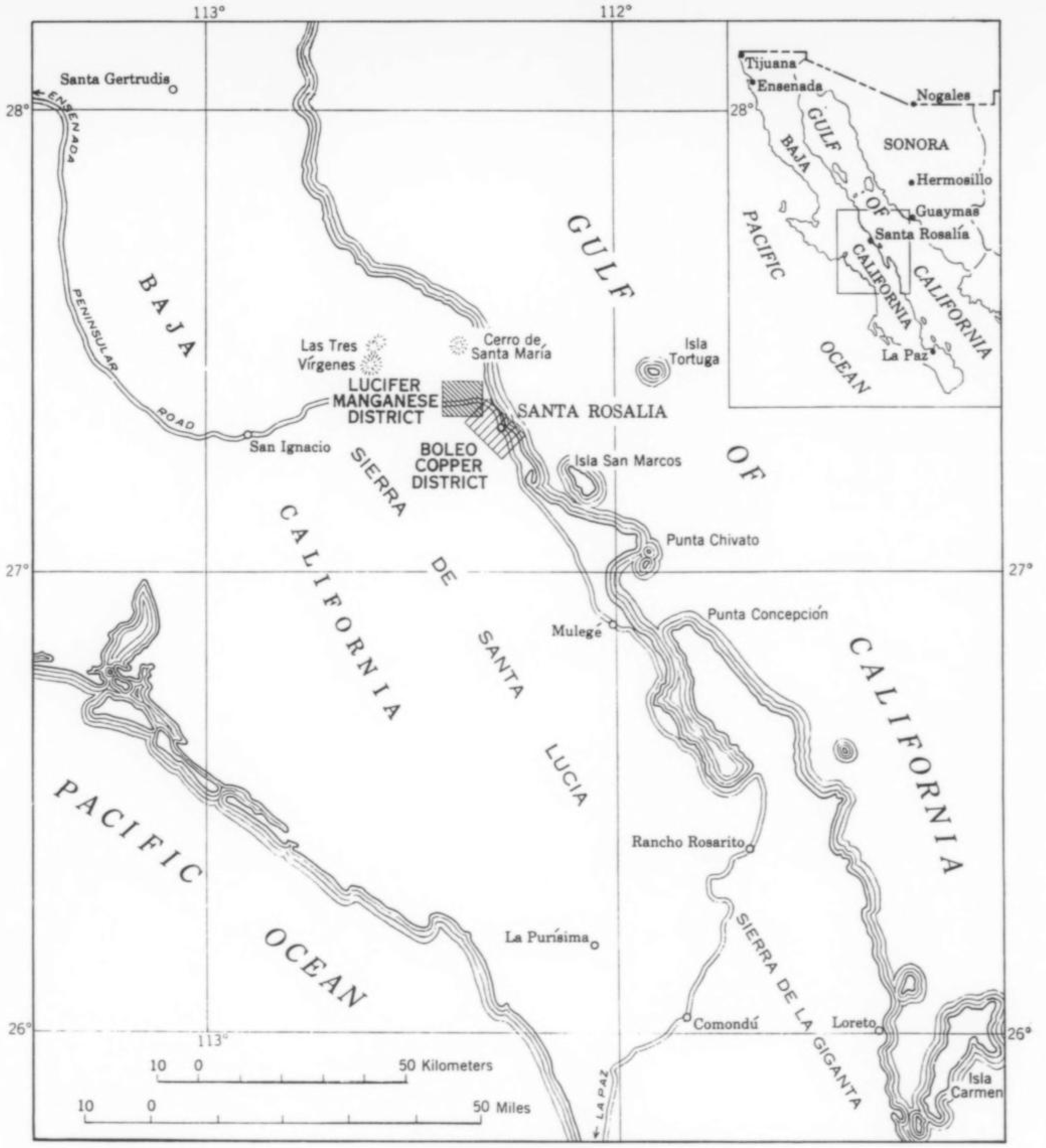


Figure 4. **Location map.**

Location

The Boléo district is located in the heart of an unpopulated peninsula—Baja California. This tongue of land, 1,300 kilometers long, narrows from the north to the south, from an east-west breadth of 180 km to less than 50 km at the narrowest point. Isolated by the Pacific Ocean on the west and the Gulf of California on the east, and characterized all along its length by mountain chains, the peninsula is an extension of the North American coastal range that runs along the Pacific Ocean coast. An extension also of the Sonoran Desert that covers the greater part of the northwestern portion of Mexico and parts of Arizona and California, Baja California receives less than 250 mm of rain annually. Some places occasionally go four or five years without a drop of rainfall.

The geographic isolation of the peninsula and the extreme aridity of its climate have always been the reasons for its low population density. In fact, while Baja California was the fourth largest state in Mexico in area (144,092 square km) at the end of the 19th century, it was nonetheless the most sparsely populated. The 1889 census records a total of 31,167 inhabitants, or 0.2 persons per square km. However, it should be noted that this was merely an average, as three-quarters of this population was concentrated at the northern and southern ends of the peninsula. In the north, the frontier with the United States attracted a number of Mexican citizens hoping to cross the border, while in the south, the port town of La Paz provided a link with the continent and Mexico City, the capital of the country.

Today, as the end of the 20th century approaches, the situation remains unchanged. Baja California is still the most sparsely populated state in the country, and the population is still concentrated at the extremities of the peninsula, with an imbalance in favor of the north, again because of the attraction exerted by the United States.

History

The history of Boléo is primarily the history of the Boléo Mining Company. The story is interesting because the undertaking developed under a particular political regime, and it would not have survived under different circumstances. The Company was a typical example of a business that prospered under liberalism but declined with the appearance of socialism. There is also the human interest aspect, involving the Frenchmen who undertook to establish a town in the desert and to take responsibility for its subsistence, whatever the circumstances might be.

Figure 5. **Porfirio Diaz (1830–1915).**

PORFIRIO DIAZ

The political environment in late-19th-century Mexico had a profound effect on many famous mines and mineral localities, including the Boléo district. A brief summary will give some insight into the times.

The presidential election in Mexico in November of 1876 put General Porfirio Diaz in power. He was installed in office in May of 1877. Forty-six years of age at that time, he was vastly ambitious and would use any means available to achieve his purposes. In 1878, 1887 and 1890, with a view to remaining in office, he altered the constitutional articles governing the procedures for gaining access to executive power. These manipulations enabled him to ensure his election to the presidency of the Federal Republic several times in succession and to remain in power for 30 years. The longevity of his administration was in sharp contrast to the previous lack of continuity; between 1821 and 1867, 32 successive governments had ruled the country. There had been a long, troubled period during which the various factions, overly involved with their own quarrels, had allowed the country to sink into chaos.

The civil wars that followed Independence (1821), and then the foreign wars against the United States and France (which ended in 1848 and 1867, respectively), had profoundly damaged the national economy, leaving it in a disastrous state. In order to recover and to launch economic development, Mexico needed stability, but also, above all, it needed capital, of which there was a severe shortage. After Independence the Spaniards had departed, taking their fortunes with them, and the foreigners who had undertaken some commercial or industrial operations had seen their assets vanish in the turmoil of wars and revolutions. The foreign debt to Western powers contracted by Mexico was not repaid, since there were no funds. The country was in ruin and had lost credibility with international public opinion.

Porfirio Diaz, a dictator unconcerned with democracy, wanted peace at any price in order to devote his efforts to economic development. Destroying opposition in every form and establishing his power over the long term, he succeeded in re-establishing order and creating an efficient administration capable of guaranteeing the transfer of his authority to the federal and municipal representatives. That having been done, he undertook to find the capital that his country lacked. In order to do so, he rebuilt Mexico's image in the eyes of the world by organizing the repayment of the foreign debt beginning in 1886. Loans were obtained in Europe to make this repayment possible, and thus Mexico was able to pay off a good portion of its debt, and to win back international confidence. It was, then, during the "reign" of Porfirio Diaz in the last quarter of the century that Mexico achieved economic stability.

To raise his country to the rank of a major power and to promote its economic potential, Porfirio Diaz promulgated major laws designed to give impetus to agriculture and to the exploitation of subsoil wealth. The first of these was the colonization law of 15 December 1883, which was designed to promote the development and settlement of the country's vast uninhabited territories, in particular the pioneer states in the north. In order to promote the sale of public lands, this new legislation provided administrative measures to facilitate the recording of titles of ownership, as well as convenient payment terms accompanied by major tax exemptions for owners; the changes enjoyed tremendous success.

In a second phase, a series of laws pertaining to the mining industry was promulgated. A new mining code went into effect on 1 January 1885. Its basic principle was the federalization of mining legislation in order to standardize the mining tax and civil mining laws. This federalization was done both to facilitate the management of the country's resources and to prevent the legislations of the individual states from either encouraging or discouraging the development of individual mining operations. This helpful but as yet inadequate reform was followed on 6 June 1887, by a law which was of major importance to the future of the country, as it gave the mining industry substantial impetus. The law exempted mining properties from all federal and municipal taxes; thus it reduced the cost of producing metals by lightening the tax burden on the mining industry. Further, mine operators were relieved of the need to pay customs duties on all of the imported articles they might need for their operations. Mining products could be transported freely throughout the country with exemption from duties. In addition, the law gave the executive branch the authority to sign contracts granting long-term concessions, as well as to award special franchises to private persons or companies willing to make a capital investment of a minimum of 200,000 *pesos* in the mining industry.

The beneficial effects of these measures soon made themselves felt, but Porfirio Diaz realized that it was necessary to go even farther. While foreign investors appeared willing to invest substantial sums into the mining industry, it seemed that they would not, in fact, do so unless they could be certain that they would not lose money; at least they wanted some assurances that there was no risk of such loss as a result of the pressure of foreign events. Such pressures had been a problem during the civil wars at the beginning of the century, thanks to the havoc wrought, the destruction of installations and the assassination of mine operators. The inevitable conclusion, then, was that in order to make mining properties profitable, their acquisition must be made easy and economical, their exploitation had to be free, and their preservation had to be assured. Titles of ownership would have to provide a guarantee of perpetuity and irrevocability.

To this end, the mining law of 4 June 1892, incorporating these principles, was promulgated. But if Mexico was to surrender ownership of its subsoil assets to investors, it would have to receive payment in return. And so the law was accompanied by new tax measures designed to bring major funds into the federal treasury: the mining properties were made subject to a federal tax, divided into two parts. The first part required a single payment for the purchase of stamps which were affixed to all titles of ownership to mines, while the second part called for annual payment for each lot included in the mining concessions. The scope of the law was fully understood by the investors, and the number of requests for consolidation of titles of ownership to mining properties, as well as the number of declarations of new mines, increased steadily in the following years.

THE BOLÉO MINING COMPANY

It was thus within this extremely favorable context, reflecting the economic upsurge of a new country, that the Boléo Mining Company (a French corporation created for the purpose of exploiting the Santa Agueda copper deposit in Baja California) was established in Paris in May of 1885.

To all appearances, this was a simple business; in reality, it represented a challenge. But this entirely marginal enterprise enjoyed the benefits of the direct support of President Porfirio Diaz, who, through the Company, was able to test his political-economic concepts regarding development. It is important to make clear that the scientific study that led to the establishment of the Company was carried out in the spring of 1884, and that the conclusions drawn by the prospecting engineers were published in Paris in December 1884, even before the new mining code was put into effect. And when the Company was established in the spring of 1885, the mining laws of 1887 and 1892, which really initiated the launching of the Mexican mining industry, did not yet exist, even in draft form.

Should we conclude that the French company was a chancy venture? Most certainly. In fact, everything in the history of the Boléo Company seems a matter of luck, beginning in 1868 with the unexpected discovery of a particularly rich deposit of copper. The discovery was unexpected because it was a farmer, Jose Rosa Villavicencio, who, making his way through the mountains, noticed an abundance of little blue spheres (*boléos*, in Spanish) beneath the hooves of his mule. He collected a few and had them assayed, learning to his surprise that what he had was rich copper ore.

When the Boléo Mining Company decided to exploit the deposit, it set itself a challenge. Simply setting up an installation was daunting, as the risk in establishing an undertaking in a burning desert on the Gulf of California—a totally isolated and entirely virgin site where not even the adventurous voyagers of the 19th century had penetrated—was great. Let us emphasize again the magnitude of the risk. The Americans had been aware of this deposit before the French, and they had chosen not to exploit it despite their much greater proximity. The French, too, were skeptical about how long the political stability recently achieved in Mexico would last. The site's difficulty of access was such that the only links with the world were the fragile skiffs that plied back and forth to the continent as best they could.

Thus one might admire these Frenchmen, setting off for exile in a remote and isolated land about which they knew little. The travels of the future employees of the mining operation began in Paris, at the headquarters of the Company on the Rue de Provence, where they obtained their travel documents—train tickets from Paris to Le Havre and steamship tickets for the crossing of the Atlantic. The Company also provided them with funds to cover the cost of the second part of the trip, from New York to Baja California. Usually the train ride from Paris to Le Havre took place at night. The *Company of the West* train that left Paris at midnight arrived in Le Havre at six o'clock in the morning, and it discharged passengers directly onto the wharf at the port reserved for the General Transatlantic Shipping Company.

At the end of the 19th century and the beginning of the 20th, two of this shipping company's steamships—the *Lorraine* and the *Savoie*—made the Le Havre-New York round trip. The departure from France took place at 7:30 in the morning, and the voyage took 10 days. The French passengers were generally entranced with New York when they arrived there. The Brooklyn Bridge and the Statue of Liberty amazed them, while the constant movement of the ferryboats and tugs to and fro deafened them. Debarkation, following the health inspection on board the ship, produced a moment of chaos when the passengers had to rush to reclaim their generally battered and smashed luggage before undergoing the customs formalities. Then, suddenly, they found themselves on the streets of New York. It was then that perplexity reached its peak as the travelers took in the immense size of the city, the intensity of the traffic, the streets with their intersecting tram lines, and the subway trains rising onto overhead tracks. Above all, they were thrilled and stupefied by the skyscrapers: one could indeed wonder how "houses like that" could stay upright. As a patriotic obligation, the Frenchmen stayed at the Hotel Lafayette on 9th Street, where they spent a night or two, time enough to plan the four days and five nights of train travel that would take them to northern Mexico.

Their route passed through Buffalo, Detroit, Chicago, St. Louis, Kansas City, Topeka, Kit Carson, Pueblo, Santa Fe, Albuquerque, Benson, and Nogales, a town on the frontier between Arizona and the Mexican state of Sonora. The Frenchmen experienced one astonishment after another as they observed the American landscapes. Once they had crossed the frontier, their trip was near its end. However, in the course of their trek across the Sonoran Desert, which took them from Nogales to the port of Guaymas, their apprehension increased.

From Guaymas the travelers left the same evening for the Boléo district, accompanied by their baggage, which had grown steadily more dusty and battered. The voyage across the Gulf of California was always made at night, because of the extreme heat during the day. The last lap of the trip, which took between seven and eight hours, was always very hard. The cumulative fatigue after 17 days of travel and the inevitable seasickness due to the decrepitude of the vessel, together with the surrounding darkness, increased the passengers' misery. As dawn approached, and the Boléo site was finally glimpsed, bitterness tightened their throats. The travelers, who had in their pockets labor contracts that would not allow them to return to France for another three years, wondered, as they saw the place where they were to live, whether this was hell or purgatory.

The adventure was indeed daring, because at the end of the 19th century the Old Continent was the center of the world, and all business ventures were conceived in relation to it. This meant that all of the equipment and raw materials the Company needed to establish itself and to operate the mine had been transported by ships which, after rounding Cape Horn, had sailed up the Pacific coast of South and Central America to enter the Gulf of California and proceed to the operational site. The voyage took four to five months, as did the return trip, when the vessels would be loaded with ore concentrates, to be sold in England.

Finally, since it was not deemed feasible to ship the raw ore out, and transportation costs had to be kept as low as possible, the need to refine the copper on the spot had necessitated the construction of a smelting works at Boléo. This had required a considerable increase in the capital of the Company, bringing it to 12 million francs: an investment that in 1885 was three to four times that of the average French corporation (Germain, 1909). To commit such a sum of money was therefore risky, and doubly so for an undertaking dedicated to the exploitation of copper ore, for which the market, although developing steadily, was nonetheless a new and unstable one.

THE COPPER MARKET

When the industrialization of Europe began in the 19th century, London, the financial and commercial metropolis of the world, a major port, the capital of the greatest industrial power and largest empire of the era, had become the major market for the majority of raw materials. The copper market was therefore the business of England, a fact not challenged until the end of the century. England had achieved this monopoly because, in addition to exploiting its own limited reserves, it processed the copper ores imported in massive amounts from the main extraction centers of that time—Spain, Germany, and above all, Chile. The abundance and the diversity of the imported ores, particularly those from Chile, had enabled the English smelters to become masters of the art of processing copper ores. The town of Swansea, in Wales, had by 1830 become the world capital of copper metallurgy. Beginning in 1875, however, British supremacy began to decline, because American copper production was developing rapidly, and London lost its monopoly on the processing and sale of copper ores. After 1893, in fact, the great American mines in Montana and Arizona no longer shipped their production to England for processing. The Americans instead built electrolytic refining plants that enabled them to produce very fine copper at a competitive price, contributing to the decline of the British market.

The French Boléo Company, whose purpose was to exploit a copper deposit, was logically established as a function of the market in London, where it would sell its production. Unfortunately, in 1885, the year in which it was established, the copper market was at its worst. Between 1860 and 1870, excessively greedy speculators had constantly forced the price of copper upward, to the level of 110 pounds sterling per ton. The higher the prices rose, the more production increased, to the point that overproduction occurred and the price collapsed, dropping to 60 pounds sterling per ton in 1880 (Edlund, 1901). The market was caught in a trap for several years, with the prices shooting upward and then collapsing again time after time. It was not until 1894, when the stock had been completely exhausted and the price of the metal returned to normal, that recovery could begin. Thus the French investors were taking very great risks, for while it was clear that the copper market would recover because of the tremendous demand for the ore resulting from the industrialization of the European countries, such a lengthy period of fluctuation had not been foreseen. The first years were therefore doubly difficult for the Boléo Company, which had to deal simultaneously with the complex problems of installation and the difficulties of a bad business situation.

ENCOURAGING EXPLOITATION

The Frenchmen proceeded to extract the best advantage from the Mexican situation. Mexico had until that time exploited only the ores of the precious metals, gold and silver. It did not venture into the exploitation of industrial metals until the very end of the 19th century, as a result of the relentless decline in the price of silver since 1875. Since Mexico was the leading world producer of silver, and the export of precious metals—gold and silver—accounted for 75% to 90% of the country's mining exports until 1890 (Gonzalez Reyna, 1956), it became urgently necessary to diversify production by promoting and encouraging the exploitation of industrial metals, the European consumption of which was still increasing. To this end, a geological institute was established in 1888. Its first task was to draft a geological map of the country so that mining research could be organized. One hundred and thirty-eight mining agencies were established throughout Mexico, mainly in the pioneer states of the north, in order to encourage prospecting outside the central portion of the country, which had been the traditional mining zone since the colonial era. This policy, undertaken at the end of the 19th century, came after the establishment of the French company, and it was not until 1890 that the exploitation of the industrial metals—zinc, antimony, lead, copper, and mercury—really began.

And so the Boléo Company was the first industrial-scale enterprise to undertake the exploitation of copper ore in Mexico. Also, in its time, 1885, it was the first French mining company to go beyond the boundaries of Europe to establish operations in a distant country that was not among the French colonies. In fact, the most incredible aspect of the affair was the somewhat illegal status of the basis on which the Company was established in Mexico. We know that the report of the geologist Edouard Cumenge, which lay at the origin of the launching of the operation, was dated December 1884, and that the corporation was organized in May of 1885—just after the new Mexican mining code had been put into effect, in January 1885. Now, this code, although it represented undeniable progress in comparison with the previous legislation, did not offer mine operators any special advantages. And so in order to test the effectiveness of future mining legislation that would be better adapted to the needs of this new country and to the risks taken by those who invested there, the president of the Republic of Mexico, who was authorized by the law to deal directly with foreign enterprises, signed a special contract with the Boléo Company. He valued the advent of a French business in a sector in which American capital predominated, and he hailed the birth of industrial copper exploitation in Mexico. In addition, he was delighted by the establishment of an economic center in the heart of the Baja California desert, an undertaking that would bring a little life to this desolate territory.

Doing his best to assist the French company, so that it would succeed and so that its success would attract other French companies to Mexico, the president placed it under his protection by means of this special contract that no one could challenge. On 7 July 1885, an agreement was signed in Mexico City by Minister of Development Carlos Pacheco, representing the federal government, and by Edouard Cumenge, the prospector, and Charles Laforgue, the first director of operations, representing the French company. This contract granted a concession for the establishment of a mining settlement in the district of Santa Agueda in the central part of Baja California. Another agreement, signed on 20 August 1885 in Mulege, Baja California, recorded the boundaries of the property as established by the preceding agreement, and defined the conditions for the establishment of the settlement.

It was under the protection of the 1883 colonization law that the French company was thus established in Mexico. This law served as a support for the contract, in which the mining concessions were called colonies. While the colonization law in its general application gave settlers numerous advantages, it also

BOLEO

COMPAGNIE DU BOLEO
MINES DE CUIVRE
A Santa-[illegible] ([illegible] de Mulegé, B[illegible]-C[illegible], Mexique)
SOCIÉTÉ ANONYME
Statuts déposés chez Me PORTEFIN, notaire à Paris, le 16 Mai 1885
CAPITAL SOCIAL : DOUZE MILLIONS DE FRANCS
divisé en 120.000 actions de 100 francs chacune
SIÈGE SOCIAL : A PARIS

Action de Cent francs au porteur
ENTIÈREMENT LIBÉRÉE
N° 034060

UN ADMINISTRATEUR
Paris, le 28 Avril 1909
UN ADMINISTRATEUR

1885

Figure 6. **A stock certificate for the Compagnie du Boléo, dated 1909.**

imposed upon them obligations, such as developing the land immediately, and using a certain number of men to do so. This latter provision was designed to encourage the establishment of centers of population in the desert portions of the country. Now, while the law served as a support for the Boléo Company contract, it only did so from a distance, and with adjustments favorable to the Company. All of the Company's operational methods had been discussed directly by the representatives of the government and those of the Company, and they were the subject of a specific article in the contract, which article superseded the provisions of the colonization law. Thus the Company enjoyed the benefits provided by this law without being bound by its restrictions. And—an incredible advantage—while the 1883 law granted tax exemptions only for a period of twenty years, the Boléo Company's contract, besides allowing multiple exemptions and privileges, granted these without limit on their duration.

Such generosity meant a substantial loss of income for the federal treasury, but the gamble was important, because the government wanted to be able to assess the benefits derived from encouraging the mining enterprise so liberally. And the attentiveness of the government, with both federal and local representatives always available to resolve the problems encountered by the Company, was more than just evidence of great goodwill: observing the operation's development as a function of the solutions provided to each new difficulty was an attempt by the Mexicans to ascertain the fundamental needs of such enterprises. The government needed these understandings in order to amend the legislation so as to render it still more favorable to development and investment. Thus we are in a position to say, on the basis of the archives we have studied, that the Boléo Company, by agreeing to serve as a "guinea pig" under conditions that were legally most advantageous (though otherwise most precarious), contributed greatly to the drafting of the laws of June 1887 and June 1892, which made Mexican mining legislation among the most liberal in the world, as was confirmed by President Porfirio Diaz himself:

> Prior to the promulgation of the law of 6 June 1887, the executive branch had awarded five contracts for the exploitation of mining zones. In first place among them was the contract signed with the Boléo enterprise, which has successfully exploited vast copper mines in Baja California. The production of this metal already obtained is considerable, and it continues to increase. . . . (Genin, 1896)

The success of the enterprise was undeniable, in fact, and the extreme liberalism of the 1887 and 1892 legislation exerted a massive attraction for foreign industrialists. Several hundred mines began operation every year, and the new mining laws made it possible to legalize the French enterprise officially. By a resolution ratified by the Mexican Congress in 1892, the Boléo Company was recognized as a foreign company newly installed in Mexico. Its position was henceforth clearly defined in relation to the mining laws, rather than in terms of the colonization law of 1883. This emergence into the open reassured the administrators of the Company, who were happy to announce the news at the annual shareholders meeting in 1893:

> The contract signed on 31 May 1892 with the Ministry of Public Works confirming and extending the privileges granted to our Company in 1885 was ratified by the Congress in December. The problems of interpretation and application raised by the 1885 contract have thus been definitively set aside. The conditions for the existence and the operation of our Company have been clearly established in terms of the mining law and the colonization law, as well as with regard to the customs administration and the local authorities. The immunities required for the development of our Company will no longer be subject to challenge. (Boléo Company Annual Report, 1893)

The term "immunities required" clearly underlines the consistent government support which the Company had enjoyed. Pablo Macedo, the Company's representative to the Mexican government, was also an influential government official.

Figure 7. **A postcard depicting the town of Boléo, "near" Santa Rosalia.**

BIRTH OF A GLORIOUS LITTLE CITY

> In Mexico, one does not see these towns appearing overnight, as happens in the USA. However, certain population centers can be described as "mushroom towns." For example, in Baja California, the Boléo Company created Santa Rosalia and its port out of nothing and settled 6,000 souls there. (Bonaparte and Bougeois, 1905)

In 1885, when Charles Laforgue, Edouard Cumenge and several other engineers arrived in the Boléo district to take possession of the region in the name of the new company, the isolation and the solitude of the site were terrible. At a distance of 1,160 kilometers overland from Los Angeles, and 553 kilometers from La Paz, the deposit was all the more isolated because there were no roads in Baja California in that era. Mules or donkeys provided the only means of transport; they were slower than horses but less demanding of water and nourishment. Since Baja California is separated from continental Mexico by the Gulf of California, a night's travel by ship (115 kilometers) was needed to reach Guaymas, Sonora, from which one still had to travel 6,400 kilometers by rail to reach New York, and 2,300 kilometers by "road" to reach Mexico City. It was in the heart of this solitude that the Company built a town.

In accordance with the agreement it had signed with the Mexican government, the Company undertook to prospect the mining zone, exploit the deposit, construct public buildings, and establish Mexican settlers. The task was not an easy one, and over the course of ten years, the employees worked unceasingly to rescue this desert area from its solitude. The Company recruited just a few hundred men to bring the little town of Santa Rosalia to life, while also spending substantial sums of money to bring the equipment for construction and exploitation to the site.

In the early years, the effort required by the exploitation work left no time to provide good lodging for the personnel, who camped out in temporary huts. Beginning in 1895, however, the expansion of the mining work, and its excellent results, changed things. As the number of workers increased, the Company undertook an intensive building program. For seven years, the work on what the Company called the new village of Santa Rosalia proceeded apace, and the town began to develop the attractive aspect it has retained to this very day. Santa Rosalia, which extends to the mouth of Providencia Canyon and is bounded on the east by the sea and on the west by the canyon walls, was not built haphazardly; rather, its construction was carefully planned around a square bordered by the main public buildings. The proximity of the coast limited the expansion of the village to only three of the four sides of the square. The grid of the streets was quite regular, and the houses were built in blocks. This "chessboard" style of city planning, which the Spaniards also brought to all of their settlements in Latin America, is not typical of native America, as has been claimed, but had its origins on the old continent. Certain Greek towns adopted it in ancient times, and in the Middle Ages it was applied in France for numerous country farms and new towns in the Midi. Thus, the Spaniards imported it from the Mediterranean Basin, and we might perhaps think that Edouard Cumenge, who came from Castres in the south of France, brought it with him from his native region.

In 1895, the Company offices were enlarged, and in 1896 ten or so other houses were built, and the so-called French Hotel was also enlarged, while the hospital was put into operation a year later, in 1897. In 1898, three groups of two-story buildings were built to accommodate shops and to lodge Company employees. Together with the hotel, the school, and the church, they framed the main square. For the workers, nine housing blocks with sixteen units in

Figure 8. **Panoramic view of the mine offices and miners' housing in Boléo.**

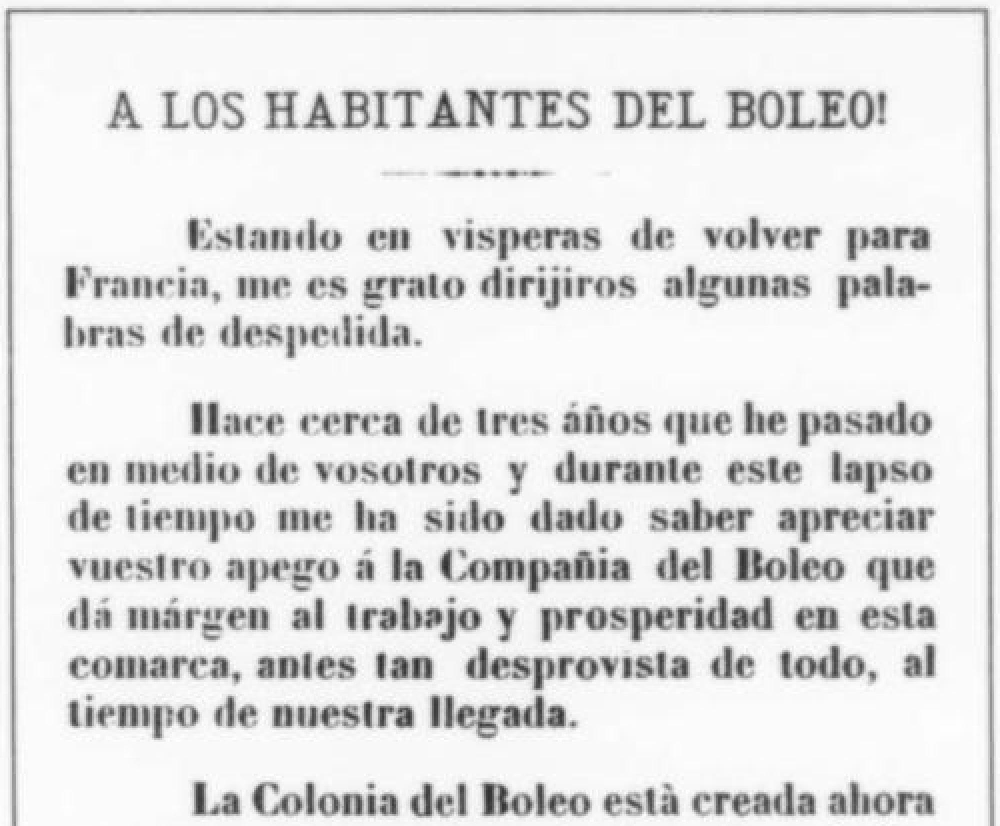
each were built. In the following year, an additional thirteen blocks with eight homes in each were built. Two years later, 375,000 francs were spent to complete the new village with the construction of ten houses for customs employees and eight for policemen, a covered market, a prison, seven houses for workers, and eight miscellaneous buildings. The government buildings, including the customs and harbor master's offices, stores and warehouses, were located near the shore at the point where goods were unloaded. A little farther to the north, but still along the edge of the sea, the copper smelting works and the construction and mechanical repair workshops were built. On the small plateau overlooking the sea was the French Quarter—the Mesa Francia. The company offices and the homes of the French engineers and government employees were located there.

Not all of the population lived in Santa Rosalia. Little villages were established at the very sites where the ore was being extracted from the ground. There were four main centers of mining activity—Providencia (Providence), Purgatorio (Purgatory), Infierno (Hell), and Soledad (Solitude), all names with evocative charm. Built on the sides of the canyons, these mining villages had the same general layout as the village of Santa Rosalia, with the workers' houses grouped around the home of the foreman, the store, the school, and the infirmary. Within a period of five years, between 1896 and 1901, more than 260 houses were built in such groups in the mining villages. Beginning with a handful of men, the Company gradually established its little colony—172 Mexican families and fewer than 100 Frenchmen just a few months after the work began, with half of the population living in Santa Rosalia and Providencia. As newcomers arrived, the colony steadily grew: in 1900, its population was 8,269, and in 1910 it passed 10,000.

The church which the French provided for Santa Rosalia merits special mention. It was metal structure, designed in the workshop of the Gustave Eiffel Company at the request of a French colonial village in Africa desirous of having a place of worship that was not likely to collapse unexpectedly (that is, was capable of resisting the action of termites). However, the sale to the African village fell through, and the building was for a time abandoned. It was subsequently exhibited at the 1895 Universal Exposition in Brussels, where it won the notice of a director of the Boléo Company. Tired of listening to the demands of the French women in Santa Rosalia for a house of worship in which to say their prayers, he purchased the little metal church. When the exposition ended, the church was dismantled and packed in wooden cases for shipment by sea. After a voyage of several weeks across the Atlantic Ocean, around Cape Horn, and up the Pacific coast, the church arrived in Baja California, where it was assembled again by the Boléo workers.

Since spring water was totally lacking in Santa Rosalia, the Company was forced to undertake major projects in order to obtain water from the subterranean sources in the region. A water pipe was first built when exploitation began, making its brave way across the desert to bring water down from Santa Agueda, a little mountain oasis 15 kilometers to the northwest of the mining operation. The spring's flow very soon proved insufficient, however, so the Company then purchased a second spring located up above Santa Agueda, and extended the initial pipeline for two more kilometers. Simultaneously, the Company installed pumps and a reservoir at the Malibran mine. These facilities supplied water in abundance. In this way, the population was provided with sweet water by the water pipeline, while the reservoir, filled with brackish water, supplied the machines and could be used to put out fires. Very soon other reservoirs and pumps were placed in the mines, while a second water pipeline, running parallel to the first and delivering 200 cubic meters every 24 hours, was constructed. However, the multiplication of water outlets and the improvements in the yield of the pipelines in no way altered the fact that a desert remains a desert. Prudence demanded careful management of water resources, and the population was therefore rationed. Every morning, there was a general distribution in which each household was provided with a quantity of water proportional to the number of people in the family. The water was delivered in buckets, and during the hours when water was not being distributed, the public water taps were constantly guarded by Company employees. The French enjoyed the special privilege of having their water rations delivered to their doorsteps every morning; however, they had to pay the water carriers.

Until 1892, the year in which the Congress officially recognized the Company, the port of Santa Rosalia had only a fragile wooden jetty barely able to accommodate the docking of vessels. This was not very practical, since access by sea had been an indispensable condition for the exploitation of the deposit. The mining shafts farthest from the coast were but 15 or so kilometers away. This degree of proximity reduced the cost of transporting the ore to the loading point—one of the main imperatives in the budget—to practically nothing. But it was not until 1892, the year of the



A LOS HABITANTES DEL BOLEO!

Estando en visperas de volver para Francia, me es grato dirijiros algunas palabras de despedida.

Hace cerca de tres áños que he pasado en medio de vosotros y durante este lapso de tiempo me ha sido dado saber apreciar vuestro apego á la Compañia del Boleo que dá márgen al trabajo y prosperidad en esta comarca, antes tan desprovista de todo, al tiempo de nuestra llegada.

La Colonia del Boleo està creada ahora y se encuentra en plena via de un buen èxito. Cuenta con 1100 operarios y empleados que están ocupados ya sèa en las minas, ó la Fundicion, ó bien, en los varios otros servicios de la Compañia, y su poblacion monta á 2800 habitantes.

En ese periodo de instalacion, y à través de toda clase de dificultades que he superado, gracias al concurso tan eficàz de mis colaboradores, no he tenido más que lisonjearme de vuestro espíritu de disciplina y sumision.

Llevo los mejores recuerdos de mi estancia en la Baja California y jamàs olvidaré, estándo con mis compatriotas, tratar de las buenas cualidades que he encontrado entre las poblaciones de Mexico de que me separo con sentimiento.

Santa Rosalia, Octubre 31 de 1888.

PEDRO ESCALLE

***Figure 9.* A small flyer quoting the farewell address given by Pedro Escalle in 1888. Escalle was the first Director of the Boléo mines.**

Company's official establishment on a firm legal footing in Mexico, that major construction work to develop an adequate port could be undertaken. The work began at the end of 1892 and continued until 1907.

In order to save on the purchase and transportation of construction materials, it was decided that the jetties would be built of blocks of slag; therefore the pace of the work was controlled by the rate of extraction and processing of the ore. As it left the smelting works, the glowing slag was poured into rectangular molds and the framework of the molds was cooled. After the slag had solidified superficially, the blocks were immediately plunged into the sea and piled upon each other. But the farther the jetty advanced, the deeper the sea bottom became, and while this project provided a felicitous method of disposing of the waste from the mining operation, a problem was posed by the fact that not enough blocks were being produced to meet the port construction requirements, and so the project fell behind. Moreover, the increased maritime traffic to and from Santa Rosalia as of the beginning of the 20th century, because of the augmented output of the mine, made it impossible for the Company to continue to allow the progress of port-building work to be delayed by the slow production of slag at the processing plant, and so the method of construction was changed. The slag was no longer used except for the lower part of the dike that was subject to the agitation of the waves, while the upper part, which was spared the movement farther down, was now constructed of gravel brought up from the sea bottom by a dredger. Soon enough, however, the dredger had scraped the bottom clean and there was no more gravel, so it was necessary to find another solution. The Company asked for and obtained the Mexican government's authorization to break up rocks in the Mexican maritime zone, and with these new materials the work was soon completed.

At the end of 1907, the finished port was inaugurated. It had a completely sheltered basin covering 16 hectares. For the jetty parallel to the coastline, there were 300 meters of wharfage with a depth of 9 meters, and for the north and south jetties, 100 meters of wharfage with a depth of 8 meters. The equipment included three pairs of powerful apparatus installed on the wharves for unloading coke for the smelting works; a landing stage 100 meters long, with depths ranging from 5 to 8 meters, for loading the barges that would go out to the steamships; and a second landing stage measuring 70 meters, also with depths ranging from 5 to 8 meters, located in front of the south jetty, for the handling of small coastal vessels. On the coastal wharf, there was a mechanical hoist used for loading wood directly from the ships onto the train cars. It was in fact by railroad that the Company met all transportation needs

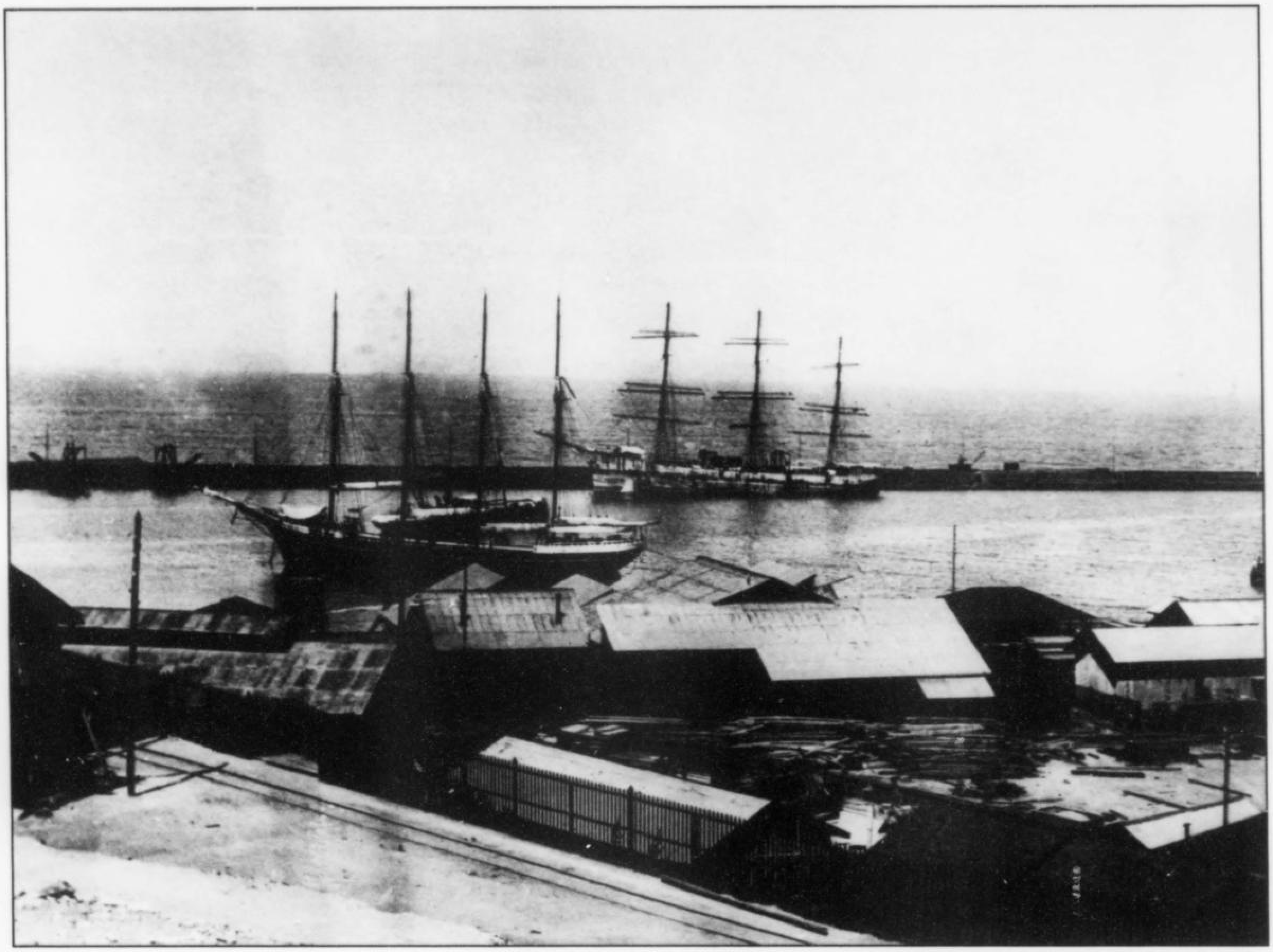


Figure 10. **A view of the harbor at Santa Rosalia.**

within the mining concession. There were 45 kilometers of track, with four locomotives—one train for each village—plying back and forth across the new port's opening, ten sailing vessels, seven of them of heavy tonnage—2,500 to 3,000 tons—converged on the port at once. The Company then had an opportunity to test the capacity of the new installations. All loading and unloading operations proceeded on schedule and without hindrance.

The commissioning of a port of this importance on the eastern coast of the Baja California peninsula was a part of the development of the national infrastructure, and it illustrated the economic dynamism of the region. As a result of the exploitation of the copper deposit, Santa Rosalia had become the leading economic center for the towns on the Pacific Coast. At the beginning of the century, this port led all the others on the Pacific Coast in the volume of goods handled. It surpassed the port of Acapulco, which had less than half its traffic—39,317 tons for Acapulco in the 1901–1902 fiscal year, as compared to 96,944 tons for Santa Rosalia during the same period (Trentini, 1908).

The heavy dependence on Europe made the Company official in charge of supplying the settlement with food uneasy; he lived with the constant worry that a ship would fail to arrive and the population would begin to go hungry. Moreover, the imported foodstuffs, apart from being very expensive, had to be entirely nonperishable. As it was necessary to provide the people with fresh produce from time to time, the French attempted the impossible: the development of farm operations. In 1901 the Company acquired, southwest of the concession, 11,920 hectares of land suitable for the raising of livestock. Three years later, in 1904, 586,698 hectares of land were purchased for 400,000 francs (0.68 francs per hectare), half of the total sum payable at the time of sale and the balance in five annual installments of 40,000 francs each. These new lands, surrounding the older properties of the Boléo Company, increased the Company's total land ownership to 20,000 hectares for the mining concession and 598,618 hectares for the farm operations. These 618,618 hectares represented 4.28% of the total area of the peninsula. This was a "little empire" that the government of Mexico could not fail to value and honor with its favors, since after all the Company was giving life to the central portion of the peninsula.

From 1905 to 1910, substantial sums of money were invested in farm operations. Land was cleared, water sources were sought, and various installations were made available for the use of the farmers. From the point of view of diet, the main concern of the Company was to provide a supply of meat, as foods with a long shelf life could continue to be imported from France. Since the 1900s, however, the large meat-canning enterprises in the United States had found it profitable to purchase their animals in Mexico, and this had driven livestock prices up substantially. So, desirous always of improving its employees' well-being, the Company undertook to raise its own animals for slaughter in order to provide

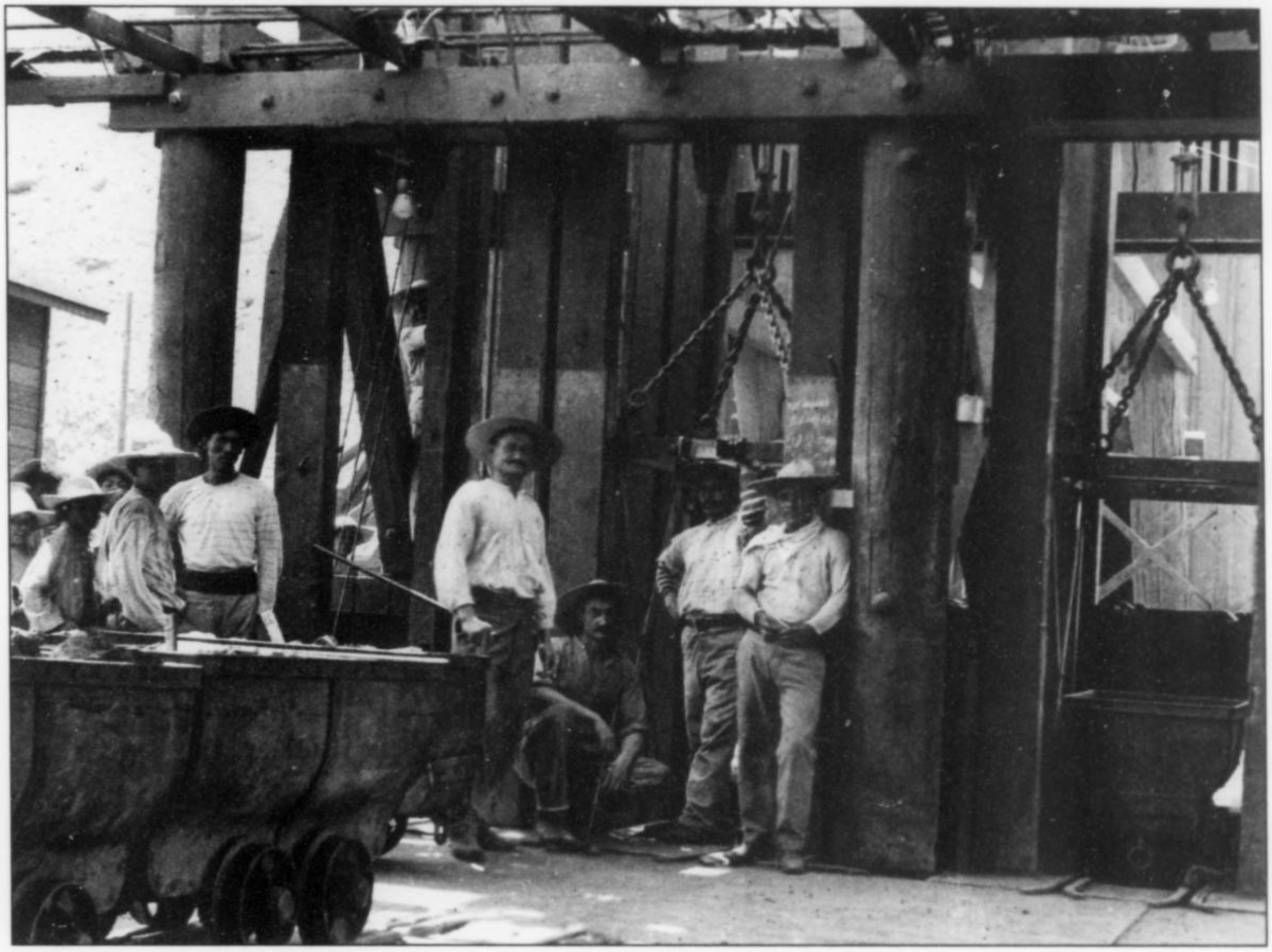


Figure 11. **Mine workers at Boléo, probably the men in charge of the mine elevators.**

fresh meat at lower cost and in substantial quantities. Livestock breeding was organized as of 1906, and in 1909 the herd included 5,106 head of cattle and 243 horses and donkeys. That same year, the herd was augmented by more than 1,000 births, making it possible to deliver 521 head of cattle for slaughter. In the following year, the herd included 5,922 head of cattle and 343 horses.

In order to provide water for the animals, as well as for the crops, the Company dug several wells to depths of between 60 and 80 meters. Windmills brought the water to the surface, and the region's irrigation began. On certain parts of the properties, there were woods that could provide fuel to run the machines, and the Company harvested these. As for crops, the Company developed olive groves and sugar cane fields. It built mills to produce oil and *panocha*, a coarse brown sugar. Encouraged by all these good results, the Company intensified the clearing of land, the building of farm dwellings and stables, the search for water sources, the laying of water pipe, and the development of reservoirs so as to begin raising table and fodder crops. Within a few years the Company was able to supply the residents of Santa Rosalia and the mining villages with a variety of fresh produce. The production of meat and vegetables substantially improved the conditions of life for the people, and if the Boléo Company exerted every effort to wrest some edible products from the arid Baja California soil, it was because it had to inspire in 10,000 people the desire to live and work in Santa Rosalia. The desert conditions were difficult, and the climate sorely tested the workers. They would have had no reason to remain if their quality of life had not been better than that which they might hope to find elsewhere. The opportunity to consume eggs, milk, meat, and fresh vegetables regularly was a compensation the miners valued highly, especially since they could purchase these products at good prices from the Company, which sold them at cost in its stores. There was a large store in Santa Rosalia and a shop in each village. These were frontier stores, something like bazaars where the workers could find everything they needed, both essential and non-essential, including foodstuffs, clothing, tools, accessories and beverages. Such frontier stores were to be found in all of the Latin American countries; they were typical of those new regions where large farming or mining enterprises had settled substantial populations in pioneer areas lacking infrastructure. Generally, the shops belonged to the enterprises, which selected and purchased the articles and resold them at whatever prices they chose. Depending upon its attitude toward its employees, an enterprise might sell at cost, or, on the contrary, at exorbitant prices that put the workers in debt. Thus enmeshed in indebtedness, the employees would then continue to work for the enterprise. Some employers exploited their labor forces in this way, simply in order to stabilize them.

COPPER PRODUCTION

The Boléo Company had good reason to be proud of having won its gamble with the Mexican government, since it had succeeded in

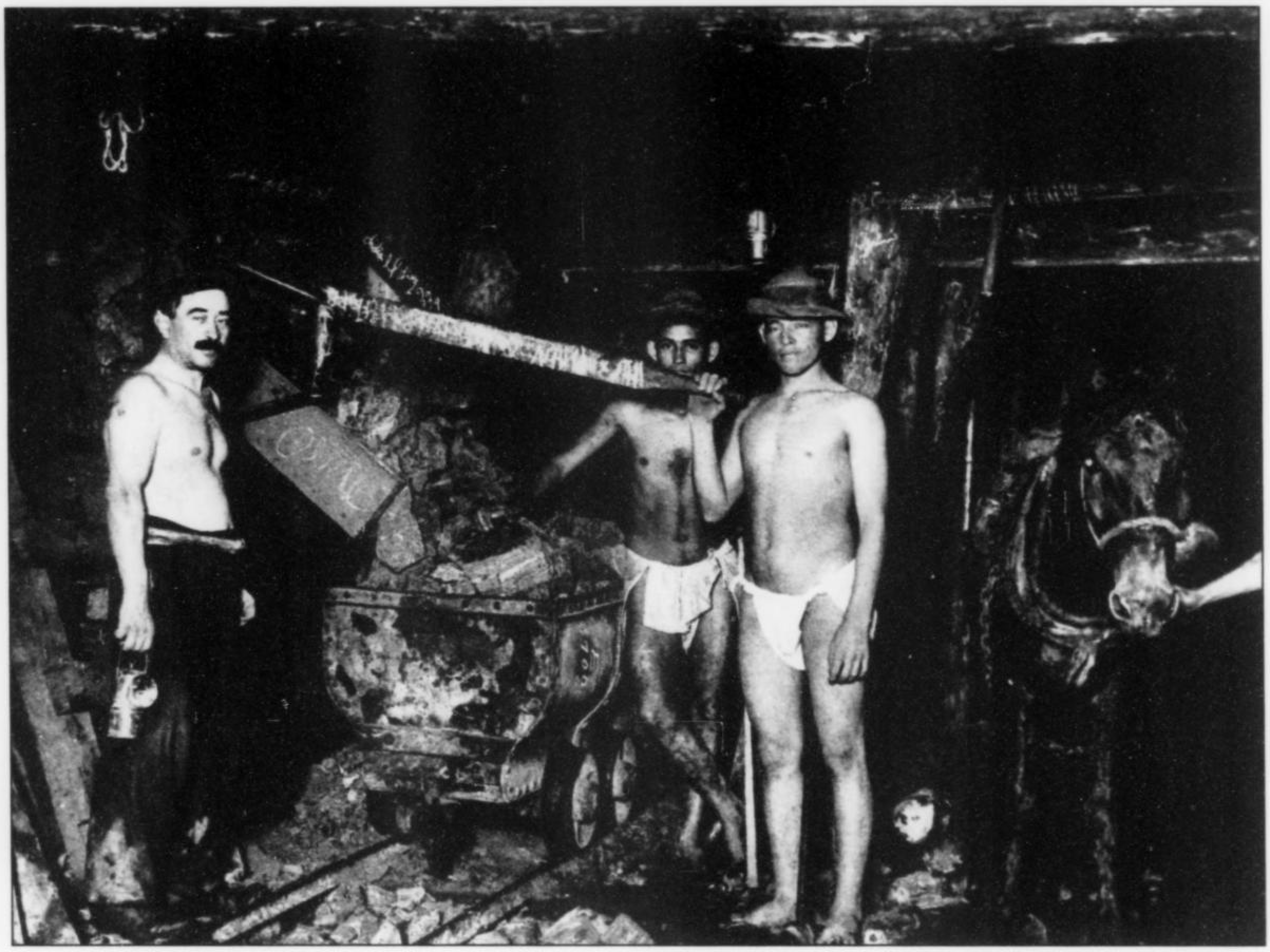


Figure 12. **Miners underground at Boléo, ca. 1928, operating an ore chute to load ore cars.**

developing a desert region and settling a sizable population there. The mining operation as such was also a success. After refining, the ore yielded copper that was 99.7% pure, making it much sought-after on the European markets.

But the success of the mines had also to do with the large role the Company played in furthering Mexico's economy; this role can be understood in the context of world production of copper in this era. Between 1850 and 1875, England dominated the copper market, but only because it processed and sold the copper ore purchased abroad, in particular from Chile, which supplied some 50,000 tons a year. But beginning in 1880, when copper production was expanding everywhere, Chile turned away from copper mining in favor of the exploitation of saltpeter, for which it had excellent markets. Chile fell from first to third place among world producers of copper, with the United States and Spain-Portugal moving into first and second place, respectively. In the decade between 1880 and 1890, it was the United States' copper production which increased most, from 27,432 tons in 1880 to 75,238 tons in 1885 and 117,520 tons in 1890. Japan also achieved a surprising advance, tripling its production from 3,962 tons in 1880 to 15,240 tons in 1890. Compared to these countries, Mexico, which had produced 497 tons of copper in 1883, cut a poor figure, ranking nineteenth in the world, with only 1% of the copper output of its imposing American neighbor. Its production between 1880 and 1886 came to 368 tons per year; however, from 1886 to 1887, production increased from 264 tons to 2,083 tons (Fuchs and de Launay, 1893). All of the credit for this growth fell to the Boléo Company, which moved Mexico up nine places, to eleventh, in the ranking of world producers. Until 1900, the Baja California deposit was the largest producer of Mexican copper and its production never ceased to increase until 1910.

Between 1887 and 1897, the Boléo Company accounted for 86% of Mexican copper production, on average, with peaks at 90%. The Company stabilized its production at an annual average of 11,000 tons beginning in 1895. Later, as the 20th century was about to begin and the mines in Cananea, Sonora, began the industrial exploitation of copper, the contribution of the Boléo Company to domestic production declined considerably, accounting for only 55% between 1897 and 1900.

Beginning in 1900, the situation changed drastically. Cananea took the lead among the Mexican producers, while the Boléo Company nevertheless outdid the third largest producer, the Moctezuma mine in Sonora, by a wide margin. Then, with the massive influx of capital from foreign investment in the mining industry, Mexican copper production generally began a steady increase, with the Boléo deposit becoming relatively less important than previously. However, we must not minimize the fact that it was in large part Boléo's success that led to the establishment of a number of other mines. By 1901, Mexico had become the world's second largest copper producer, with a total production of 33,943 tons (Gonzalez Reyna, 1956). Between 1901 and 1911, the Boléo deposit would only contribute 24% of all Mexican copper production, a share which was to decline steadily until the exploitation of the deposit ended. Losing its first rank was no cause for shame for the French company, which had developed one of the great copper mining operations in the world, and which could take pride in having been directly involved in the economic upsurge of Mexico by having paved the way for the industrial exploitation of copper there.

One of the special characteristics of this enterprise was that it maintained its production at a very uniform rate despite a chronic and cruel shortage of manpower. In the early years, the Company had no problem bringing workers from Europe, but beginning in 1900, with the establishment of mines all over Mexico, it became increasingly difficult to attract workers to Baja California, where the climatic conditions were so extreme. In fact, the Company was faced with its more serious manpower shortage every year during the hot season between May and October, when many workers went home to devote themselves to farming, and production rhythms were imperilled. The problem appeared insoluble until the Company decided to bring in Asian workers. In 1902, arrangements were made to bring 400 Chinese laborers to the Boléo district, but at the last moment the authorities in Hong Kong balked, and the project failed. In 1904, the Company tried again, but with Japanese workers. A first ship arrived in the Boléo district with 500 Japanese on board, but at the first glimpse of the desert, they rebelled and refused to leave the ship.

In 1905, another attempt at importing workers had a happier outcome: 500 Chinese arrived in Santa Rosalia by ship, and stayed. In 1907, 450 more Chinese arrived in the Boléo district. They proved to be sturdy workers who gave the company full satisfaction; however, they did not succeed in mixing with the other miners, and the behavior of some became so aggressive that in 1908 the Company was forced to send 305 Chinese workers home. And so, even after bringing in nearly a thousand Asian workers, the Company still had not fully resolved its manpower problem. The shortage of workers was never to cease plaguing the mine's administrators, who at last hired recruiters to scour the European continent in an attempt to attract workers to the Boléo district.

THE REVOLUTION BRINGS CHANGES

Aside from the manpower shortage, everything went well and the future appeared secure. But the Mexican Revolution that erupted in 1911, when Porfirio Diaz ran for the presidency of the Republic for the ninth time, reversed the fortunes of the Boléo Company. Porfirio Diaz had literally sold Mexico off to foreign capitalists, and the revolutionary government, intending to put an end to this economic colonization, soon made moves to threaten the foreign enterprises, and more particularly the mining companies, which were the principal sources of the country's wealth.

With a view to ratifying the Revolution, Mexico promulgated a new constitution, which was proclaimed on 5 February 1917. While it sought to preserve a federalist democratic regime as stipulated by the 1857 constitution, the new government tried to adapt its new constitution to the Mexico of the 20th century. Still in effect today, the 1917 constitution is liberal, while establishing a framework for limitations on private ownership. It sets forth principles of agrarian reform and specifies measures to protect the economic and social rights of workers. It is nationalistic in that it confirms the country's ownership of the subsoil wealth, and guarantees ultimate national control of natural resources by regulation of the rights of foreigners to own property. Finally, the 1917 constitution established a modern, secular state (Manigat, 1991). Three of its articles have been highly important in directing the country's future:

Figure 13. **Emiliano Zapata (1877–1919), a hero of the Revolution.**

Article 27 proclaimed three major principles. First, the nation itself owned all land, water, and forest resources. The nation could delegate partial ownership rights to private individuals, but it reserved the right to restrict private ownership at any time as required by justice or by the national interest. Second, the nation held direct and inalienable ownership of the subsoil and its assets. Third, all state-granted concessions for the exploitation of natural resources were subject to Mexican law exclusively.

Article 123, a veritable Mexican labor charter, provided for an eight-hour working day and equal pay; prohibited child labor; established owners' responsibility for labor accidents and work-related ailments; established state control of wages, with a minimum wage; and guaranteed trade-union rights, the right to strike, and profit-sharing.

Article 130, finally, excluded the Church from property ownership, civil status, and public education, while at the same time guaranteeing religious freedom.

On the economic level, Article 27 reversed the foreign-investor-friendly mining laws of 1887 and 1892, and on the social level, Article 123 proclaimed the major principles of progressive labor

Figure 14. **Miner tramming ore at Boléo.**

legislation. The message was perfectly clear, and the administrators of the Boléo Company, who in 1910 were still congratulating themselves on the steady support of the central government and its federal and local representatives, became cruelly aware that henceforth the Mexican government might soon turn from an ally into an enemy. Uncertain about the future, the administrators made the following announcement at the annual general stockholders meeting held on 22 May 1917:

> We have every reason to be concerned about the measures that reflect the economic and financial policy of the Mexican government, as well as the serious changes made by the new constitution in the fundamental bases for the legislation. We have, on numerous occasions, had to deal with administrative and fiscal provisions that were difficult to reconcile with our rights and our labor conditions in Baja California, and we cannot conceal from you the difficulties with which we will be threatened if the agreements now in effect and the universally accepted legal principles cease to be respected.

These statements arise specifically from several damaging actions undertaken against the Company beginning in 1912, which we will review briefly here. In 1913, the state had commandeered the Boléo Company's two ships, *Korrigan II* and *Korrigan III*. The former, which flew the Mexican flag, had already been seized on several occasions without prior warning. The latter was not returned to the Company until 1917, four years after its seizure, and it was then in such deplorable condition that more than three months of repair work costing 350,000 francs were required. Apart from the general disruptions in operations caused by these actions, the need to charter other vessels imposed a burden on the general expenditures category of the budget. Even more troublesome than these material problems was the trend in government policy that they exemplified. A further sign came when the Mexican government demanded payment of export duty for the 1916 fiscal year. Despite the protests of the Company, which argued that the original contract signed directly with the executive branch formally granted exemption from any duties on copper produced, the government remained adamant, refusing to allow the Company to market its product until the duty had been paid. The charges came to 5% of the value of the copper content of the products exported; the cost to the Company in 1917 was 2,278,644 francs. Each day brought its quota of disappointments as the government increasingly strove, through measures of this type, to make it clear to foreign capitalists that they were no longer anything more than temporary guests on sufferance. The warnings were multiplied by various instances of arbitrary interference in the internal affairs of foreign companies. In 1918, for example, while the Boléo Company was trying to arrange shipment of its copper to Europe to help in the allied war effort, the pro-German Mexican government on several occasions requisitioned the Company's copper production. And the government itself established the price it would pay for the ore (Archives of the Ministry of Foreign Affairs, America 1918–1940 Series, Mexico Section, Mines and Metallurgy, Paris).

Earlier concepts of ownership rights were consistently flouted. A presidential decree dated 7 November 1916 made Santa Rosalia a free municipality (the little town had previously been attached to the municipality of Mulege), and when the new municipality needed property on which to install public service facilities, 34 hectares of land which the Boléo Company had purchased were expropriated, the Company getting no compensation (Romero Gil, 1991).

On the social level, the revolution had led the workers to hope that the government would give their demands unconditional support. Article 123 of the 1917 Constitution strengthened this hope by providing protection for the workers in agriculture and industry. As soon as the right to strike and the right of association were recognized, the workers began to make unceasing demands. Protests spread to every part of the country, and, like other enterprises, the Boléo Company was to suffer from the frequency of these demonstrations.

The most important of the strikes at the Boléo mine broke out in the spring of 1925, on 17 April. Because the trade union had achieved complete mobilization of the workers, it was a general strike, and paralyzed operations. The list of demands included a general pay increase from 2.5 pesos to 4 pesos for a day's labor, company responsibility for tools and mine lamps, improvement of the living conditions, and payment of compensation for labor accidents and illnesses. In addition, the trade union demanded that all of those who had worked for the Company for 20 years be retired on pensions equal to the wages they were receiving when they stopped working. Deeming these demands excessive, the Company decided to reject all of them. The union ordered the strike extended, and as the workers blocked access to the mines, interfering with the regular pumping of water, the mine began to flood, and the deepest work sites filled with water. The situation between the union and the Company became so tense that after 10 days of conflict, the director of the Company went to Mexico City. On 29 April, he made an active approach to the government authorities. The negotiations dragged on, but thanks to the intervention of the Ministry of Industry, Commerce and Labor, an agreement with a view to ending the strike was reached. On 12 May, the Ministry sent a telegram to Santa Rosalia, ordering the workers to return to work while promising that the demands presented by their representatives would be discussed, one after another. Four days later, on 16 May, work resumed without incident in all departments.

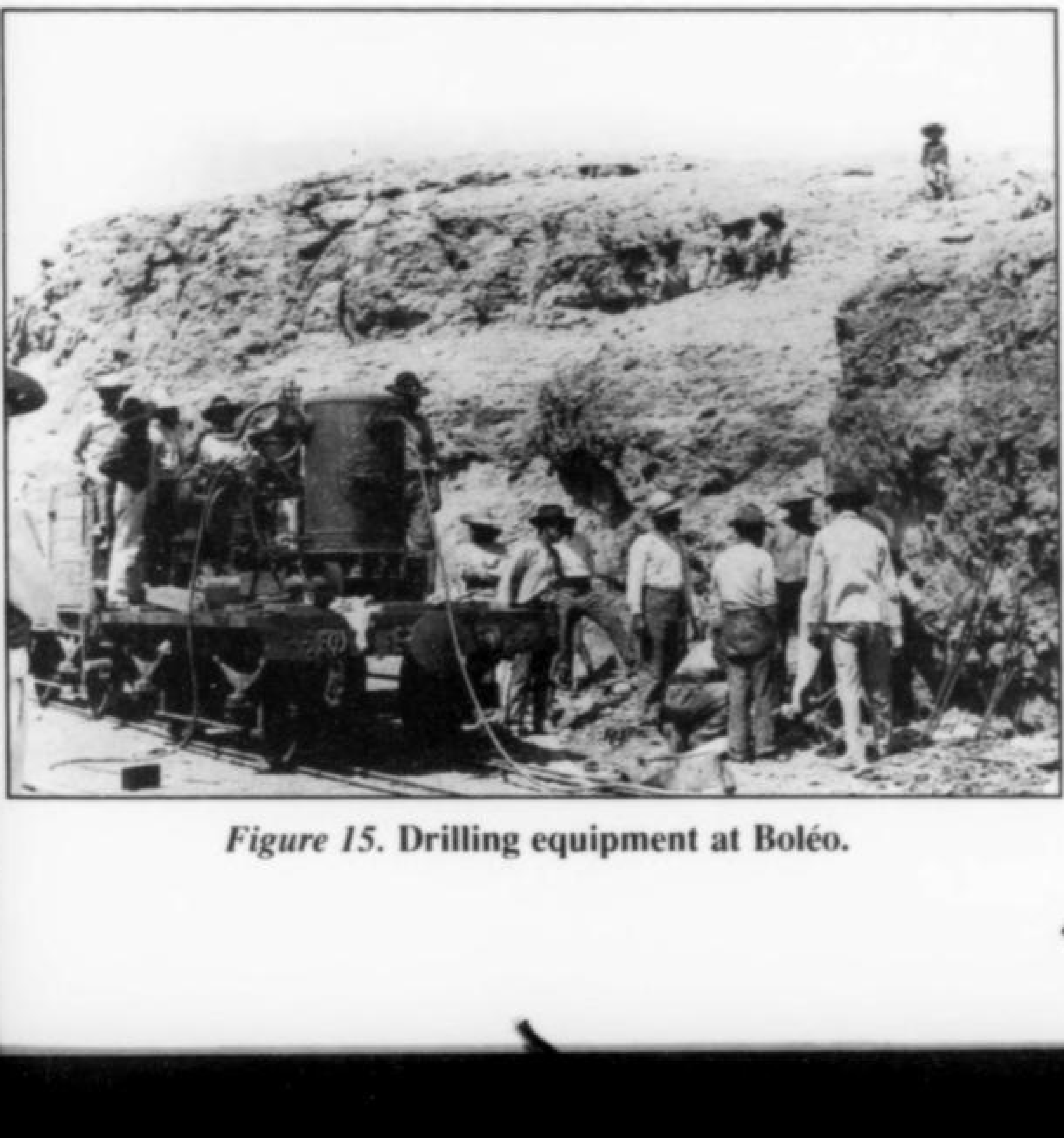


Figure 15. **Drilling equipment at Boléo.**

Figure 16. **The church of Eglise de Santa Rosalia, designed by Gustave Eiffel.**

The negotiations continued until, on 27 May, an agreement brought the difficulties to an end. This first collective bargaining contract, which was later to be revised twice, was jointly signed by the director of the Company, the representatives of the workers, and a representative of the government. The contract had 20 articles, and the gains of the workers were substantial; the syndicate had won the day on all the demands except retirement. The most significant advance was the agreement of the Company to deal with the trade union to resolve all future labor problems. A mixed commission was appointed for the purpose.

As the Company had been forced to compromise, the union pushed even harder following the strike. During the strike, the workers of course had been paid no wages, but as the strike had lasted a long time, they had asked the Company to grant them credit in its stores, so that they could meet the daily needs of their families. When work resumed, the union pointed out to the Company that since the strike had been long, any repayment of this credit by the workers would mean a major reduction in their income, amounting to a negation of the advantages gained by the workers, i.e. in wages and standard of living, and leading inevitably to further friction between the workers and the Company. As a result of this pressure from the trade union, which had the implicit support of the government, the Company was forced to forgive the debts (General Archives of the Nation, Department of Labor Section, Mexico).

At the end of the fiscal year, the Company was able to assess the extent of the damage. The strike accounted for a financial loss of 1,199,639 francs, and it had caused a drop of 1,150 tons in the usual annual production of copper. It marked the beginning of a new era; subsequent, if smaller, strikes would occur, and mining progress would regularly be hindered by workers' demands. Furthermore, the enterprise had been forced to yield under pressure from the government, which, for its part, seemed bent on crushing the Company by overwhelming it with new financial burdens. The privileges and tax exemptions granted in 1885 and renewed in 1892 fell away, one after another, while new burdens came to weigh down the enterprise.

The Boléo Company nonetheless remained courageous and confident about the future, even as it appeared ever more clearly to have been abandoned by Lady Luck. On two occasions, in 1911 and 1931, cyclones ravaged Santa Rosalia, damaging the port, wrenching loose the water pipelines, destroying houses, and flooding a number of shafts. The damage came to several million francs, and

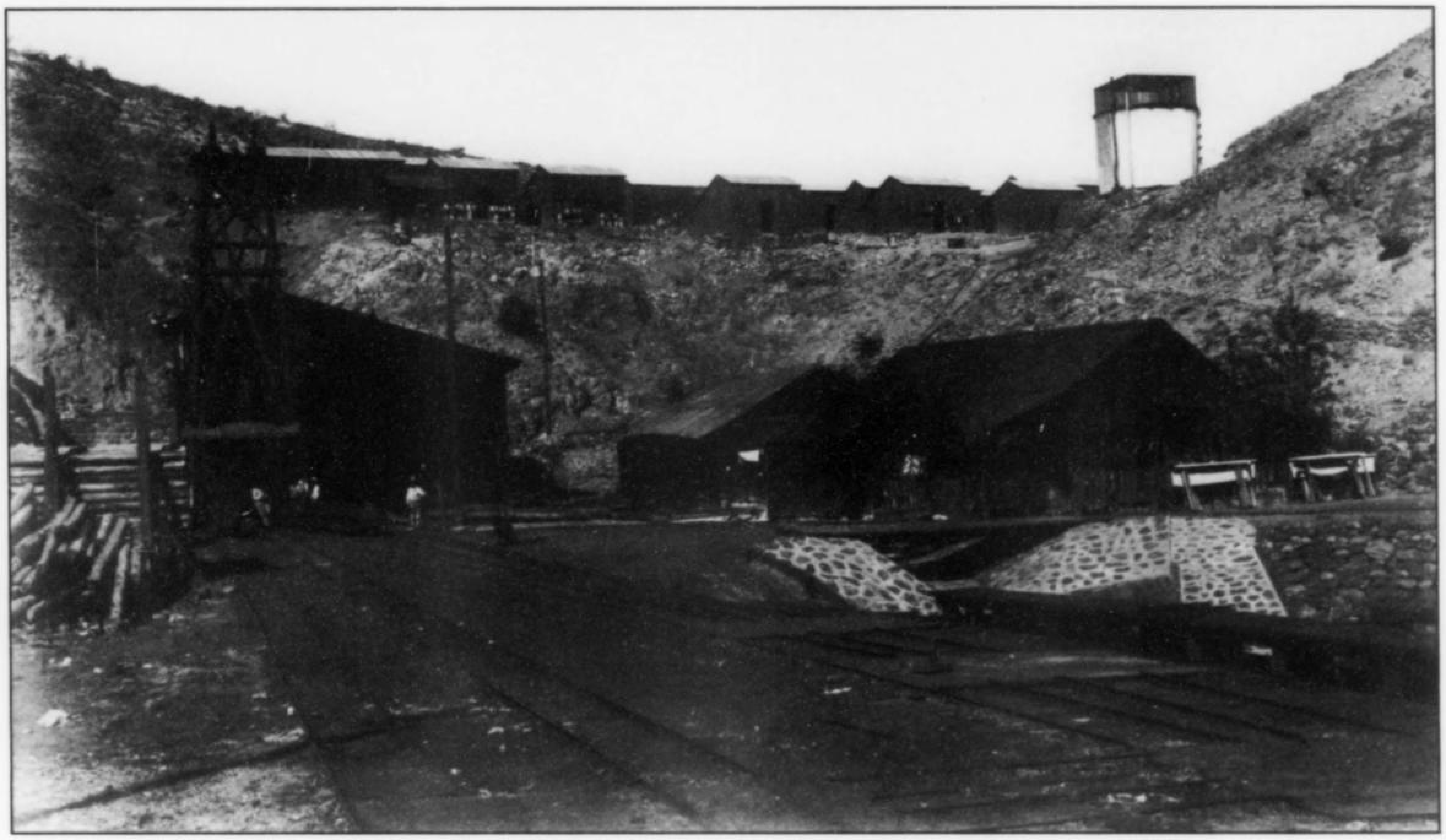


Figure 17. **Rail yard at the Amelia mine, 1920, with miners' houses and water tank above.**

some parts of the deposit were rendered useless for exploitation for several years following each storm. Adverse economic situations developed as well. First, the market for copper completely collapsed in 1919, when the Armistice ending World War I brought demand for the ore to a standstill. This crisis lasted until 1922, and during these three years the Company was forced to dismiss a large part of its personnel. In agreement with the government (it goes without saying), only enough workers to keep the installations functioning were retained, and production of ore was suspended.

As soon as the market improved, beginning in 1922, production began again. In five years, and despite the 1925 strike, the mine was able to regain its prewar production rate of 11,000 tons of copper annually, and the profits very soon covered the financial losses of the bad years. The Company completed major modernization work on its installations with a view to reducing the costs of mining and looked toward the future with calm—a courageous calm, as Mexico's domestic policy was hardly reassuring.

In 1924 Plutarco Elias Calles was elected president of the Republic of Mexico, and he worked ceaselessly for the liberation of his country's economy from foreign capital. Wanting Mexico to be a modern state which would promote and direct its own growth solely in its own interests, he undertook to free the mining industry, the main source of the nation's income, from foreign tutelage. In October 1925, he decided to put Article 27 of the constitution to effective use—this was the article assigning direct ownership of all land, water, forest and subsoil assets to the nation. According to the constitutional text, the government could in fact grant concessions to private, civil entities, or to commercial companies. But since the nation's property could not be lost by prescription, the nation had the right to take back concessions already granted and to expropriate the assets of those exploiting them if, in the government's judgment, the public interest required such a move. Accordingly, under this government, when a foreign enterprise came to seem undesirable, it was immediately expropriated. Many foreign companies had to wonder how long their period of sufferance would last. To the ever-present threat of expropriation under Article 27 was added, too, the increasingly frequent interference by the state in the internal operations of enterprises: enforcement, for example, of a new requirement that the enterprises include a certain percentage of Mexican personnel in their administrative structures. These employees cooperated closely with labor inspectors, appointed by the Ministry, who never ceased to check on the application of government labor, health and safety regulations, very often forcing the enterprises to undertake onerous projects in order to meet the prescribed norms.

In 1929, after the Company had managed to forge its way through a difficult situation, it, like all the other mining enterprises, was struck a crushing blow by the world economic crisis. Since it had just survived the other serious economic tests, it faced the crisis with optimism. Thanks to its excellent financial management and the various contingency funds it had established during the good years, it coped easily until the end of the 1931 fiscal year. But beginning in 1932, reductions in general expenditures ceased to cover income losses, and despite the dismissal of more than 40% of its personnel, the Company ended the year with a deficit. More deficits accumulated throughout 1932, 1933, and 1934, but recovery began in 1935, and that fiscal year ended with a positive balance. The Company could have begun to flourish again soon if the government had wanted it to, but that was far from the case. Indifferent to the economic problems of the mining industry, the government maintained fiscal pressure on it. As early as 1929, the Boléo Company had been burdened by a regrettable tax surcharge—290,567 francs, representing various taxes augmented by a provincial tax of 2% on commercial sales—plus 1,271,214 francs in increased import duties and consular taxes. After a further increase in 1930 the total tax burden came to 1,340,000 francs; this expense, combined with revenue losses caused by the Depression, gave the Company a deficit for the year of 3,707,393 francs.

In 1934, with the world economic crisis at its peak, the election of President Lazaro Cardenas definitively tolled the death knell for the Company. The new president's program called for a national mobilization to promote economic development, and for more effective application of the 1917 Constitution to the benefit of the workers and the peasants. The national economy was not doing well, and the tendency was to blame the foreign industrialists who were monopolizing the resources of the country. According to this line of reasoning, the consolidation of national sovereignty was a prerequisite for achieving real economic independence, and a resurgence of state intervention was necessary. The policy of Lazaro Cardenas, strongly oriented toward a planned economy, took from the businesses most control of their organization and labor programs. Mining legislation became ever more restrictive. Taxes increased, pushing the cost of a ton of ore ever higher and commensurately reducing the companies' profit margins. This painful situation was aggravated by the frequency of strikes, which were the more virulent since the workers' movement was openly supported by the government.

The workers' demands and the fiscal pressure at last became intolerable. For the Boléo Company, the mortal blow was struck in June of 1935, when the state demanded a payment of 8 million pesos, that is to say more than 32 million francs, the greater part of this sum representing a tax on mining concessions. Under the terms of a contract signed with the government in 1892, the Company was exempt from this tax; however, Lazaro Cardenas did not recognize the agreements signed prior to the revolution, and his government persisted in demanding the retroactive payment of the full tax. The Company attempted to avoid payment by pointing out the role it had played, and was still playing, in the economic development of the country and of Baja California. The government's only concession was to allow the conversion of the tax: the Company would have to pay only one million pesos in cash, and the other seven in kind, by surrendering to the state all the houses in the village of Santa Rosalia and the mining villages, as well as the farm properties of the Company. This arrangement, which more nearly resembled plunder than a friendly agreement, clearly illustrated how the government policy had developed and hardened. In the following year, 1936, new labor legislation further increased the burden on mining enterprises by forcing them to pay workers full wages for one day off for every six days of work. And, to top it all, the Boléo Company would now have to pay rent to the Mexican state for the houses it had "ceded" to it a year earlier. Since the union had obtained a guarantee that the workers would be housed free, it naturally fell to the Company to pay the rent on the houses the Company itself had built.

Finally, when in March of 1938 the government expropriated the American oil companies, the Boléo Company decided that it had no further business in Mexico. Its situation was weakening further every day, and its prospects for making a profit were dwindling steadily. A special general stockholders' meeting was held on 8 July 1938 in Paris. The participants voted to liquidate the enterprise, effective 1 July of the same year. This liquidation took a long time, because World War II interrupted the process. Liquidation activities were resumed in 1945, and continued for several more years because the French did not want to abandon Santa Rosalia abruptly. They had built the little city and they did not intend to let it die. Porfirio Diaz had assigned them a mission—to settle the desert—and they had carried it out. They had been given a challenge and they had taken it up, developing a town in the heart of Baja California and giving it life. They loved this town, and knew that a quick departure of the Company would condemn it to death. And so, in order to avoid forcing an exodus upon the residents of Santa Rosalia, they made every attempt to transform the local economy before they left, in particular by creating a number of fishing associations. When all of the workers were assured of employment and Santa Rosalia was able to guarantee its own subsistence, the last Frenchmen left Baja California, 1954. They departed from the port that would henceforth be crowded with little fishing boats, but would never again welcome huge vessels arriving from Europe.

Edouard Cumenge (1828–1902)

Edouard Cumenge was born to a Protestant family in Castres (department of Tarn) in the southwestern part of the Central Massif in France, an area that suffered greatly during the religious wars in the 16th century.

Passionate about travel from a very young age, he enrolled in the Naval Academy, and graduated from the Polytechnical School on 1 November 1845. He graduated first in his class, and chose to serve in the Mining Corps. When the revolution broke out in Paris in 1848, Cumenge took part in the defense of the Hotel de Ville, an action which he later described in a poem devoted to the siege of Paris.

He was taken on as an engineer in the Assay Office of the School of Mines in 1851, but in the following year, he took indefinite leave. He had just married the daughter of a major industrialist specializing in the rubber sector, with whom he was to work until 1873.

He then resumed his mining studies and embarked on a series of trips to Spain, Italy, Greece, Venezuela, Colombia, the United States and Mexico. In the numerous poems he wrote, he provided fascinating accounts of his many adventures.

With his friend Edouard Fuchs, he undertook a project of major scope pertaining to gold; the resulting work, "Gold, Its Characteristics, Deposits and Extraction," published in Paris by Dunod (1892), is now almost impossible to find. It was Cumenge's experience with gold-bearing deposits on several continents that made him an expert. His various research projects were the subjects of original publications by the Academy of Sciences. Sadly, the last such project, involving hydraulic placer mining in Junction City, in the United States, left him a ruined man.

In 1897, his passions aroused by the gold-bearing deposits in Witwatersrand, South Africa, he participated, gun in hand, in the war waged against the British by the Boers, his co-religionists. He provided a picture of this experience in a superb poem entitled "The Boers." The poem appeared in the most striking of his travel writings, *Black Tales and Blue Tales* (1878–1895), which he published at his own expense.

But it was the Boléo mine in Baja California, Mexico, that occupied the best part of his time. In a letter addressed to his brother-in-law, he described his first impressions on his arrival in Mulege on 26 August 1885:

> I don't want my journey to end without your receiving fresh news of the Wandering Jew. After having stayed for 3 weeks in Mexico, whence I sent my mother numerous letters (which she has shown you if she received them, for the postal service is very deficient), I made my way to Lower California and here I have been for two weeks on holiday at Mulege, the capital of the central part of the peninsula.

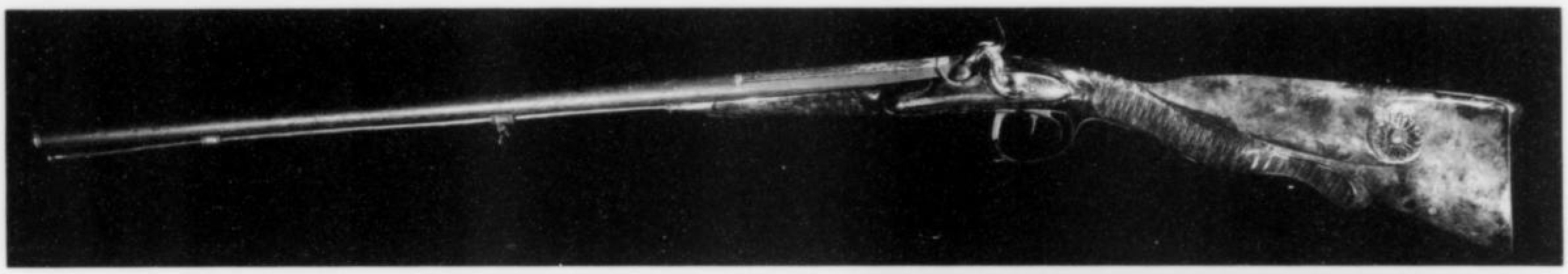


Figure 18. (above) **Cumenge's gold-inlayed, cap-and-ball hunting rifle. Photo by Nelly Bariand.**

Figure 19. (left) **Mine foreman's pick with a silver 10-centavo coin set in the head, from Boléo. Photo by Nelly Bariand.**

Figure 20. (right) **Miner's "lenticular" oil lamp of the French type, with Virgin Mary or Saint Barbara finial (very rare), from Boléo. Photo by Nelly Bariand.**

> What a capital! 400 inhabitants, one-floored houses made of bricks dried in the sun, dust a foot deep in the streets where domestic animals stand around with flocks of trash-cleaning vultures and where people sleep in the windy streets on chairs unfolded in the evening. If there weren't any mosquitoes and if the cows and calves didn't make such an awful row all night long, you could sleep under the stars, for the temperature is pleasant at night, but you must really be in good health, as I am, to prevail against insomnia and the terrible food.
>
> Even so, the valley is a real oasis: baked-brick color bare-topped mountains on which the outlines of giant cacti and the silhouettes of enormous palm trees can be made out. There's a real forest of the latter in lines 4 to 5 kilometers long. And there are also olive trees, pear trees, orange trees, lemon trees and fig trees, each with its special green hue, fields of sugar cane and corn watered by the little river, vines with bunches of grapes weighing 4 or 5 pounds.
>
> When you see an Indian woman passing by, draped in her *rebozo* and carrying an antique earthenware jug, you are reminded of the Biblical landscapes of the Nile or the Jordan . . . all that is not worth a well-kept garden, or a cool house, and you quickly get tired of local color and long for the comfort which is completely lacking. I hope to go more often to the mine where I intend to go tomorrow evening. The people here are so lazy they don't want to get anything for you to eat other than their meat as tough as leather; there are fish, turtles, lobsters, edible oysters, not to mention the pearl oysters that are dived for around here, but it's impossible to find a fisherman, and the daily fare is atrocious.
>
> In the mines I hope my friend La Bouglise, who has been there for a few days with his wife, will have organized board and lodging; I'll be able to eat and sleep! It's a delightful prospect; it's so true that pleasure and happiness are only relative. Up to now I've had no worries about my health nor about my work and I've been able to carry out the first part of my mission, a jurist's work, in which I've been helped by my lawyer friends: now I'll be on my own ground and will try to sort out our great future project.
>
> I don't quite know how long I'll stay at Boléo, about two weeks surely, and then I'll go home. If nothing goes wrong I should be back in France at the beginning of October.

After numerous difficulties, Cumenge had the pleasure of seeing all his dreams realized, and in the last years of his life, despite the cataract from which he suffered, he made the crossing of the Atlantic several more times to visit the site.

A mineralogist of great talent, he discovered "guejarite," a sulfoantimonide of copper later found to be chalcostibite. He brought back from Mexico the first samples of lead and copper chlorides—boleite and cumengite. And from the United States he brought back carnotite from Montrose, Colorado, on which (with Friedel) he reported in 1899.

He was quite surprised that one of his findings was named after him, and was inspired to write a fulsome poem. *(See next page.)*

Edouard Cumenge was not only an engineer of the first rank, and a learned man; he was a personality, with high color, keen eyes, and a great fan-shaped white beard which gave him a very affable and exotic air. He was vivacious in a southern manner, and he liked to

Advice to a Mineralogist

Never admit anything! Jean Hiroux* used to say
Never write anything! Again I pray
This is good advice between you and me
Today it has been proved to me.
My dear fellow, you've concealed a founding
So you think everyone is gossiping
I myself feel very offended
For my detractor is a friend indeed
Certain as he is of the facts
Out of his pocket he extracts
A good book in which the word
Appears in black and white.
You see for sure it is Cumengite
And you must really show me the site.
This is how gossip begins
And since then
Trying in vain to discover
Which scientists
Caused me such a bother
I am sorry I wrote an article long ago
Which today I can only understand
Reading a book secondhand.
So never put anything in writing
It's more exciting. . . .

(Translated by Wendy M. Bachet-Harris)

recount in colorful language the adventures he had had on his far-ranging travels. These colorful traits were well described by Louis de Launay, a geologist who was also a graduate of the School of Mines in Paris and was well known for his treatise on metal-bearing deposits. It was he who eulogized Edouard Cumenge in the *Mining Annals* in 1903:

> The taste for travels to distant places, for that free, sometimes adventurous, and often arduous life led by the explorer of mining deposits, depending on the luck dictated by the circumstances, from one end of the world to the other, naturally entails a love of nature, a sense of the picturesque, the habit of observing customs, and sometimes even a certain penchant for solitary reflection or dreaming. During the long hours of travel, during the rides through the mountains or the desert, his thoughts turned inward as he sought to give his ideas flexible form. Like his friend and companion Edouard Fuchs, with whom he had so many things in common, Cumenge enjoyed putting into verse sly little jokes, friendly but mischievous quips, which sometimes veiled melancholy thoughts suggested to him by the luck of his travels. He wrote sometimes in French, sometimes in the peasant language of Tarn, which he spoke as a matter of choice. He was fascinated by the question of when this dialect would cease to be used. It seems to me that his poems in the vernacular, the "Rapapiatses d'un Biel d'al pais de Lengo d'Oc" ("Ramblings of a Son of the Languedoc Region"), for example, or the poem on the old Castres, "lou biel Castros" ("The Child of Castres"), have a freshness and a savor that are quite special. These old local languages of the people, which are in reality the forerunners of our language, those that made the spontaneous transitions between Latin and French, are particularly well-suited to the expression of simple sentiments that are without pretense and the affectations of scholarly technique and the literary profession.
>
> I have already mentioned the profound sorrows that afflicted this good man—the loss of his wife and his two children tested him cruelly. And then blindness descended to halt his activity, which had previously been tireless. But he was not one of those individuals whose restless and painful search is limited to the quest for the meaning of life, ending with doubt about the very virtue of moral conscience or of labor. He had a calm faith in certain simple principles, proven by time, which served to support him. Thus it was that he was able to continue to the end without flagging, having attempted to learn and to advance up to his very last day. To the last he was working, following the precept that, if it does not guarantee happiness, does at least ensure that the worst suffering is forgotten: *pertransit laborando.*

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*Famous 19th century French swindler who never admitted anything.

History of Investigations on the Boleite Group

INTRODUCTION

Since their size was amply sufficient for chemical analyses and their well-formed crystals were suitable for crystallographic analysis, the indigo-blue minerals found in the Boléo district should not have posed any particular problems in determination, or at least description. The development of scientific study methods, both theoretical and experimental, even in the absence of X-ray diffraction techniques, was already well advanced at the end of the 19th century. However, boleite and the related minerals found in association in the Boléo deposit, because of their formation and their unusual method of growth in assemblages of oriented crystals, proved to be one of the most difficult puzzles which mineralogists have ever had to unravel. The history of the determination of these minerals is a story of many of the kinds of difficulties and contradictions, and of the resulting erroneous conclusions, that have plagued the scientific community. This interesting history, exemplary in more than one regard, extended over nearly a century, and merits a detailed description.

DISCOVERY OF BOLEITE

Following the initial prospecting in 1884 and the establishment of the Boléo Company, Cumenge traveled often between Paris and Santa Rosalia. Each visit resulted in the collection of specimens and in new studies that made it possible for him to draft a rather complete mineralogical and geologic table. It was not, however, until 1891 that he noted the indigo-blue crystals in the part of the deposit served by the Cumenge shaft. On his return to France, he worked on the analysis of these crystals with the famous mineralogist and crystallographer Mallard (Mallard and Cumenge, 1891).

Two chemical analyses of the cubic crystals had been undertaken by Diguet, a chemist at the Boléo deposit, and Jacomety, a chemist in Hayange. These men obtained quite similar results (to better than 5%), arriving at the formula $PbCl_2+CuO.H_2O+1/3AgCl$, or the equivalent $3[PbCl(HO)\cdot CuCl(HO)] + AgCl$. Mallard and Cumenge noted how close this composition was to that of *percylite*. Groth (1889) had, in fact, assigned the formula $PbCl(HO)\cdot CuCl(HO)$ to this latter species, established by Brooke (1850) on the basis of minuscule blue cubic crystals obtained from a deposit in Sonora. The possibility of a similarity between *boleite* and *percylite* was considered by the authors, but it was finally rejected because of the limited knowledge of the characteristics of percylite and the presence of silver in the boleite, which they refused to regard as accidental.

As for the crystallographic analysis, it was to prove complex. The authors distinguished three main forms: first was the *cubic* form, in some cases modified by faces of the *octahedron* or the *dodecahedron*. The cubic form showed "grooves in the ridges." A tetragonal dipyramidal form was also noted as singles and as symmetrical groupings. The authors attributed the presence of the grooves associated with this habit to a "very unusual anomaly" wherein on each ridge, two symmetrical faces {210} alternated. Since the cube was hardly compatible with the tetragonal dipyramid, chemical analyses of the little tetragonal crystals were carried out, but they did not yield results that were clearly different from those for the cubic crystals.

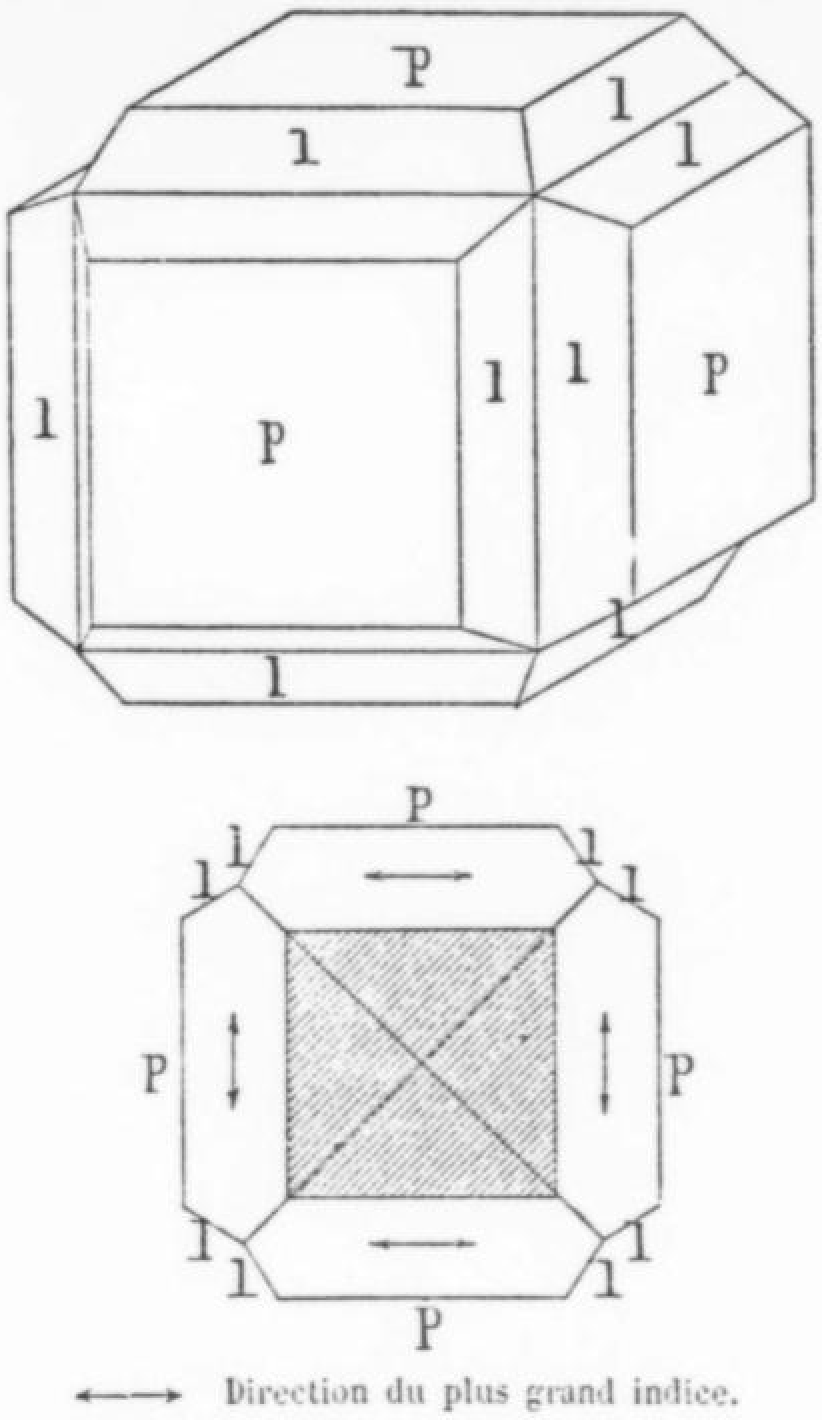

***Figure 21*. Boléite and pseudoboléite overgrowth (Mallard and Cumenge, 1891).**

At this stage in the observation process, Mallard's genius paved the way for an interpretation that would place boleite (and subsequently, the related minerals) in the center of a fundamental and unexpected mineralogical and crystallographic controversy. Before discussing the ins and outs of this interpretation and its development, a detailed explanation of the original nature of Mallard's work is required.

This scholar was one of the leading representatives of the French crystallographic school, which ascribed fundamental importance to the crystallographic arrangements of mineral components, i.e. of complex particles (Bravais), or molecular polyhedrons (Mallard), the distant descendants of Haüy's "integrant molecules." This school followed a path different from that of the "German geometric" school, which, through the more formal continuation of Bravais' works on the concept of networks of equivalent mathematical points, was to lead to a complete mathematical description of the symmetry of all possible crystals (the space groups of Schoenflies-Fedorov). The French crystallographers, who focused less on geometry and more on physics, were to play a predominant role in the realm of crystal physics and the crystallography of "pathological crystals." As a result they were the early pioneers in the study of twinning, pseudosymmetry, and crystal facies. The first of Mallard's works, entitled "Explanation of anomalous optical phenomena" (1877), was based on the optical anomalies in certain crystals observed under the polarizing microscope, which had recently come into use. This work stresses the importance of

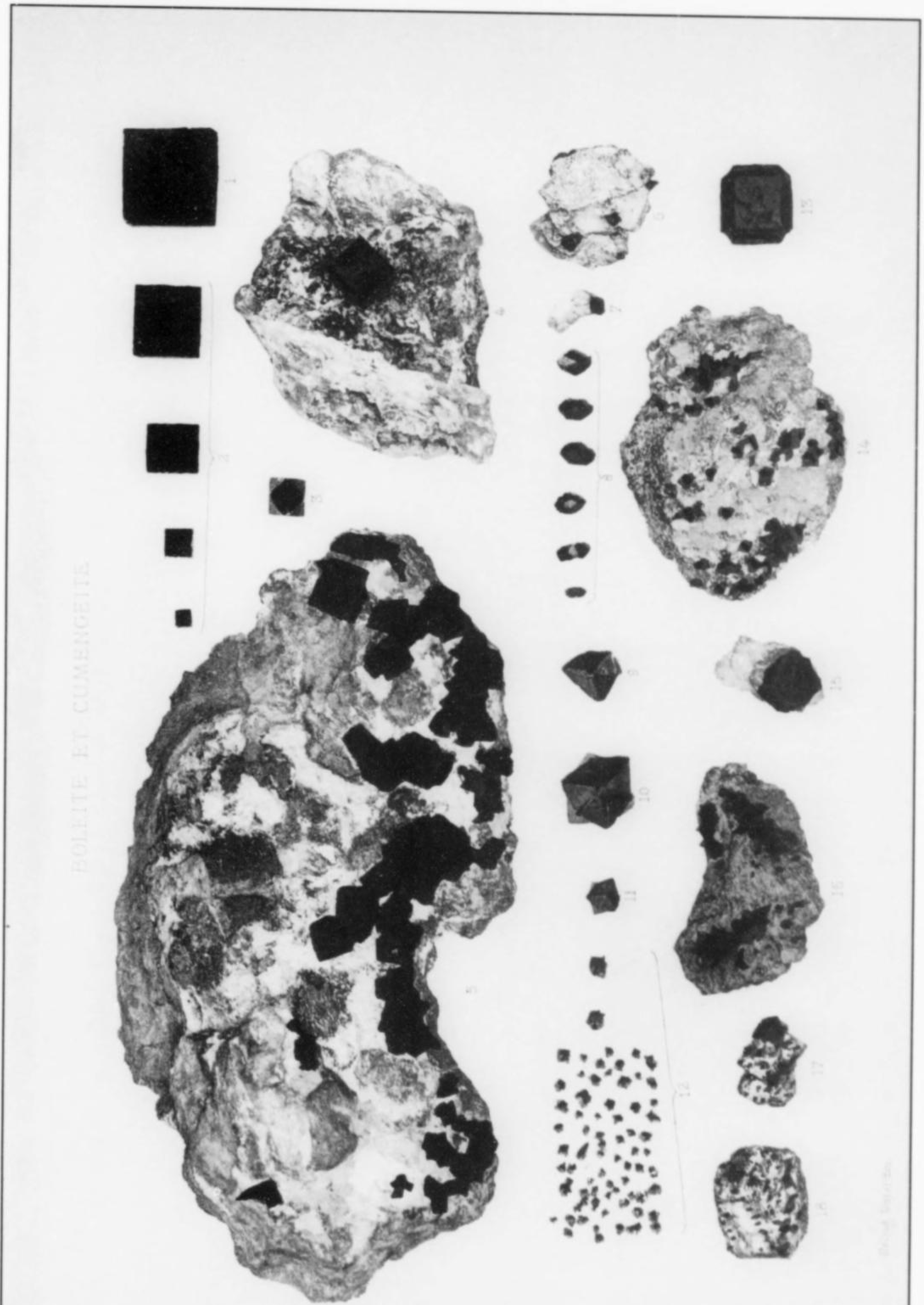

Figure 22. **The color plate from Cumenge's 1893 description of boléite and cumengite.**

the concept of twins and pseudosymmetry. Pseudosymmetrical crystals, Mallard said, were those with parameters such that their ratios were close to those of crystals with greater symmetry; for example, a pseudocubic tetragonal crystal would have a ratio of $c/a \approx 1$.

The publication of Mallard's views provoked a keen controversy. For the majority of known examples, the German school (Klein, 1883, 1895; Brauns, 1891) had won acceptance of the concept of purely accidental optical anomalies. In 1879, Mallard published the first volume of his *Treatise on Geometrical and Physical Crystallography*, in which he dealt with geometric crystallography, the mesh theory, and morphology. And in 1884, he published the second volume, in which, dealing with physical crystallography, he established for the first time the relationship between the mathematical concept of crystal lattices and the very recent description of the properties of anisotropic crystals in terms of characteristic ellipsoids. In 1891, Mallard was a greatly admired and well rewarded scholar in France. He held a number of the highest scientific posts, and continued to be a pioneer and a motivating force in the difficult fields of study he had initiated.

Thus no one was better able than he to set forth the particular characteristics of the boleite he had studied with Cumenge. In addition to doing crystallographic analysis on the faces of crystals, he undertook an optical study in thin section, using a polarizing microscope. He detected a central portion with isotropic optical behavior (compatible with the cubic symmetry), bordered by birefringent (and thus, theoretically, anisotropic) bands. This phenomenon was also to be seen in the grooved cubic crystals. He concluded from this that: "The above does indeed seem, to indicate that boleite is not cubic, but pseudocubic, and that its true symmetry is that of the tetragonal system, since the isotropic or almost isotropic portions are made up of intersections, of greater or lesser molecular size, in the tetragonal network." This conclusion was found to be justified by the tetragonal crystals and the stellate groups of quadratic pyramids.

But this consistent, subtle, and scientifically correct model was not to endure.

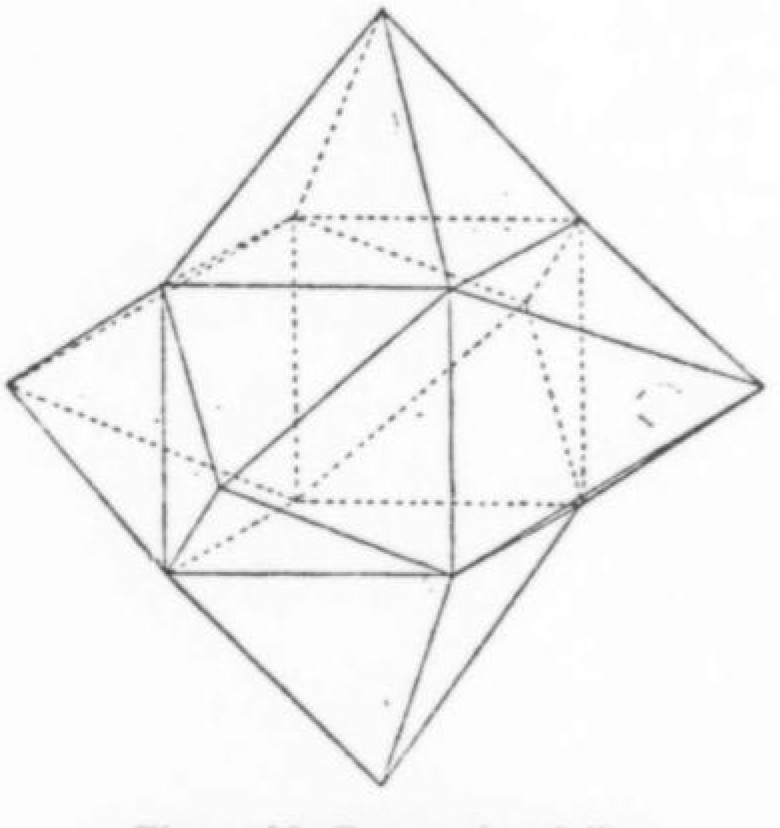

Figure 23. **Cumengite sixling (Mallard and Cumenge, 1891).**

DISCOVERY OF CUMENGITE

Following Mallard's discovery, Charles Friedel (1892), who was intrigued and puzzled, made a study of the synthesis of percylite by the action of lead hydrate on a solution of copper chloride. He obtained octahedral crystals and some cubic crystals, analysis of which yielded $PbCl_2+CuO, H_2O$. The analogous relationship between the crystalline forms and some of those described by Mallard and Cumenge led him to suspect a similarity between the two species. "As we have seen, percylite has been found in two forms, which were described by Mallard for boleite, and with a composition that is, so to speak, theoretical." At about the same time, Cumenge, who had meanwhile found octahedral samples, as well as crystals in stellate groupings of more consistent size, resumed analysis of them and obtained the composition $PbCl_2CuO \cdot 2H_2O$. He described his discovery in a memorandum submitted to the institute, but after carrying out a test, Charles Friedel reported that the proportion of water was incorrect, and he redetermined it. The proportions of other elements were meanwhile also being measured by Fourment, a chemist at the Boléo mine; by Lombard, a chemist and director of a chemical products company in Marseille L'Estaque; by Charles Friedel; and by Cumenge. These efforts produced the formula $PbCl_2+CuO \cdot H_2O$, free of silver.

Subsequent to his discoveries, Mallard saw his model for explaining the optical anomalies challenged, and he had to return to his work on the blue Boléo crystals. He proposed the name *cumengeite* for the dipyramidal minerals. Although a chemical composition close to that of *percylite* was involved, he rejected any similarity, since this species had been described as cubic (Mallard, 1893).

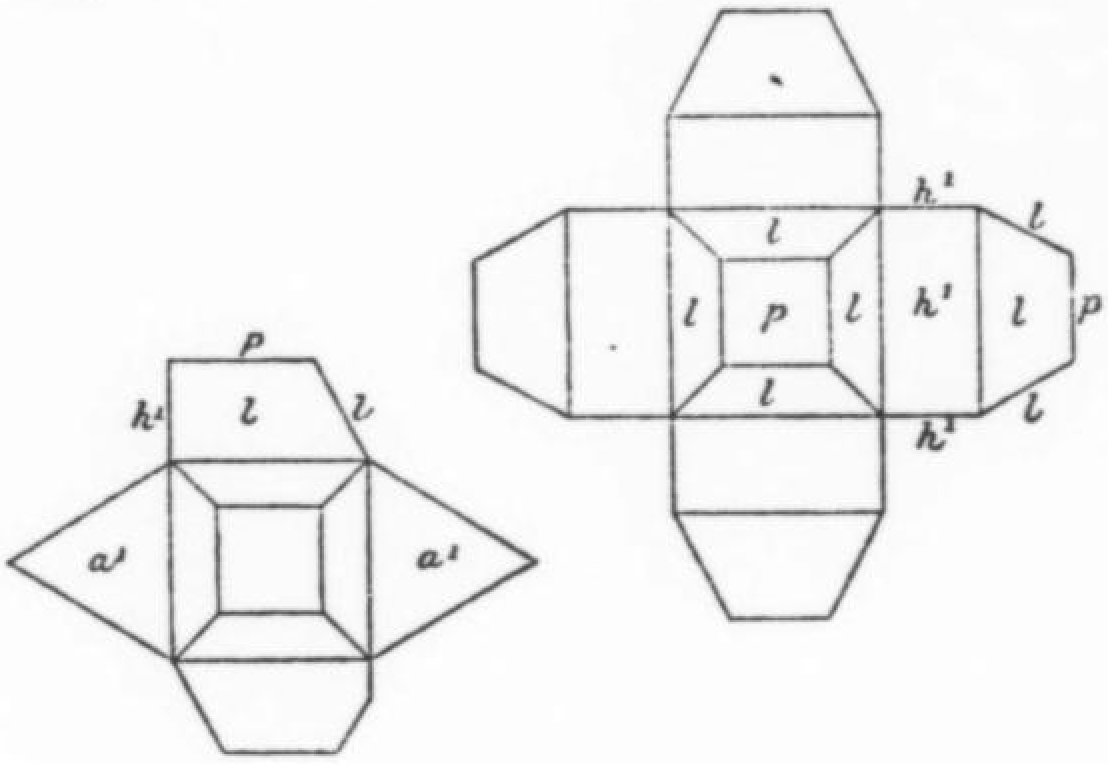

Figure 24. **Pseudoboléite on boléite (Mallard, 1893).**

As for the *boleite*, Mallard's alternatives were either to abandon his hypothesis of a pseudocubic tetragonal boleite by twinning, or to find other indications of the tetragonal nature of boleite. Mallard turned his attention, first of all, to the grooved cubic crystals, explaining them as groups entirely similar to those the cumengite formed on the cube, the crystals overlying each face of the cube now being prisms and/or truncated tetragonal pyramids according to (001). He also observed, on a cross-section of a stellate grouping of crystals, an association involving a nucleus of boleite surmounted by two tetragonal crystals and two diametrically opposed crystals of cumengite. However, he rejected the hypothesis of a similarity between these truncated tetragonal crystals and cumengite, because he noted a slight but significant incompatibility between the angles of these different crystals, and in addition, based on observation under a polarizing microscope, stronger birefringence in the cumengite.

From this he concluded that:

> Since boleite itself, as we have demonstrated, is pseudocubic, it appears that our new substance and boleite are one and the same thing. . . . I think that boleite is formed by multiple intersections of this tetragonal substance. However, since this matter has not been clearly, resolved, I think it desirable to

> give a special name, at least provisionally, to this particular tetragonal substance, distinct from cumengite. I would propose that it be called *percylite*, a name created for a cubic substance whose optical properties have not been determined.

Mallard's crystallographic observations thus returned to the hypothesis that boleite-percylite was "formed by multiple intersections of a pseudocubic tetragonal substance with the parameters $c/a = 2.026$, or, dividing by 2, $c/a = 1.013$." The optical anomalies had been explained again! The conclusions of this scholar were cautious, however, since he was unable, lacking large enough samples, to undertake a chemical analysis of the flattened octahedrons of the grooved crystals.

Percylite (boleite) did not have acknowledged status in the scientific community for long; the future was to bring further surprises and further discredit to Mallard's model.

In that same year (1893), Cumenge reviewed the work of Mallard and Friedel and set forth his own commentaries. What is most remarkable is that he gave no credit to Mallard's central hypothesis, making instead the assumption that the "percylite" (in this case, the species made up of flattened prisms and/or truncated octahedral pyramids) in the Boléo district was a species distinct from boleite. In order to study this "percylite," he sacrificed some large grooved crystals in his collection, from which he ground the well-developed protruding parts. The analysis of the dust yielded 1.2% silver. From this, Cumenge concluded that the tetragonal substance making up the truncated flattened octahedral pyramids (grooved crystals) and the birefringent parts surrounding the isotropic boleite nuclei was a combination of 6 molecules of cumengite and one of boleite. He confirmed the novelty of the boleite and cumengite and suggested that this substance might be "percylite" in which the low concentration of silver had gone undetected in the earlier analyses! He also postulated that other stages between the poles represented by boleite and cumengite might exist in nature or be reproduced artificially. This work by Cumenge, published at his own expense, seems to have gone unnoticed.

Then, Charles Friedel (1894) presented his latest chemical synthesis results in a brief memorandum. To the mixture used for the synthesis of what proved to be cumengite, he added a small quantity of silver oxide. After several months, he obtained small cubic crystals surrounded by six tetragonal crystals, similar to the stellate groupings found in the Boléo district. (He made no mention of the presence of grooved crystals.)

In a preliminary memorandum a year later, Lacroix (1895) reviewed the studies of these minerals, which he classified in the *cumengite group*, subdividing this into two subgroups, the *cumengite subgroup* and the *boleite subgroup*. He put cumengite, for which he adopted the formula $PbCl_2 \cdot CuO \cdot H_2O$, in the first subgroup. In the second subgroup he put boleite, noting that "the examination of a thin plate of cubic cleavage made it possible to see that the boleite was pseudocubic, and that each cube was made up of a grouping around the center of six tetragonal pyramids, with one of the faces of the cube as the base." He analyzed the grooved crystals and, thanks to several measurements of the birefringence, became convinced that these crystals were the product of a complex association that always includes boleite, and very often cumengite, with a third species (never known in isolated crystals) to which he gave the name *pseudoboleite* (this species is the equivalent of the *percylite* of Cumenge and of Mallard). In addition, he noted that "among the Boléo crystals, I found cuboctahedrons on which the octahedral faces were well-developed, and generally irregular and concave. They were isotropic, or rather, their birefringence measured less than 0.001." Since these properties were shared by the little blue crystals of percylite that Mr. de la Bouglise had collected at the Buena Esperanza mine (Challacollo, Atacama, Chile), Lacroix named this mineral, in the boleite subgroup with extremely low birefringence, *percylite*. Since these crystals were argentiferous, he presumed that the silver that had previously been regarded as an impurity in the percylite was in fact an essential component, particularly since he linked the density of the crystals, which was somewhat greater than that of the cubic boleite, to a greater proportion of silver. Thus he obtained a generic chemical formula for the *boleite subgroup:* $PbCl_2CuOH_2O + nAgCl$, with $n < 1/3$ for *pseudoboleite*, $n = 1/3$ for *boleite*, and $n > 1/3$ for *percylite!*

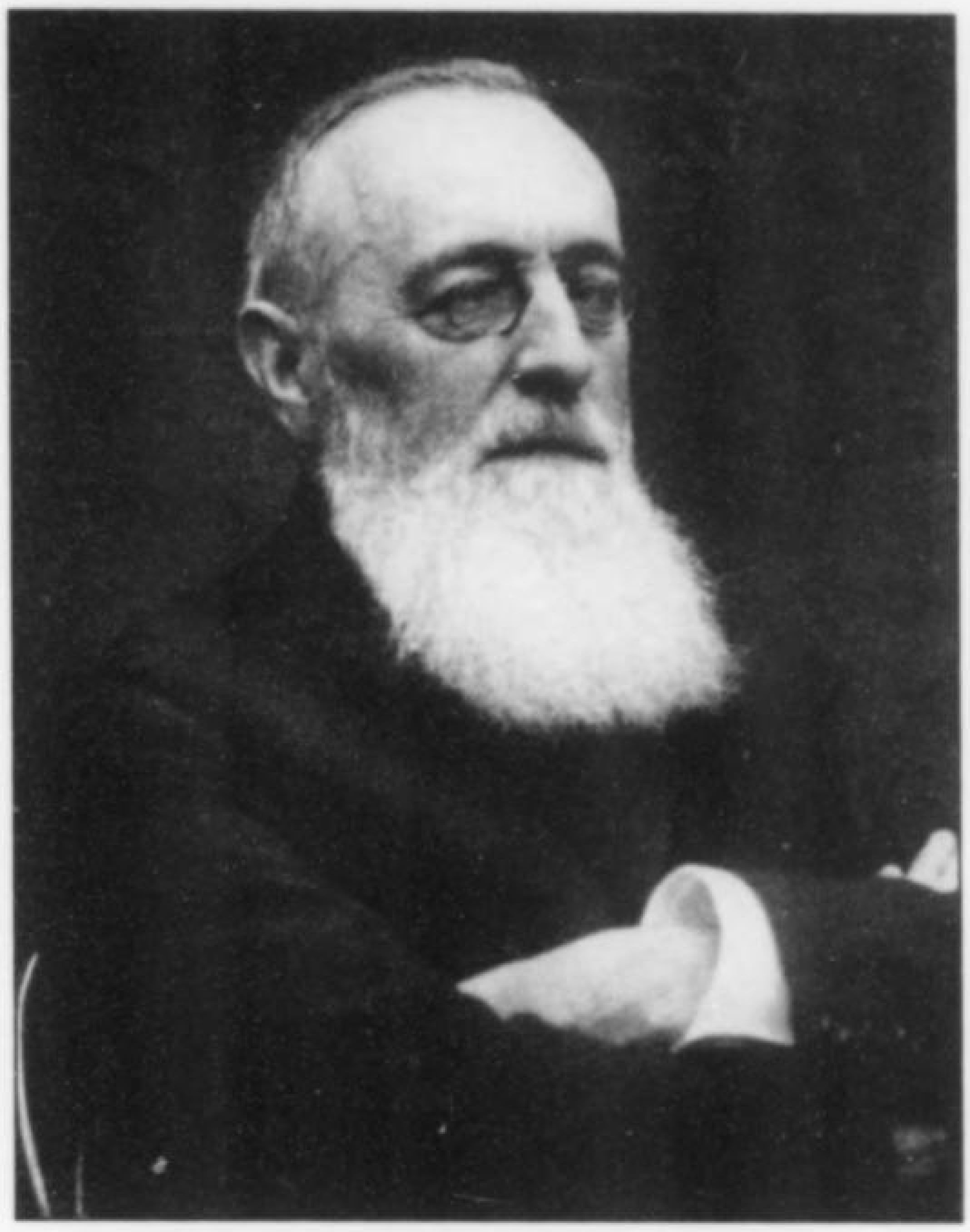

Figure 25. **Alfred Lacroix (1863–1948).**

This work, following that of Cumenge and the discovery of cumengite by Mallard and Cumenge, definitively placed Mallard's hypothesis about the relationship between the isotropic part of boleite and the various tetragonal pyramidal crystals in limbo. The explanation of the optical anomalies remained in suspense . . . for the time being.

MODELS OF WALLERANT AND FRIEDEL

At the end of the 19th century, Mallard's theory was completely abandoned outside France, and the early works of Sohncke, more mathematical and geometric, enjoyed success by confirming the works of Schoenflies and Fedorov on the space groups. However, the pioneering work by Mallard had not been entirely forgotten, and thanks in large part to the great French crystallographers, this work was to lead to original theoretical advances. Boleite, a mineralogical curiosity, was to become a prime example.

In 1898, Wallerant published an important dissertation on "The Theory of Optical Anomalies, Isomorphism, and Polymorphism." In the first part of this work, he demonstrated the consistency of Mallard's work with the most recent discoveries of Schoenflies and Fedorov. He then went back to Mallard's questions and interpretations and reinterpreted them within the framework of the formalism of the new theories. At the end of his dissertation, he discussed in detail three examples of polymorphism: *boracite*, Pyrenean *black garnet*, and, finally, *boleite*. To clarify the symmetries of this mineral, he cut thin strips parallel to certain notable orientations in the boleite crystals. He then submerged them in very weak nitric acid, and analyzed the etch figures. Based on this series of experiments, he concluded that the biaxial peripheral zones of the crystals were characterized by tetragonal symmetry. Once the tetragonal nature of the boleite had been revealed, Wallerant could again explain the optical anomalies on the basis of a model similar to that of Mallard. The cubic form (and the uniaxial central portion) was the result of penetration twinning along the three orthographic axes of these tetragonal crystals. This scholar did not, however, describe the c/a ratio of the tetragonal mesh.

Following Wallerant, G. Friedel, the son of Charles Friedel (the author of several works we have mentioned), became interested in the Boléo minerals in 1906. At that time, Friedel was regarded as one of the great crystallographers of his era. In 1904, based on numerous observations, he had demonstrated the validity of the Bravais law, which had until then been speculative and given little credence by the scientific community. This law established a correlation between the distances d_{hkl} of a family of parallel crystalline planes and the frequency of the appearance of these planes {hkl} in the form of a crystal. At that same time, he set forth the first expression of the general law governing the geometry of all twins. This law postulated the existence of a crystal lattice extending exactly or approximately to the entire twinning structure. At a later date, in 1933, in order to explain the only known exception to this law, that is to say the Zinnwald quartz twin, he showed that the twinning network was not always triperiodic, but could be monoperiodic (and, by interpolation, diperiodic).

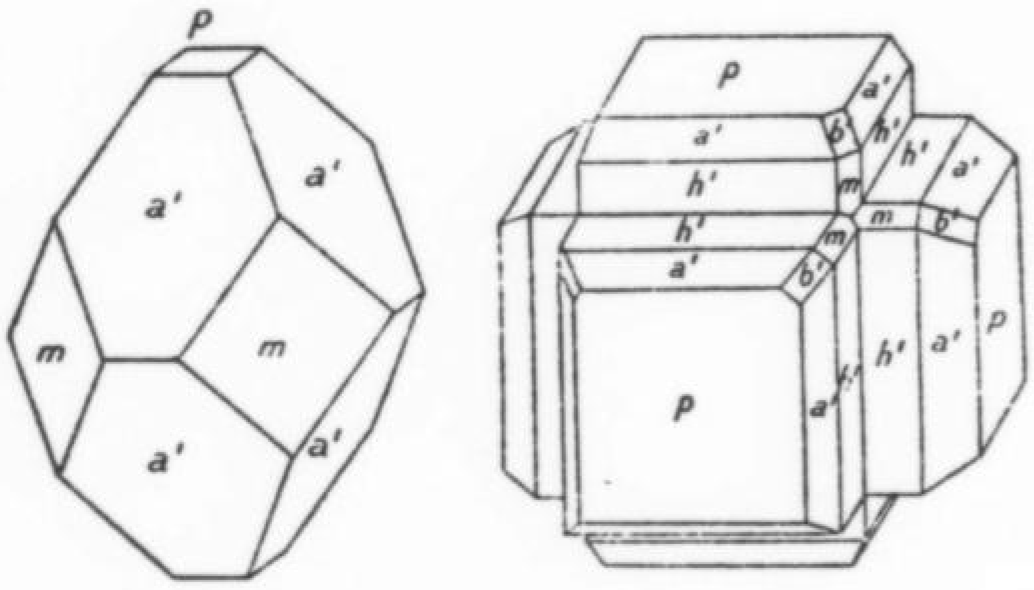

***Figure 26.* Cumengite (left) and pseudoboléite on boléite (right) (Friedel, 1906).**

The work of G. Friedel (1906) remained the definitive analysis of the indigo-blue minerals in the Boléo deposit for a number of years. Initially his interest focused on cumengite, and he refined its crystallographic, density and optical measurements. Relying on the law of twinning he had established, he confirmed that the stellate groupings could not be twins. He went back to chemical analysis and rejected his father's formula $4PbCl_2 \cdot 4CuO \cdot 5H_2O$. Friedel then reported on his work on boleite, devoting particular attention to the problem of the birefringent zones. In a detailed study of the cleavages, he noted a curious one, seen exclusively in the birefringent zones:

> This octahedral cleavage is indeed remarkable. It reveals in the clearest possible way that boleite *is not at all pseudocubic*. It is in fact almost exactly parallel, for each orientation, to four faces h^4 {410} of the cube. Now, not only does the Bravais law assign minimal importance to such a form in a cubic structure, but even without recourse to this precise law, it suffices to note that no cubic crystal has ever presented such a cleavage. . . . When one is free of the idea that the trirectangular twin of the tetragonal crystals necessarily indicates a pseudocubical network, an idea that, as I have made clear elsewhere, leads to contradictions, there remains no reason at all to regard boleite as pseudocubic. Its lattice, the parameter c:a of which is equal to cot14°3′, that is to say 3.996, or within the limit of measurement accuracy 4.00, allows it be grouped, according to the law of reticular pseudomeriedry, by a 90° rotation around one of the axes [100] or [010].

Friedel continued with a discussion of the exterior forms of twinned crystals, in the course of which he demonstrated the exemplary character of boleite. All that was left for him was to redo the precise chemical analyses of the isotropic zones and the birefringent zones. A comparison of the results revealed no significant difference and confirmed his interpretation. Just as in the case of cumengite, he challenged Mallard's formula and proposed $9PbCl_2 \cdot 8CuO \cdot 3AgCl \cdot 9H_2O$.

The third and most important part of G. Friedel's dissertation was devoted to complex crystals (that is to say, the groupings of boleite-pseudoboleite-cumengite crystals). First of all, he studied pseudoboleite, confirming its species status by optical analysis. By measuring the angles and the cleavages, he showed that it is not pseudocubic, but, like boleite, definitely tetragonal, with c:a = 2.023. A comparison of the chemical analyses of pseudoboleite and boleite indicated that the pseudoboleite definitely contained more lead than the boleite, and a small proportion of silver (1.6%), which Friedel refused to regard as significant, and which he attributed to contamination. Finally, he proposed the formula $5PbCl_2 \cdot 4CuO \cdot 6H_2O$. He then set forth his observations on the characteristics of the boleite-pseudoboleite, boleite-cumengite, and pseudoboleite-cumengite contacts. He suggested that the pseudoboleite-cumengite group had undergone simultaneous crystallization, unlike the boleite-pseudoboleite and boleite-cumengite groups. He also attributed great importance to the orientation of the crystals in these groupings.

Friedel continued with a basic discussion of the oriented growth of crystals of different species, explaining that:

> It is precisely to obtain more accurate data on this subject concerning a point that is still poorly understood that I undertook this present work. [He noted first of all] that it has long been established that the species likely to cling to a certain face have, for this common face, structures that are remarkably analogous in form. Thanks to the Bravais law, it can be ascertained and stated that one of these two flat structures is either almost identical to the other or almost identical to a simple multiple of the other. . . . There is here a phenomenon that is from all appearances very close to twins, and also to syncrystallization, forming in a way the transition between these two categories of occurrences.

Farther on, Friedel became emboldened, and he put forth a basic hypothesis that the future was to confirm.

> The almost identical nature *of the forms* noted for the joined flat structures or their multiples, or in some cases for entire structures, is likely to be accompanied by quasi-identity *of dimensions*.

To support this hypothesis, he estimated the lattice parameters with molecular weights and densities, as a result of which he obtained a consistent model. With this work, Friedel established the foundations of the theory of *epitaxy.*

Friedel's model was hardly challenged, since this scholar had brilliantly utilized every experimental and theoretical possibility available in his era and had resolved numerous questions. The only remaining uncertainty concerned crystalline distances. The crystallographers of the German school, who had little sympathy for the theory of Mallard and his heirs, appear to have ignored the theory. In any case, the existence of boleite, pseudoboleite, and cumengite seemed as of that time to be definitively accepted.

After an intensive period of initial work and discoveries, the study of these minerals experienced a period of calm . . . before the storm.

X-RAY ANALYSIS

Hadding (1919) was the first to propose the hypothesis that boleite is cubic and that, consistent with the theory of Brauns, the optical anomalies are accidental. He believed that the birefringent portions were inhomogeneous and were made up of alternating thin sheets rich in silver and others containing very little silver. His work apparently aroused little interest.

There was a veritable resurgence (or rather, a revolution) in the interpretation of the structures of the minerals in the boleite group as the analytical methods based on the use of X-rays became widespread. X-rays were discovered in 1895 thanks to the perseverance and perspicacity of Röntgen, and their potential for use in crystalline analysis was demonstrated in the decade between 1910 and 1920 by the work of Laue, Ewald, Debye, and the Braggs (Lima-De-Faria, 1990). After more than a century of speculation, intuition, and effort, crystallographers finally had adequate experimental tools available to them. The lattice and motif concepts were finally proven, and in addition it became possible to measure the size of crystal lattices.

Because of their complexity, the X-ray methods of crystallographic analysis spread among mineralogists rather slowly. Thus it was not until 1929 that Gossner and Arm undertook a study of boleite and the related minerals. These scholars, too ready to overlook earlier efforts, limited themselves to radiological analysis, failing to take into careful account the highly heterogeneous nature of the crystals. For boleite, they analyzed the isotropic portion and came to the conclusion that boleite is "cubic," or rather, they recognized that the optical anomalies are an indication of pseudocubical symmetry, and that the isotropism of the nucleus results from repeated twinning. However, the disparity with the cubic symmetry characteristic of the structure of the boleite, assuming that a disparity existed, did not seem susceptible to experiment, in their view. Where pseudoboleite is concerned, they concluded that it was perfectly identical with boleite, and they concluded that twinning on (035) accounted for the star groupings of cumengite.

The authors of this obviously imprecise work seem to have neglected preceding works that had emphasized the value these minerals had acquired as examples and archetypes. Friedel's response (1930) was surprisingly violent, if not scurrilous. In a preface he wrote that: "The principal argument of Gossner and Arm, in comparison to which none other exists, in the eyes of many people, is radiological analysis." Without disputing the importance of this method, Friedel easily showed the inaccuracies in these authors' use of it. They had in fact studied only the isotropic part of the boleite, and Friedel wrote: "It goes without saying that in order to observe this parameter [the parameter c/a] correctly, one must not address the isotropic or quasi-isotropic portions in which the three orientations of the tetragonal crystal are closely intermixed. It is necessary instead to examine the birefringent sectors in which one of the orientations is, insofar as possible, isolated." In addition, relying on the works of his assistant Hocart, then in the process of being published, Friedel raised serious doubts about the experimental conditions employed by Gossner and Arm. "There is a more serious source of error in the use of inadequate intensities or exposures, which allowed the lines of intermediary (Schichtlinien) spots, the existence of which multiplies the parameter c:a by 4, to go unnoticed." In addition, these authors failed to find the cleavages (h0l) at 14°3′ on the faces {100}, thereby creating doubt about Friedel's experimental skill. With regard to the chemical formula, they adopted Mallard's, although their two quantitative analyses were more consistent with Friedel's. Where pseudoboleite was concerned, they had available only very small samples, and that fact places their conclusion in doubt. As to the existence of cumengite twinning, it was not absolutely dismissed by Friedel, but it does not fit well with the systematic presence of a core of boleite within the stellate groupings.

Just after Friedel's article was published, the work of his assistant Hocart (1930) came out. It included a short memorandum in which the results obtained using X-rays ("Revolving Radiograms") were set forth. For *boleite,* Hocart analyzed a fragment of the birefringent zone, and he concluded that there was a tetragonal lattice with c = 62Å and a = 15.4Å (the latter value being consistent with that of Gossner and Arm), that is to say a relation of c/a ≈ 4, consistent with Friedel's model. For *pseudoboleite,* Hocart took a homogeneous fragment on which he observed octahedral cleavages and the basal cleavage reported by Friedel. He obtained c = 31.2Å and a = 15.4Å, in which c/a ≈ 2, and confirmed the determination by the cleavages, which yielded c/a ≈ 2.023. Finally, for *cumengite,* Hocart obtained c = 24.25Å and a = 14.9Å (close to the values obtained by Gossner and Arm; c = 24.71Å and a = 15.17Å).

This latest work, appearing subsequent to Friedel's virulent response to Gossner and Arm's work, seems to have had an effect, and following this period of controversy there was a long period of calm during which Friedel's point of view appeared to have won the day. In 1934, Hocart published a major study on optical anomalies, in which he adopted the theory of Mallard and Friedel and expounded the hypotheses of Klein and Brauns (Klein, 1883; and Brauns, 1891). Experimentally, using X-ray methods, he confirmed Friedel's theory, citing boleite as an example, among others.

The spirited arguments pertaining to the minerals in the boleite group now began to fade away. But future works on these minerals would appear whose precision would keep pace with technical and theoretical developments in crystallography.

MODERN STUDIES

It was 26 long years before boleite reappeared in scientific discussion—as a mineral exemplifying polymorphism and/or mimesis. In 1950, Ito carried out work on polymorphism using X-ray techniques. By this time, the old quarrels had been forgotten, and the theory of twinning and Friedel's model of epitaxy had been confirmed and accepted by the scientific community. However, Ito returned to the analysis of anisotropic boleite, and proposed a complex model presuming the existence of twins of cubic units within the crystalline lattice. The resulting symmetry was tetragonal I4/mmm and the parameters had a value of a = 15.27Å and c = 60.94Å. The twin is made up of four cubic lattices, each of them having the symmetry Pm3m and a parameter equal to 15.27Å, close to that determined by Gossner and Arm. Later, Winchell (1963), in a Ph.D. Thesis, returned to the study of the minerals in the boleite group, although some of his conclusions were not to be published until much later (Winchell and Rouse, 1974).

In 1968, Keester and Johnson carried out an analysis of pseudoboleite obtained from a specimen from Chancay (Peru). The result was not an article, but was published in the American Society for Testing and Materials (ASTM) index. The parameters obtained by these authors were $c = 30.588$ and $a = 15.294$Å. The formula they proposed was $Ag_9Pb_{26}Cu_{24}Cl_{61}(OH)_{48}\cdot 3H_2O$. It should be noted that this formula re-proposed that the mineral contains essential silver, an idea which had been forgotten after the works of Cumenge (1893) and Lacroix (1895).

The most notable contribution published after the work of Ito was that of Mucke (1969, 1972); two short and concise memoranda on the crystallographic characteristics of boleite. These two works, containing contradictory conclusions but still in the tradition of recognizing the exemplary structural value of the minerals in the boleite group, essentially adopted Ito's hypotheses and attempted to establish structural analogies linking boleite, pseudoboleite and percylite, without returning to the earlier questions. In the first memorandum, Mucke adopted Friedel's point of view, and concluded that boleite is tetragonal, with $a = 15.27$Å and $c = 61.30$Å. In the second work, without explanation, he assigned it a value of c equal to 30.65Å and a $P4_2/$ mmc group. His conclusions on pseudoboleite were equally contradictory. He obtained the parameters (Mucke, 1969) $a = 30.46$Å and $c = 30.81$Å, with a change in the space group from P4/mnc (1969) to $P4_2$/mnc (1972), and a change in the chemical formula from $14PbCl_2\cdot 12Cu(OH)_2\cdot 7.5H_2O$ to $28PbCl_2\cdot 24Cu(OH)_2\cdot 2AgCl\cdot 15H_2O$. No detailed discussion accompanied these results. His crystallographic analysis of cumengite (Mucke, 1969) was consistent with the earlier works, but he proposed the following chemical formula derived from synthetic cumengite: $5.5PbCl_2\cdot 5Cu(OH)_2\cdot 0.5H_2O$. Let us also note that he analyzed percylite from the Santa Ana mine (Caracoles, Sierra Gorda, Chile) and found its cubic symmetry to be Pm3m, with a structure similar to that of boleite and a unit cell almost equal to that of the square base of the tetragonal boleite. Finally, he proposed the term *paraboleite* for all of the intermediary stages of silver concentration between *boleite* and *pseudoboleite*. The absence of commentaries and the disparities between the two works render them suspect and not very credible.

Next, Rouse (1973) and Winchell (Winchell and Rouse, 1974) carried out in-depth studies of a more mineralogical and less crystallographic nature. These studies are still regarded as authoritative today, and they are cited in the international databases used by mineralogists throughout the world.

For *boleite*, Rouse (1973) determined that its symmetry is cubic—Pm3m with $a = 15.29$Å and its formula is $Pb_{26}Ag_9Cu_{24}Cl_{62}(OH)_{48}$. He established its structure and came to the remarkable conclusion that the silver atoms were grouped in octahedral packets ("clusters"). Boleite would be the first natural example of the group of substances known by the name "metal cluster compounds." The X-ray photographs of the anisotropic peripheral zones, when examined carefully, show that the reflections linked at distances of 61Å are not, in fact, periodic, and can be broken down into two series of periods at 15.3 and 30.7Å, consistent respectively with boleite and pseudoboleite. Winchell and Rouse therefore proposed that these zones are the result of the intersection of boleite and pseudoboleite. Although this hypothesis is supported by a number of other observations, these authors, for lack of a local chemical analysis, did not reject Ito's twin model.

Their analysis of *cumengite* yielded results consistent with and close to those of Gossner and Arm and of Hocart. They proposed the formula $Pb_{19}Cu_{24}Cl_{42}(OH)_{44}$. For *pseudoboleite*, these authors speedily confirmed the work of Hocart, and made no new contributions. Their analyses of all the samples of *"percylite"* they could obtain proved to be compatible either with *boleite* or with *boleite-pseudoboleite* mixtures; thus they proposed that this species be discredited. In addition, they did not recognize Mucke's *paraboleite*.

Following the determination of the complete structure of boleite by Rouse (1973), that of cumengite was determined by Hawthorne and Groat (1986). Analyzing a crystal of about 2 mm, these authors found a tetragonal lattice with $a = 15.065$Å and $c = 24.436$Å, a space group of I4/mmm, and the chemical formula $Pb_{21}Cu_{20}Cl_{42}(OH)_{40}$. They noted a strong variation in the coordination of the cations, and determined five different sites for lead and two for copper.

Finally, Giuseppetti *et al.* (1992) recently established the structure of *pseudoboleite*. It is tetragonal, with $a = 15.24$Å, $c = 30.74$Å, and a space group of I4/mmm. They demonstrated that pseudoboleite has a crystalline structure very close to that described for boleite by Rouse (1973). Apart from the rearrangement of sites leading to the doubling of the lattice and a change in the space group, the essential difference between these two structures would be the partial occupation by lead of the sites occupied by silver in the boleite. By refining the structure, these authors obtained the formula $Pb_{31}Cu_{24}Cl_{62}(OH)_{48}$ for pseudoboleite.

CONCLUSIONS

The history of the determination of "boleite and the related minerals" prompts us to make a few remarks about the operational methods of the scientists interested in this subject. The work has not, first of all, shown that consistency, that linear forward development, described for us by the majority of the texts on the history of the sciences. In defense of the scientific community, one must recognize that these minerals pose particular difficulties: they have always been "sufficiently accessible" for precise analysis, but the problems they pose are "sufficiently difficult" to push available theories and practices to their limits.

The history of this work reminds us, too, that understanding, in science, may come from discovering hierarchical orders in the questions to be asked, and is subject to varying influences from schools of theoretical thought. It is for such reasons that this more-than-a-century's worth of work on boleite and its related minerals has proceeded in three clearly distinguishable phases.

In the initial period that followed collection of the samples in the field, the scholars, despite the adequate experimental resources available to them, succumbed to a certain degree of haste, and made mistakes. As a result it took a full three years to proceed from boleite to the boleite-pseudoboleite-cumengite triad, although characteristic samples had been found as of the very first collection efforts, and the angular and chemical measurements should have made it possible to distinguish one substance from the other. This was also the era of the appearance of percylite, a catchall term and "concept" mineral that, rigged out with a theoretical formula that was sometimes argentiferous and sometimes not, was to be introduced a number of times, despite the fact that its description was always incomplete. More than a century would have to pass before the works of Winchell and Rouse (1974) raised serious doubts about the existence of percylite. However, interest during this period focused, appropriately, on the optical anomalies of boleite and the groupings of crystals. The early work would assign considerable prototypical importance to the minerals in the boleite group in the theories of isomorphism, twinning, and epitaxy developed by the French crystallographers.

The second period, characterized by the appearance and development of X-ray analysis, brought a resurgence of the influence of the various schools of crystallography. The French school, the heir to Mallard's theory, would, in its description of boleite, remain faithful to the concept of the piling up of different crystals

***Table 1*. Chemical formulae proposed for minerals in the Boleite Group.**

Boleite

$Pb_3Cu_3AgCl_7(OH)_6$ (Mallard and Cumenge, 1891)
$PbCl_2CuOH_2O + 1/3AgCl$ (Mallard and Cumenge, 1891; Lacroix, 1895)
$9PbCl_2 \cdot 8CuO \cdot 3AgCl, 9H_2O$ (Friedel, 1906)
$Pb_{26}Ag_9Cu_{24}Cl_{62}(OH)_{48}$ (Rouse, 1973)

Cumengite

$PbCl_2CuO \cdot 2H_2O$ (Cumenge, 1893)
$PbCl_2CuO \cdot H_2O$ (C. Friedel, 1892; Lacroix, 1895)
$4PbCl_2 \cdot 4CuO \cdot 5H_2O$ (G. Friedel, 1906)
$5.5PbCl \cdot 5Cu(OH)_2 \cdot 0.5H_2O$ (Mucke, 1969)
$Pb_{19}Cu_{24}Cl_{42}(OH)_{44}$ (Winchell and Rouse, 1974)
$Pb_{21}Cu_{20}Cl_{42}(OH)_{40}$ (Hawthorne and Groat, 1986)

Pseudoboleite

6cumengite + 1boleite (Cumenge, 1893)
$PbCl_2 \cdot CuO \cdot H_2O + nAgCl, n < 1/3$ (Lacroix, 1895)
$5PbCl_2 \cdot 4CuO \cdot 6H_2O$ (Friedel, 1906)
Idem boleite (Gossner and Arm, 1929)
$Pb_{60}Cu_{48}Cl_{120}(OH)_{96} \cdot 24H_2O$ (Dana, 1951)
$14PbCl_2 \cdot 12Cu(OH)_2 \cdot 7.5H_2O$ (Mucke, 1969)
$Pb_{56}Ag_4Cu_{48}Cl_{116}(OH)_{96} \cdot 28H_2O$ (Strunz, 1970)
$28PbCl_2 \cdot 24Cu(OH)_2 \cdot 2AgCl \cdot 15H_2O$ (Mucke, 1972)
$Ag_9Pb_{26}Cu_{24}Cl_{61}(OH)_{48} \cdot 24H_2O$ (Keester and Johnson, 1978)
$Pb_{31}Cu_{24}Cl_{62}(OH)_{48}$ (Giuseppetti *et al.*, 1992)

(twinning). The German school (Hadding, and Gossner and Arm) neglected or ignored these models, going back to those to which it remained faithful, and explaining the optical anomalies in terms of insignificant defects. It was the French school that won these spirited polemic arguments. During this period, too, reliance on optical analysis lessened gradually, despite the fact that such analysis is a necessary prerequisite for sampling highly dissimilar crystalline groupings (see Friedel, 1906).

The third period, which one could date from the beginning of Ito's work (1950), has been characterized by fewer studies of these minerals, but considerable development in theoretical and experimental resources. Understanding has developed slowly, and different models survive. With regard to *anisotropic boleite*, for example, some interpretations, like that of Ito, are based on Friedel's model, while others (Winchell and Rouse) suggest the presence of defects resulting from a pseudoboleite-boleite mixture. Be that as it may, the anisotropy in boleite has ceased to be a major problem, and studies of it were gradually abandoned as the cubic nature of this mineral was confirmed and Friedel's model involving twins was rejected. A new mineral, *paraboleite*, was suggested, but soon abandoned. The complete crystalline structures of the minerals in this group were then finally determined.

We might note that, as a general rule, during all three of these periods crystallographic analysis was greatly favored over chemical analysis. Where boleite and cumengite are concerned, quite satisfactory consistency in the chemical analyses can be observed. This is not the case for pseudoboleite (see table of formulas), the argentiferous (or non-argentiferous) nature of which has not been determined. The most recent works have relied heavily on crystallographic methods for the determination of the chemical formula.

But all of the equivocations, the errors, the omissions and/or uncertainties that have developed during the work done on boleite and the associated minerals should not lead us to forget the work's great importance to the advancement of the theories of isomorphism, twinning and epitaxy. At the present time, these theories are widely used in microelectronics, so that ultimately it is not unrealistic to say that the science of electronic data processing owes much to these minerals.

Geology

The Boléo copper deposit is located on the eastern coast of Baja California near the Lucifer manganese bed. Both of these deposits have a shipping outlet thanks to the artificial port of Santa Rosalia on the Gulf of California, opposite Guaymas, where the Sonora railroad line ends. The two deposits are contiguous and cover a combined area of about 200 square kilometers.

A number of studies mark the history of the Boléo mines. As early as 1873, Tinoco (1874, 1894) undertook the first work on this deposit, which was then being exploited on a small scale. These efforts were followed by those of de la Bouglise and Cumenge (1885), who were working for the future Boléo Company. Fuchs provided the first exhaustive geological analyses in 1886. Later, Touwaide (1930) provided a precise description of the ore, and Bellanger (1931) gave an accurate description of the conditions of exploitation. It was in 1948–49 that Wilson drafted the synthesis (Wilson, 1955) which has served as a basis for this presentation.

At the present time, the Boléo mining district is a vast, almost flat plateau with a gentle incline toward the sea, divided by four large ravines and overlooked by isolated peaks. It extends 11 km to the northwest and from 500 meters to 3 km in a northeasterly direction. It is made up alternately of tuffs and other volcanic rocks, and conglomerates.

The marine terraces formed in the Pleistocene, known as the Santa Rosalia formation, retain the marks of the most recent volcanic episodes, accompanied by tectonic movements. To the west, these areas are adjacent to an irregular chain formed in the Miocene and running parallel to the coast, comprising the sole plane of this sector.

The cupriferous mineralizations are located in the so-called Boléo formation, made up of tuffaceous and conglomeratic alternations. The tuffs are argillaceous, feldspathic and micaceous. The conglomerates are made up of rounded fragments of eruptive rocks that become increasingly acidic toward the upper part of the formation, except for the uppermost conglomerate, which is made up of basic rocks, like the base conglomerate. These two conglomerates encompass a complete volcanic cycle. Copper is present in four principle sequences, encased in the tuffs, in all cases above the conglomerates. The mineralized horizons are irregularly distributed in beds, lenticular bodies and nodules of oxides and carbonates. It is the remarkable presence of these nodules, called "Boléos," that gave this deposit its name.

It took a lengthy history to create this landscape. The oldest known volcanic complex is located on the western edge of the peninsula; because of erosion, it is no longer present in the Boléo region. The oldest known series in this region is the Miocene Comondu series, which bears witness to intermittent, very lively volcanic activity, with calmer periods during which sediments were deposited. Beneath a relatively shallow sea, the volcanic series was deformed and faulted by tectonic movements, creating a pronounced relief. The Boléo formation appeared during the Pliocene, when a first major marine transgression covered the older relief and created a landscape dotted with islands. The calcareous series

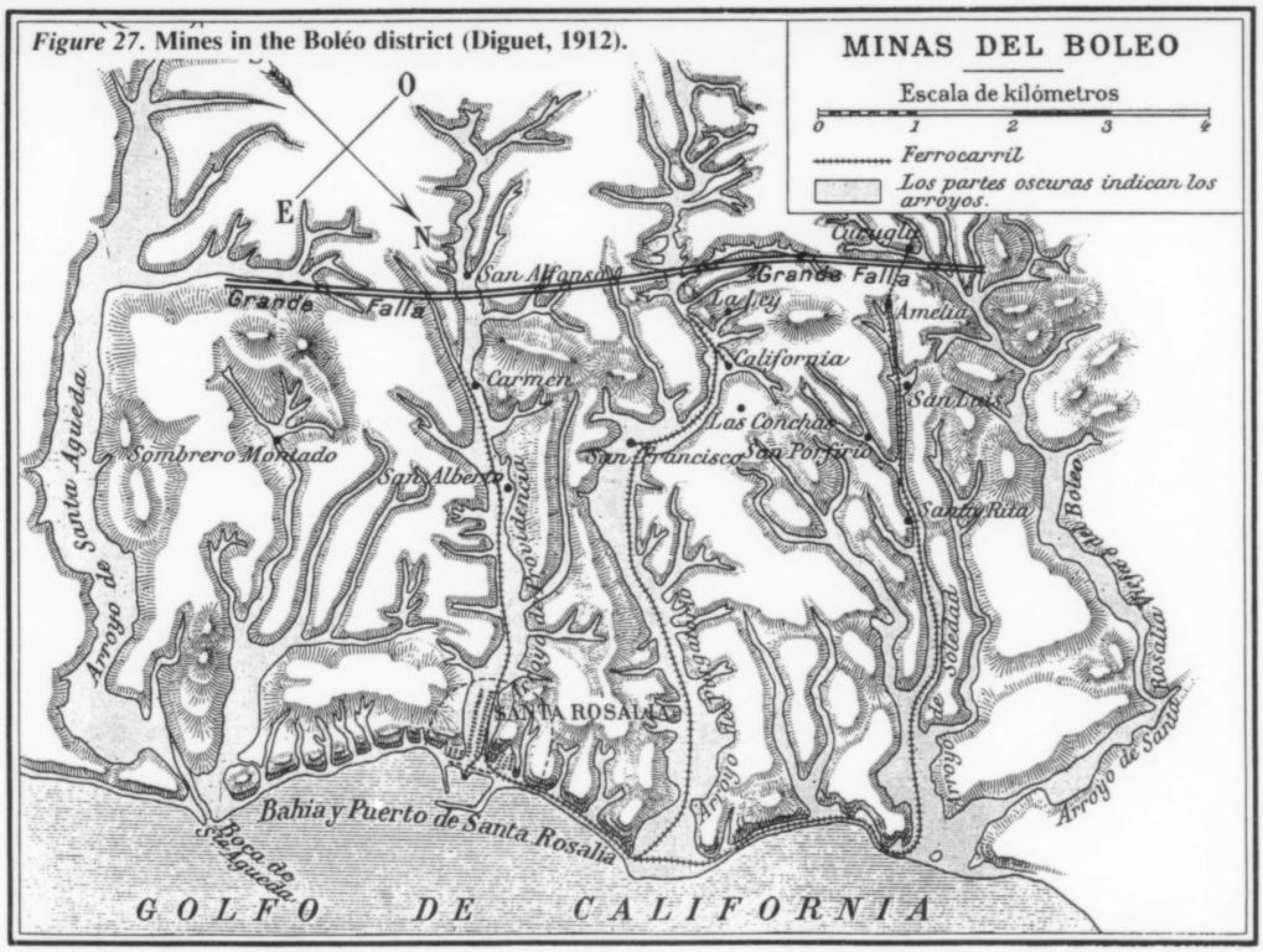

Figure 27. **Mines in the Boléo district (Diguet, 1912).**

then settled at the base. These sediments in turn were covered over by new detrital discharge from the west, following new volcanic episodes that deposited the series encasing the mineralization. These series were of the deltaic type. The contour of the shoreline changed as the sedimentary accumulation progressed. Thus at least five violent eruptive volcanic episodes interrupted the calm deposits and caused the subsidence evidenced by conglomerates, the product of the erosion of the Miocene Comondu series.

A fracture parallel to the shoreline cut across the terrain to the west, forming a channel for the passage of acidic solutions. The eruptive ash, dust, and lapilli formed the tuffs that later underwent alteration. These tuff levels formed traps for the solutions and concentrated the copper and manganese.

In the Middle Pliocene, there was another marine invasion during which the sediments of the Gloria formation were deposited, followed by those of the Infierno formation. The Pleistocene deposits of the Santa Rosalia formation, previously mentioned, were accompanied by tectonic movements. The last known volcanic episode occurred during the Pleistocene.

There are five principal mineralized horizons in the Boléo formation, usually numbered from zero to four. The majority of the production has come from the second and the fourth (that is to say, mineralized layers No. 1 and No. 3). The thickness of the mineralized bodies varies, but averages about 80 cm. The copper concentration comes to about 4.8% with variations from 3.5% to 8%. Between 1886 and 1947, the total production was 540,342 metric tons of copper concentrate, obtained from 13,622,327 tons of ore. The deposit was subjected to underground exploitation rather similar to that in coal mines, where there are thin little veins. The network of galleries has a total length of 588 km.

A number of theories have been put forth to explain how the Boléo mineralizations were deposited. Some of those with the greatest acceptance at present credit the action of hydrothermal solutions whose upward circulation was facilitated by the numerous faults and fractures in the Comondu series. A number of observed features support this thesis, including the presence of stockworks and veins; the vertical zoning of the ore with copper, then zinc; and finally, the zoning of the principal mineralized horizons, reflecting the presumed flows of solutions. Many analogies, in particular those involving the characteristics of the encasing rocks and the metallic arrangement, establish a similarity between this deposit and the Kupferschiefer in the Mansfeld district of Germany.

Today, the Boléo deposit appears to hold little promise for copper. Although a significant tonnage of ore remains, it is low-grade and difficult to access. The major remaining potential of the Boléo deposit is in such elements as manganese, cobalt and sulfur, and materials such as gypsum, carbonates, pumice, perlite and building stone.

The Amelia Mine

The Amelia mine, and secondarily, perhaps, the adjacent Curuglu mine, have provided the bulk of the remarkable specimens of minerals in the boleite group. The Amelia mine is located near the upper end of the Soledad Arroyo. Two other mines are adjacent to it—the California-Lugarda mine in the Purgatorio Arroyo, to the east, and the San Luis mine in a lower portion of the Soledad Arroyo, to the northeast. To the west and northwest, the Amelia mine ends at the banks of the Curuglu Cañada and the branches of the Boléo Arroyo. The Curuglu mine is located on the western bank of the Curuglu Cañada (*cañada* is the term used here for a glen or dale).

A number of parts of the Amelia mine have been given individual names, including Olvido Viejo, Olvido Nuevo, San Andrea, San Jorge, and Fortuna. The northern and western portion is called the Santa Teresa mine.

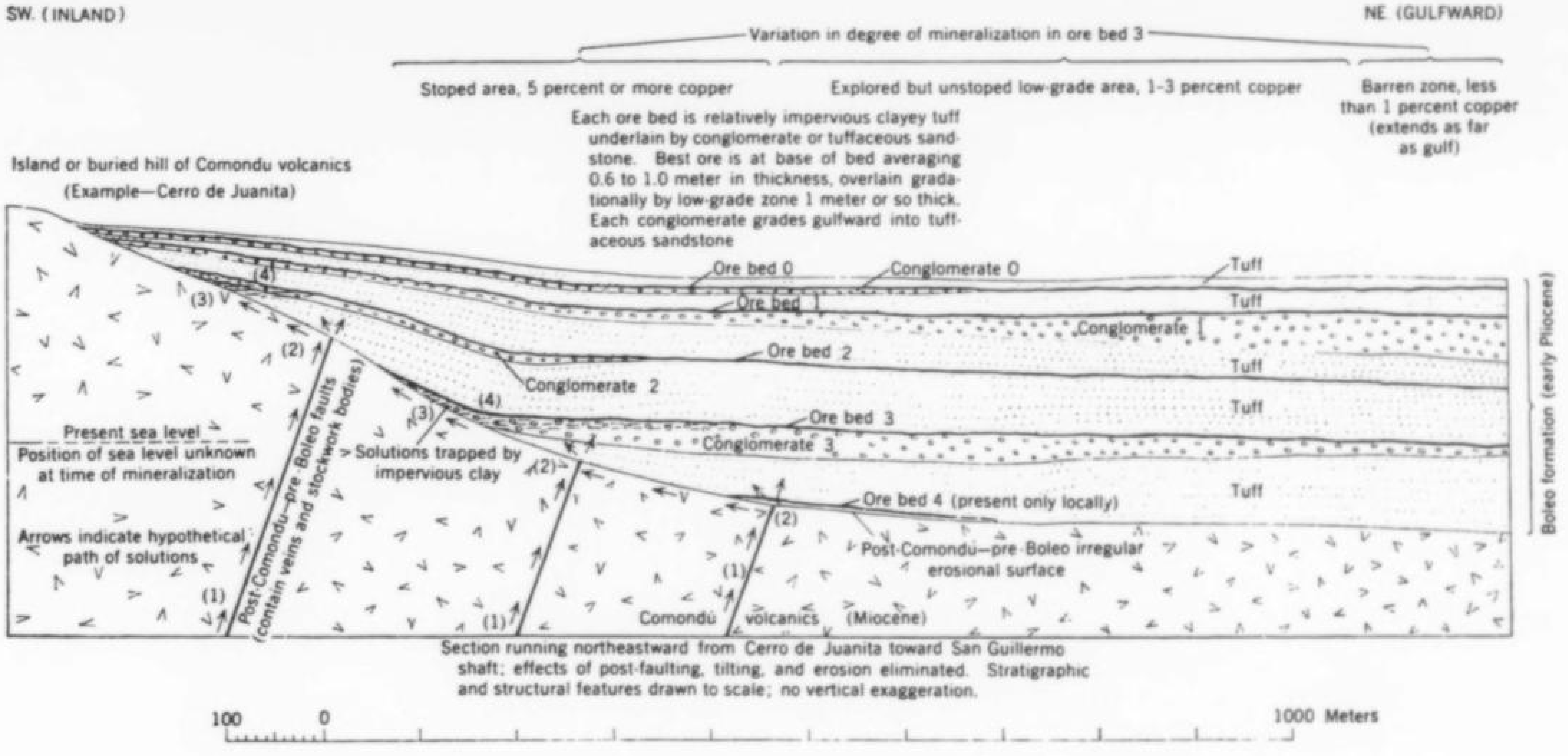

Figure 28. **Diagram suggesting a mechanism by which ascending hydrothermal solutions were trapped to form the Boléo deposits (Wilson, 1955).**

(1) Hydrothermal mineralizing solutions (?) rise from depth along faults and fractures in Comondú volcanics. (2) Solutions ascend along irregular Comondú-Boléo contact and may be dispersed upward and outward through porous beds of Boléo formation. These beds may or may not already be saturated with water; in any event, warmer mineralizing solutions will rise toward top. (3) Solutions are trapped by relatively impervious clayey tuff and back up below the trap in conglomerate (or sandstone) which underlies clay and serves as an aquifer. (4) Constant contact of solutions with clayey tuff permits diffusion of copper into clay, where it is precipitated as chalcocite. Best ore is where most effective trap for ascending solutions exists against volcanic hill. Ore beds become lower grade and eventually barren away from hills. NOTE: In the area of the diagram, bed 3 has best ore; bed 2 is mineralized in a narrow zone, and beds 1 and 0 are practically unmineralized. Assumed reason: Higher beds have very limited contact with volcanic basement rocks, and bed 3 has extensive contact; most of the solutions were trapped by bed 3, and only a small part could reach the higher beds.

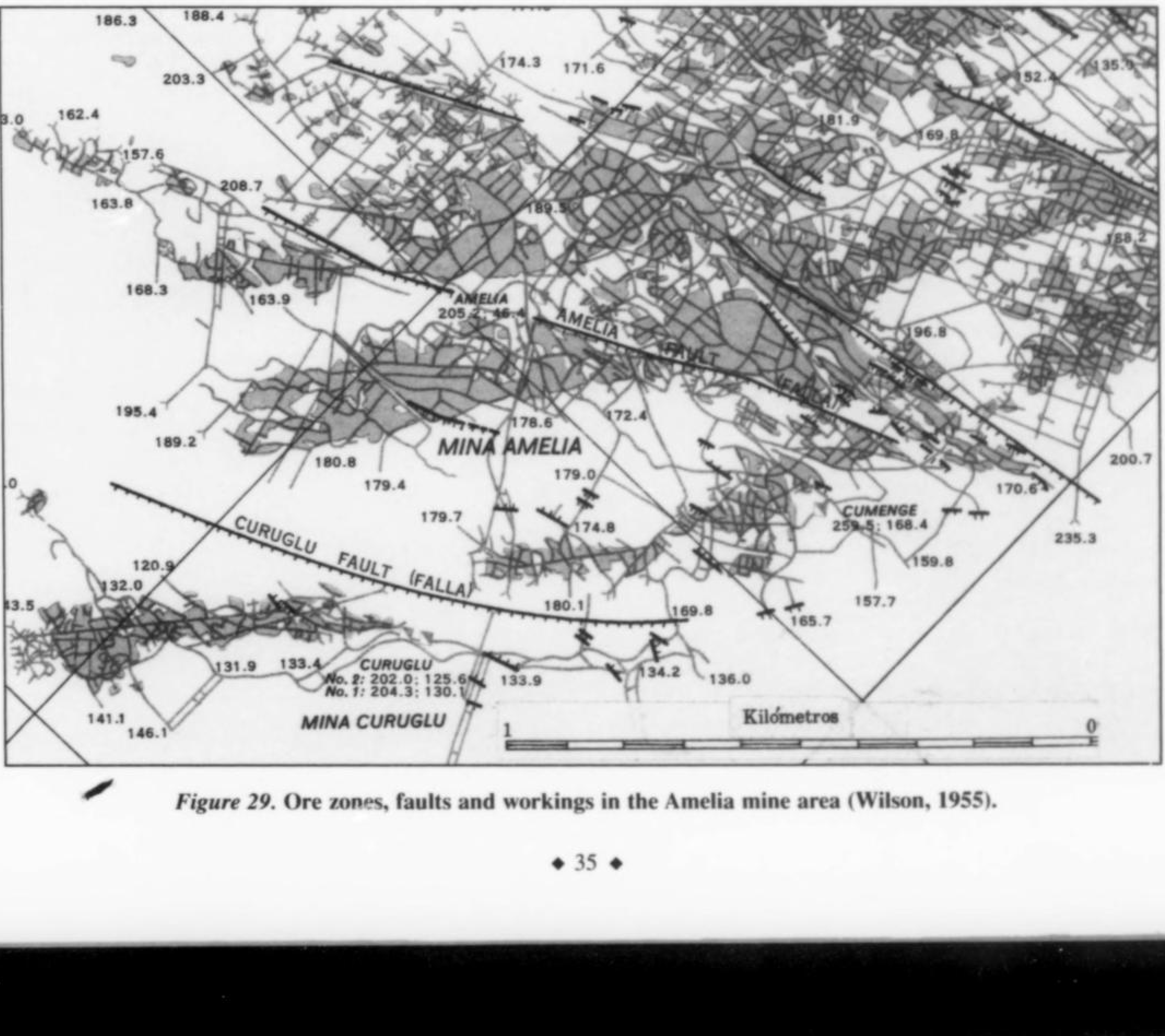

Figure 29. **Ore zones, faults and workings in the Amelia mine area (Wilson, 1955).**

The ore was taken from level number 3, of which there are outcroppings in numerous places. The elevation of this level ranges from 144 to 209 meters above sea level. The Curuglu fault on the west bank of the Curuglu Cañada lowers the level of this bed for the Curuglu mine and marks the separation between it and the Amelia mine.

The surroundings of this mine were recognized by the prospectors from the beginning as one of the most promising sites, and major exploitation work was undertaken there as soon as the Boléo Mining Company had been established in 1886. The period of its greatest activity ended about 1919, and the site was subsequently exploited only sporadically and on a more or less minor scale. The period of major activity at the Curuglu mine ended about 1900. Two shafts were dug in the Amelia mine—the Amelia shaft in the northern part, and the Cumenge shaft in the southern part. Level No. 4 was found at this site 141 meters below bed No. 3, and prospecting of it was possible thanks to the Amelia shaft. However, this level was not deemed worthy of commercial exploitation, and no substantial work was undertaken. Two shafts without individual names were dug close together at the Curuglu mine.

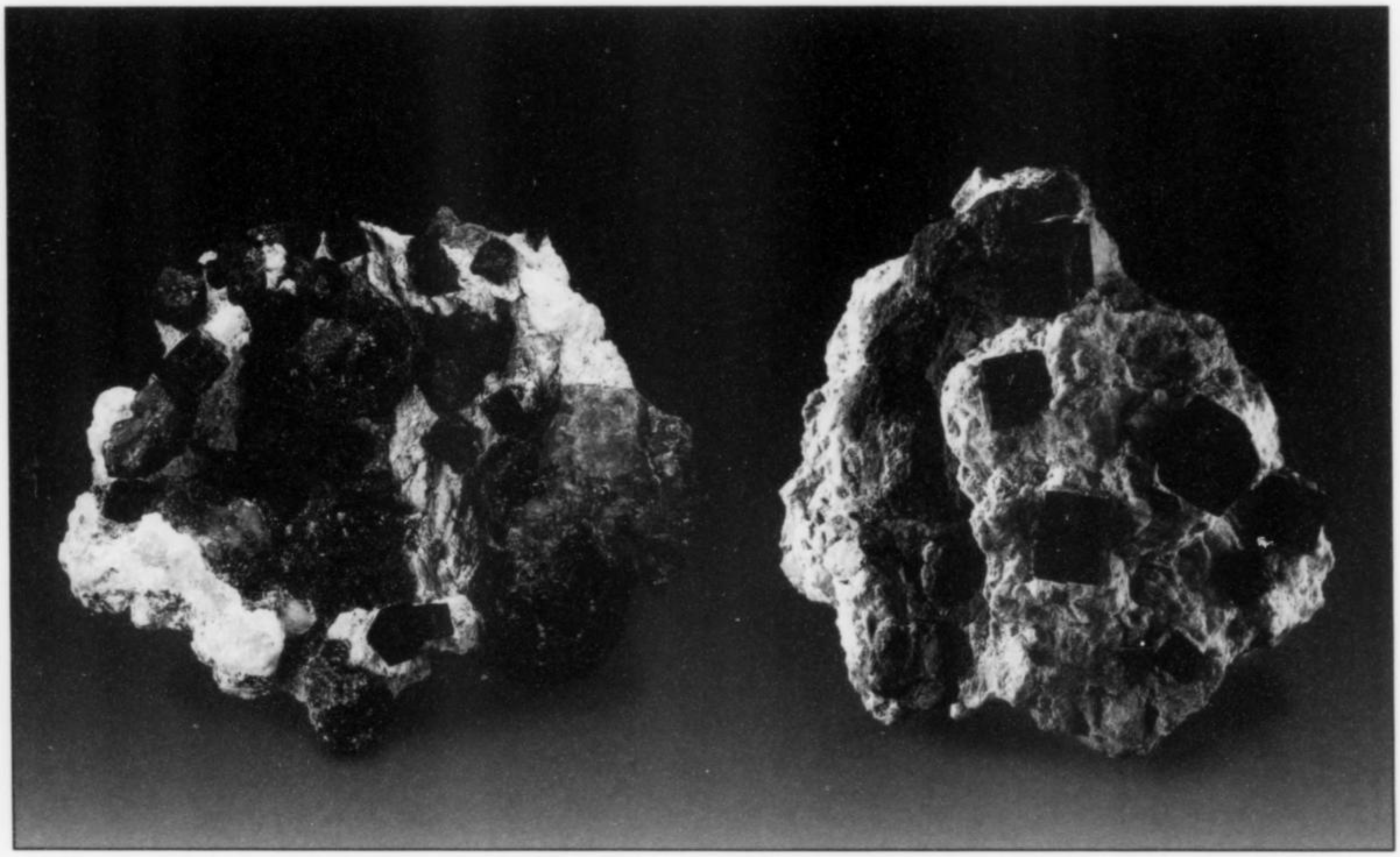

Figure 30. **Boléite crystals to about 1 cm with paratacamite and clay, recovered in 1973. Pala Properties International specimens; photos by Harold and Erica Van Pelt.**

Mineralogy

Few exhaustive mineralogical studies on the distribution of the Boléo minerals and their associations have been undertaken to date, since the mine ceased activity in an era during which this kind of work and the dispatch of courageous young doctoral candidates to engage in field work were rare. A brief statistical study of the scientific works pertaining to this deposit and its minerals reveals two periods of heavy activity. The first, from approximately 1880 to 1900 corresponds to the discovery and initial exploitation of the mine, while the second, from 1925 to 1940, coincides with the period of withdrawal and disengagement by the French. During this latter period, mineralogical studies experienced a resurgence as a result of the development of X-ray techniques. During the first period there was a very high proportion of French efforts, which dwindled steadily thereafter as Mexican and American research increased.

The sources contributing to an understanding of the mineralogy of the Boléo deposit are the old, rather brief narratives written by the various collectors, and the scientific works, and the samples on exhibit in collections accessible to the public. Moreover, except where the Amelia mine is concerned, it is hard to know which minerals were found during the various different projects undertaken at this vast mining site. Two rather vague, geologically oriented works (Wilson, 1955; Touwaide, 1930) which describe some characteristics of the minerals that had been found as of their respective dates do provide a good idea of the mineral wealth of this deposit. Three families of minerals were distinguished—those in the sulfide zone, the oxidized minerals, and the gangue minerals.

Species having some geological or collector interest are discussed below; all species reported from Boléo are listed on Table 2.

Anglesite $PbSO_4$

Anglesite appears in the form of compact orthorhombic crystals

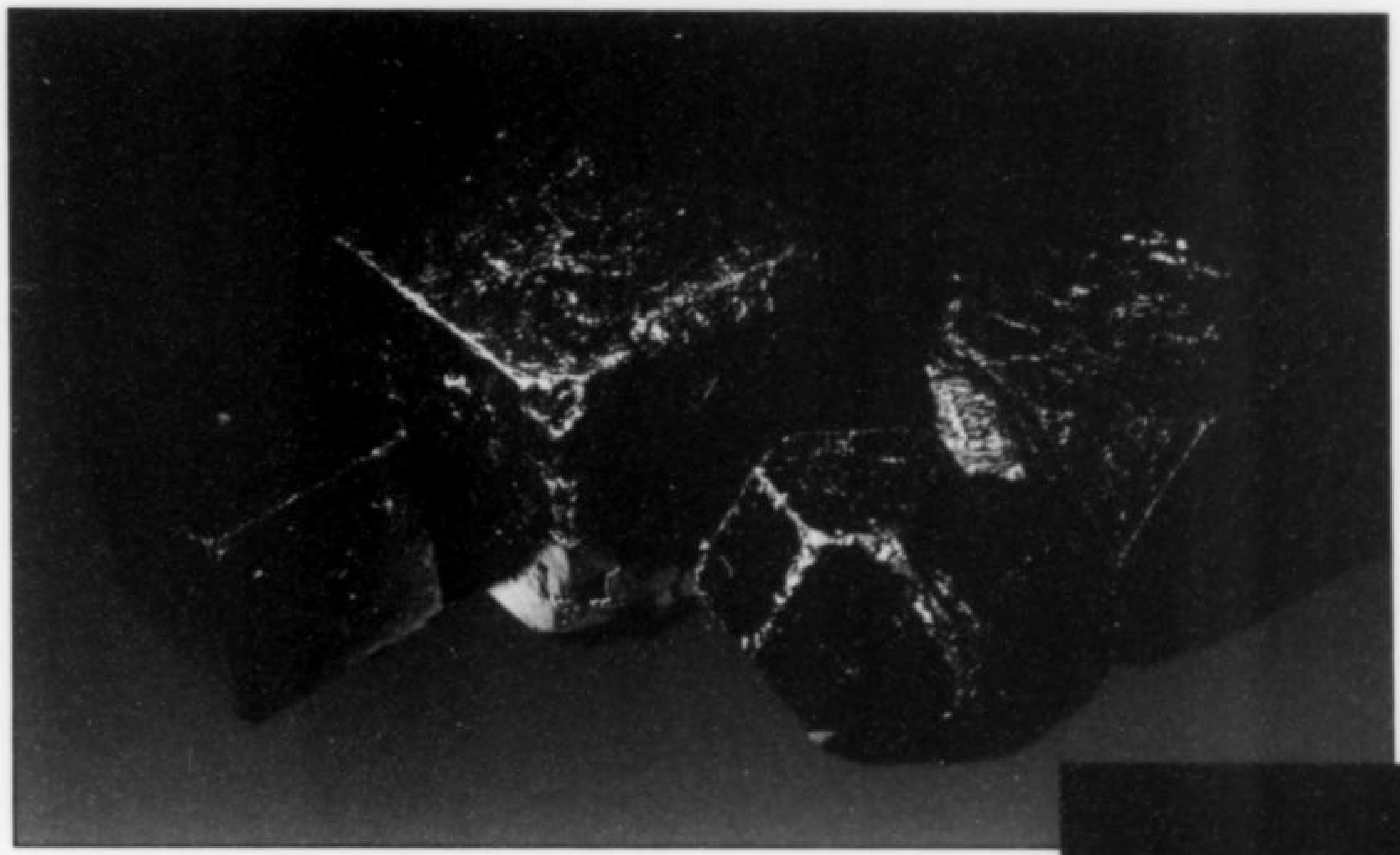

Figure 31. Boléite crystals, cubes and cuboctahedrons, from Boléo. Smithsonian collection; photo by Wendell E. Wilson, 1972.

Figure 32. Cumengite-on-boléite, about 1 cm, on matrix, from the Amelia mine, Boléo. Sorbonne collection; photo by Nelly Bariand.

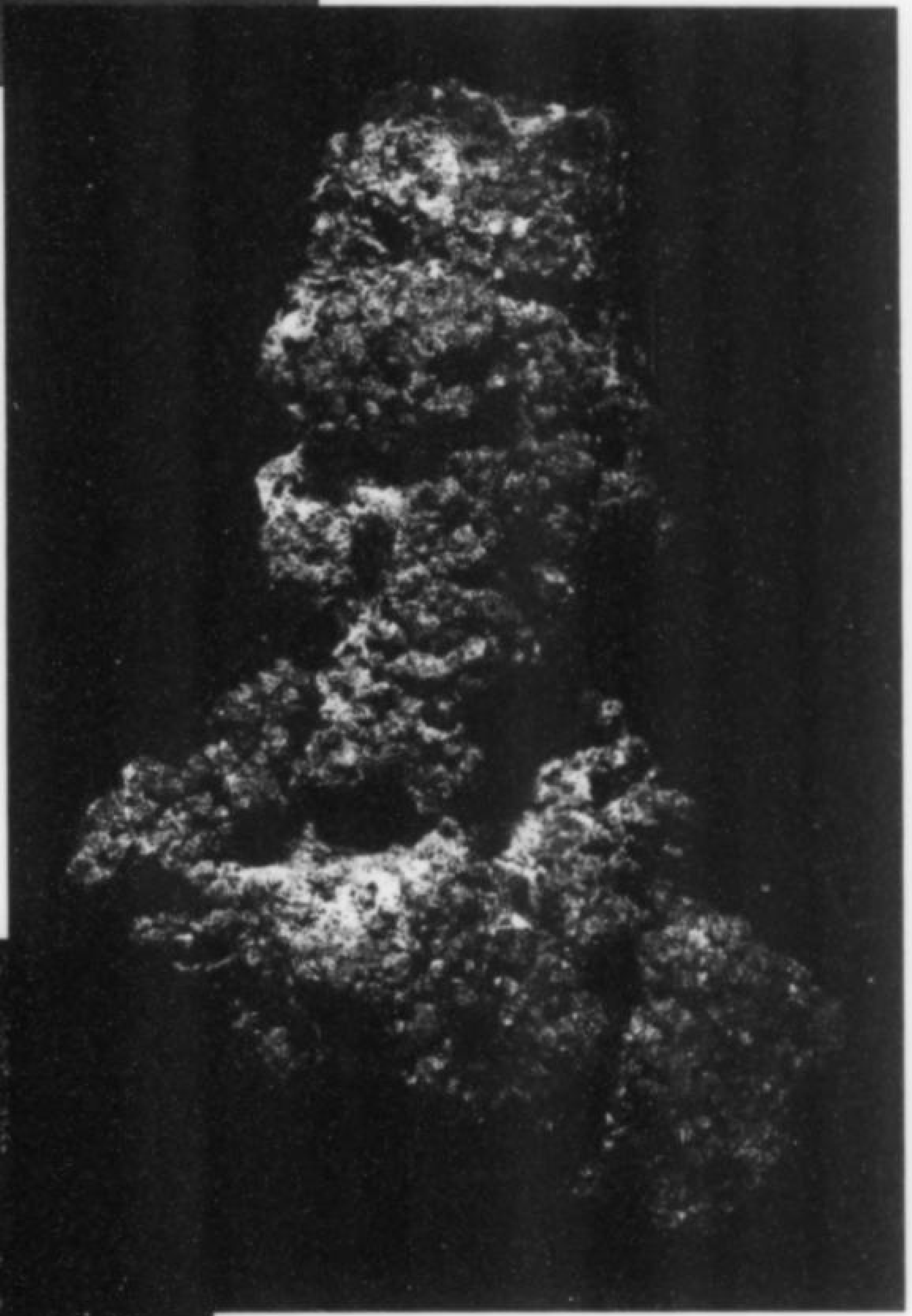

Figure 33. Octahedral cuprite crystals on native copper, from Boléo. Private collection; photo by Nelly Bariand.

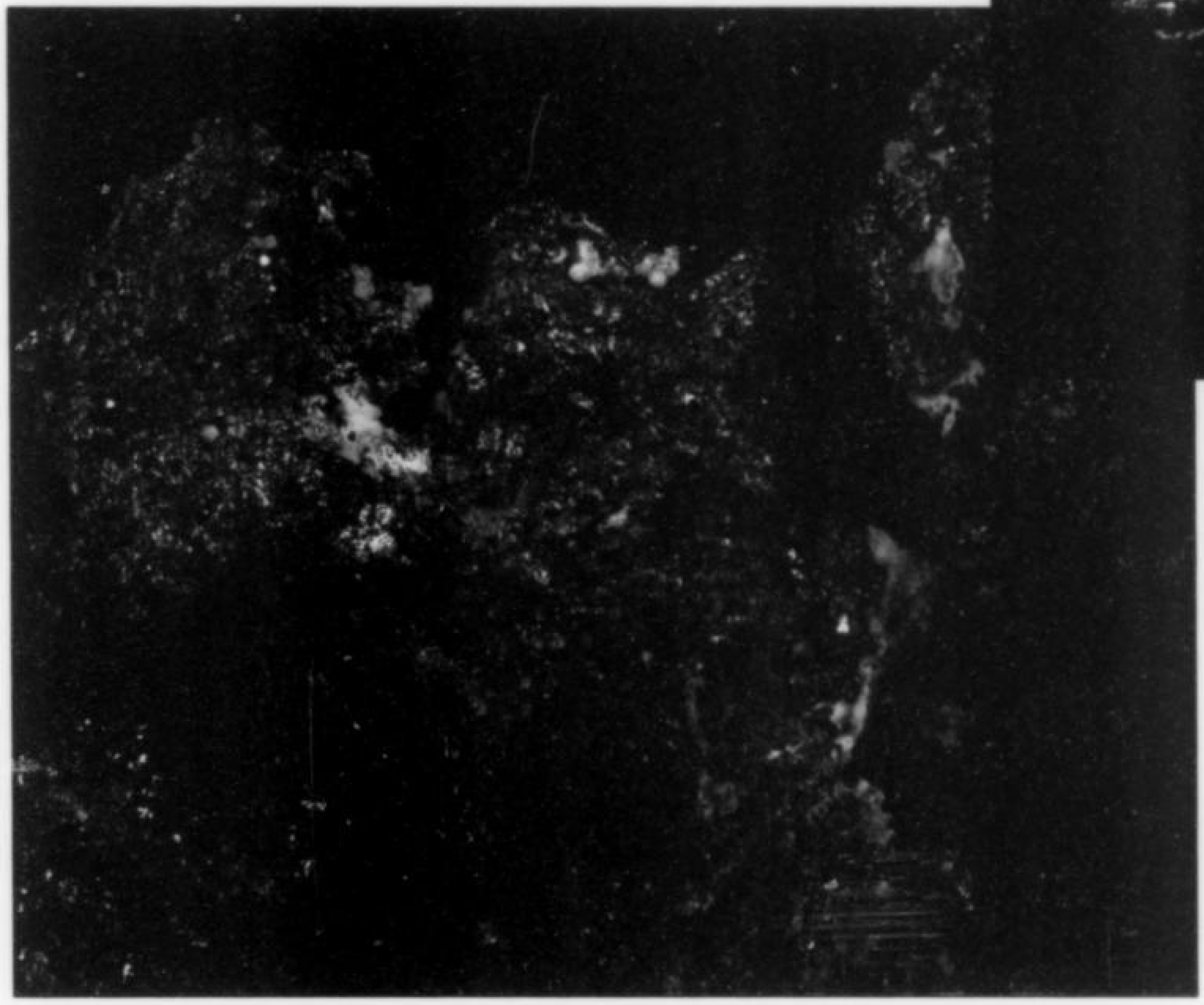

Figure 34. Cuprite and native copper, from Boléo. Private collection; photo by Nelly Bariand.

with irregular, deformed, rough faces {110}, {102} and {001}. Usually around 1 mm, the crystals may in exceptional cases reach 2 cm. They are opaque, their luster is waxy, and they are white in color, slightly bluish in places. They have a singular characteristic in that they are not only covered with gypsum, but are in addition penetrated by this substance, which appears in thin plates scattered sometimes unevenly and sometimes with a certain symmetry. The forms of the anglesite crystals are not, however, altered thereby. This curious association gave rise to the hypothesis of a new species—*bouglisite*, which has since been discredited (Genth, 1893; Lacroix, 1895). These crystals, which are particularly rare, are associated locally with cumengite and boleite (Cumenge, 1893). Some were found during the work done in 1974 (Swoboda, 1976), in association exclusively with boleite.

Azurite $Cu_3(CO_3)(OH)_2$

Azurite is one of the components of the "boléos"—the balls found in abundance before the exploitation of the deposit. This mineral sometimes appears in the form of spherical aggregates of crystals, as in the classic specimens from the Chessy mine (Rhone, France) or those obtained recently from China. The size of the Boléo specimens is rather modest—a few centimeters at most. There is sometimes alteration to malachite on the surface.

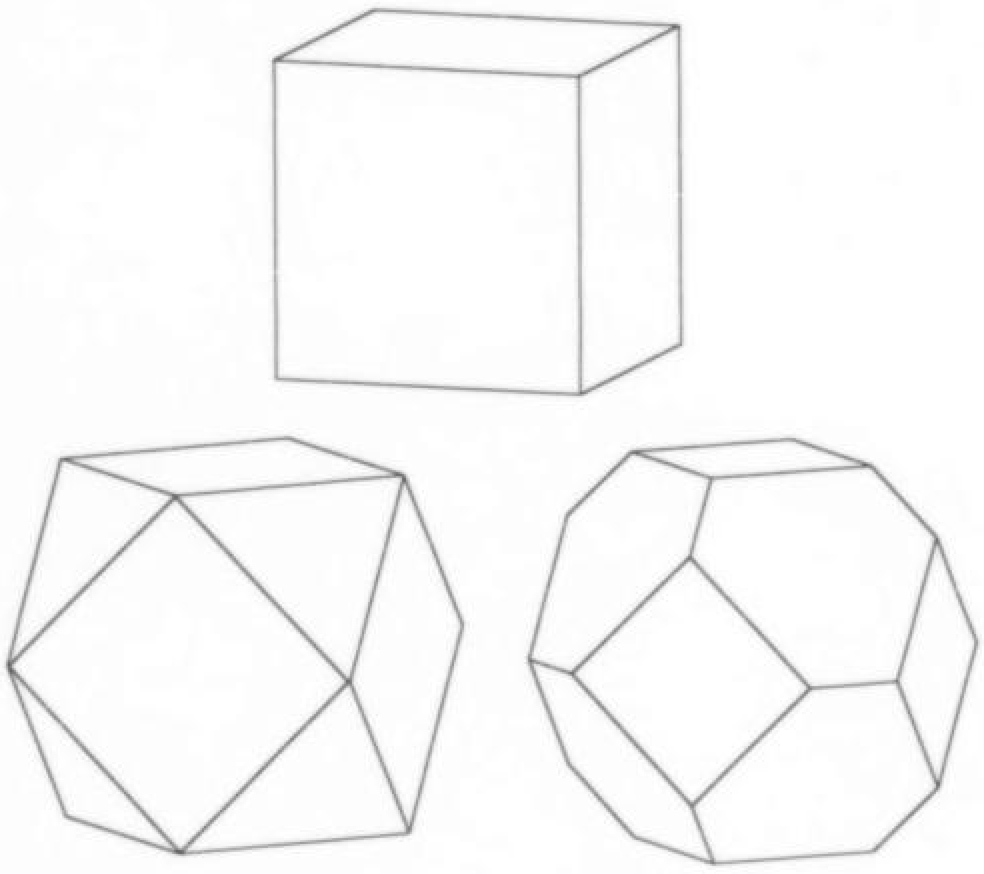

Figure 35. **Boléite crystals: cube and cuboctahedrons (drawing courtesy of R. Peter Richards).**

Boleite $Pb_{26}Ag_9Cu_{24}Cl_{62}(OH)_{48}$

The boleite in the Boléo deposit, like the cumengite and pseudoboleite, is always crystallized. These crystals are opaque to translucent (on the edges or under a microscope) and of a deep indigo-blue color. This color is almost unique in the mineral world, although it may sometimes be confused with that of certain azurites.

The most common form is the cube. As a general rule, the faces are brilliant but only moderately flat. One may also find cubic crystals modified by the faces of the octahedron, which are clean and brilliant. The modifying faces of the rarer dodecahedrons are also clean and brilliant, but often small in size. Finally, some "extremely rare" octahedral crystals merit mention (in fact, only one single octahedral example truncated by small faces {100} is known as of the present).

The cleavage on {100}, parallel to the cube face, is distinct and easy. However, the cleavage on {111}, parallel to the octahedron faces, is much less so.

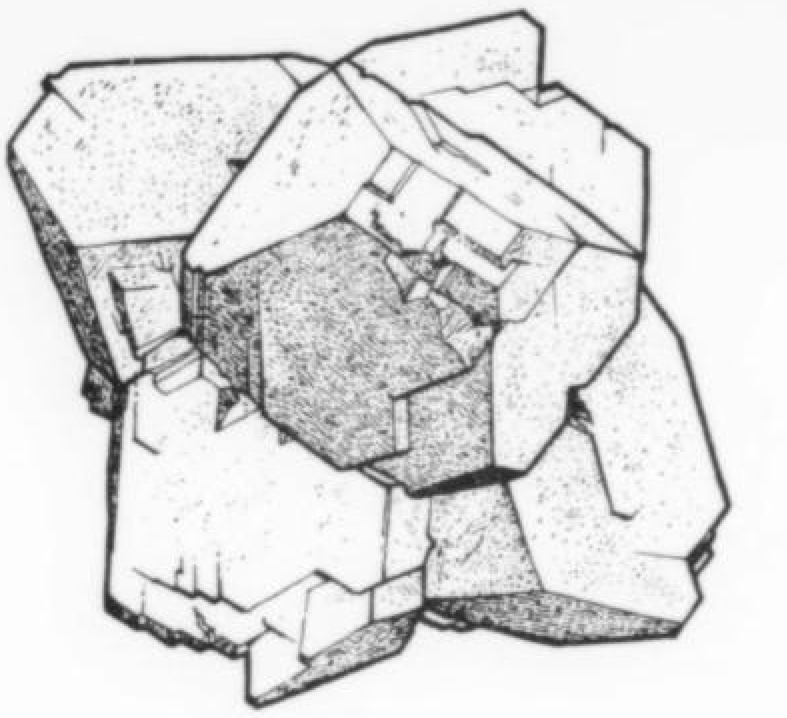

Figure 36. **The largest of the cumengite specimens: 3.5 cm. Sorbonne collection; sketch by Wendell E. Wilson.**

The argillaceous and fragile gangue does not adhere well to the boleite crystals, which explains the large number of isolated and little-damaged crystals, and the great rarity of crystals on gangue. In the majority of matrix specimens, crystals have been reattached, a fact widely known and generally accepted. The late mineral dealer Al McGuinness was in the habit of asking "Do you want boleites on matrix or with matrix?"

Cubic crystals of millimetric size (up to 5 mm) have been found in abundance, while those approaching a centimeter are very rare. Crystals of larger size (the record being about 2.5 cm) are highly exceptional; a few are on exhibit in New York (American Museum of Natural History), London (British Museum of Natural History), Paris (Advanced National School of Mining), and Tucson (Arizona Sonora Desert Museum and University of Arizona Mineral Museum).

Bouglisite

The description by Mallard and Cumenge of the anglesite mixed with gypsum in the Boléo deposit (Mallard, 1891) aroused the curiosity of Genth (1893), who obtained samples from Mr. Clarence S. Bement. He carried out chemical analyses that showed that the crystals contained two molecules of anglesite to one of gypsum. From this, Genth concluded that the anglesite in the Boléo deposit might be a pseudomorph after a mineral the theoretical composition of which would be $2PbSO_4 \cdot CaSO_4$. This kind of hypothesis was widely used in that era in which experimental and theoretical resources were still unrefined. Lacroix (1898), inspired by Cumenge, gave this calciferous anglesite the name *bouglisite*. Genth's hypothesis was not to endure. Bouglisite has now been discredited and is recognized as being anglesite.

Calcite $CaCO_3$

In addition to the argillaceous minerals and the oxides of manganese and iron, calcite is a mineral abundant in the gangue (Wilson, 1955). It appears in small veins and also as the product of the alteration of the tuffaceous masses in which the ore is encased.

Cerussite $PbCO_4$

Cerussite was mentioned but not described by Mallard and Cumenge (1891) and Lacroix (1898). It is thought to have been found accompanying minerals in the boleite group.

Chalcocite Cu_2S

Chalcocite makes up the greater part of the primary copper ore. It is found in the form of minuscule crystals and scattered grains. A microscopic study (Touwaide, 1930) revealed formless grains, fine needles, prismatic crystals, and larger pseudohexagonal crystals resulting from twinning of orthorhombic crystals. Larger masses, probably formed by the accretion of these particles, were also found. Some of them reached a kilogram in weight. Chalcocite replaces chalcopyrite and bornite locally.

Chalcopyrite $CuFeS_2$

Chalcopyrite, the second most abundant sulfide mineral at Boléo, is much rarer than chalcocite. It too occurs as grains, sometimes large enough to be discernible to the naked eye (Touwaide, 1930).

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot Nh_2O$

Chrysocolla is dominant in the oxidized zone of the deposit and is the major component in the Boléos. It is accompanied on certain specimens by azurite, malachite, and paratacamite. Its color ranges from green to blue, and it often impregnates the argillaceous gangue of montmorillonite.

Cryptomelane KMn_8O_{16}

According to Wilson (1955), cryptomelane is probably the principal manganese mineral at Boléo. It appears throughout the oxidized zone in massive form and in fine, incoherent grains.

Copper Cu

Native copper appears at Boléo as thick, more or less formless sheets. They may reach a substantial size (up to 20 cm), but they are often altered to cuprite or copper carbonates. Cumenge (1893) did not mention copper in the accounts of his collecting. Touwaide (1930) found copper in the sulfide zone of the Santa Rita mine in association with zeolites, as well as near the oxidized zone of the Montado mine, in flecks joined to grains of bornite. Wilson (1955) mentioned flat encrustations in the threads of gypsum in the oxidized zone, and plaques in the sulfide zone.

Cumengite $Pb_{21}Cu_{20}Cl_{42}(OH)_{40}$

Cumengite is opaque to translucent (on the edges), of a blue color similar to that of boleite, but a little paler and with a slight violet tinge. Its luster is a little brighter than that of boleite.

Cumenge (1893) reported the first discoveries of cumengites as follows.

> The *cumengite* found first of all in the same part of the deposit as the *boleite*, in the form of very rare octahedral crystals of a more purplish blue, proved much more abundant in a neighboring pocket, where it predominated and was dispersed in rather substantial quantity in a clay or whitish *jaboncillo* (Spanish for soapstone), splitting readily in water so that a simple sluicing makes isolation of the crystals possible. Some, however, reveal unusual and characteristic forms . . . they are implanted either on atacamite in mamillated crystalline masses or on individual crystals of anglesite, forming a crystalline covering of a beautiful azure-blue with more sizable and very brilliant twinned crystals.

This mineral occurs in two principal habits—the tetragonal dipyramid and the tetragonal pyramids implanted epitaxially on the faces of boleite cubes.

The dipyramidal crystals are often isolated and complete. They are made up of eight predominant faces {011} truncated by the four lateral faces {110}. More rarely, they are truncated by the two basal faces (001). The faces are generally brilliant, but sometimes imperfect, irregular, and striated. Cleavages are found on all the faces of the tetragonal dipyramids, and they are very distinct on the faces {110} and {011}. Very rare groups of crystals (different from those described subsequently) have also been found. The orientation of certain individual crystals in relation to the others suggests the existence of twinning.

The second habit in which cumengite is seen is certainly one of the leading curiosities in the mineral world, and it has made a major contribution to the celebrity of this deposit. There are magnificent groupings of six tetragonal pyramids {011}, each of them implanted epitaxially on one of the six faces of a cube of boleite. The result is a polyhedral form suggestive of a star. This assemblage cannot be considered similar to a penetration twin, but, as Mallard demonstrated (1893) at the time of its discovery, exemplifies a special form of growth that is now called heteroepitaxy. This term designates the growth of one mineralogical species on another, with a very precise orientation. Another remarkable example of heteroepitaxy is that of rutile on hematite. As the work of Friedel (1906) on thin sheets of star-shaped groupings showed, the cumengite pyramids are rarely found in direct contact with boleite. In general, cumengite grows on pseudoboleite with irregular contact.

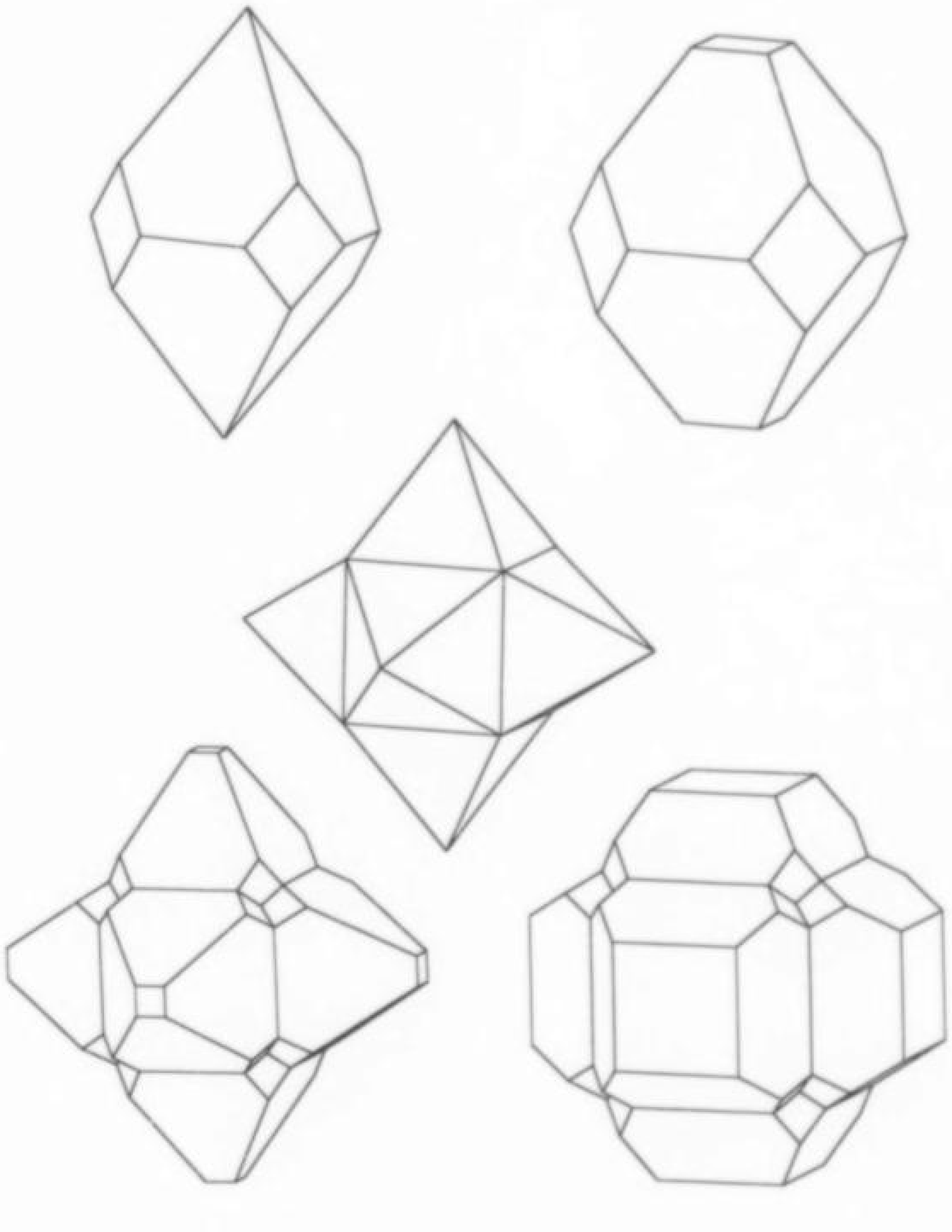

Figure 37. **Cumengite single crystals (top), and cumengite-on-boléite sixlings; crystal drawings by R. Peter Richards.**

The isolated tetragonal crystals are very rare and often 1 mm or so in size; the largest known specimens slightly exceed 1 cm. The stellate groupings are not quite so rare, and their attractive qualities certainly account for their having been more frequently collected. They often reach several millimeters in size. The largest known examples measure up to 3 cm and were collected in about 1920. Panczner (1987), quoting Mallard (1893), reported groupings of 6 cm to 8 cm on matrix, but all of our studies contradict these amazing sizes. None of Mallard's known writings makes mention

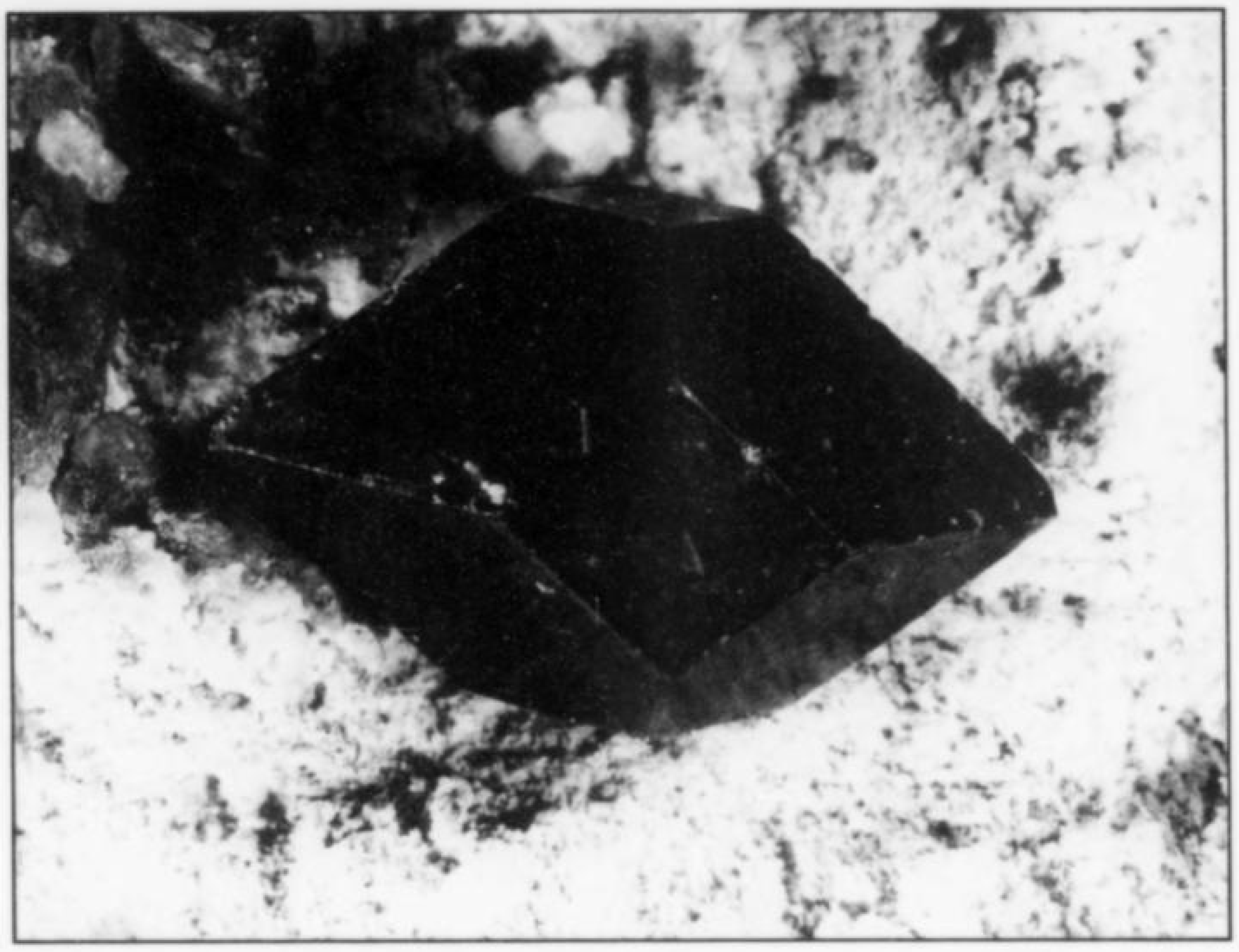

Figure 38. **Cumengite single crystal, 2 cm, placed on typical matrix, from the Amelia mine, Boléo. Sorbonne collection; photo by Nelly Bariand.**

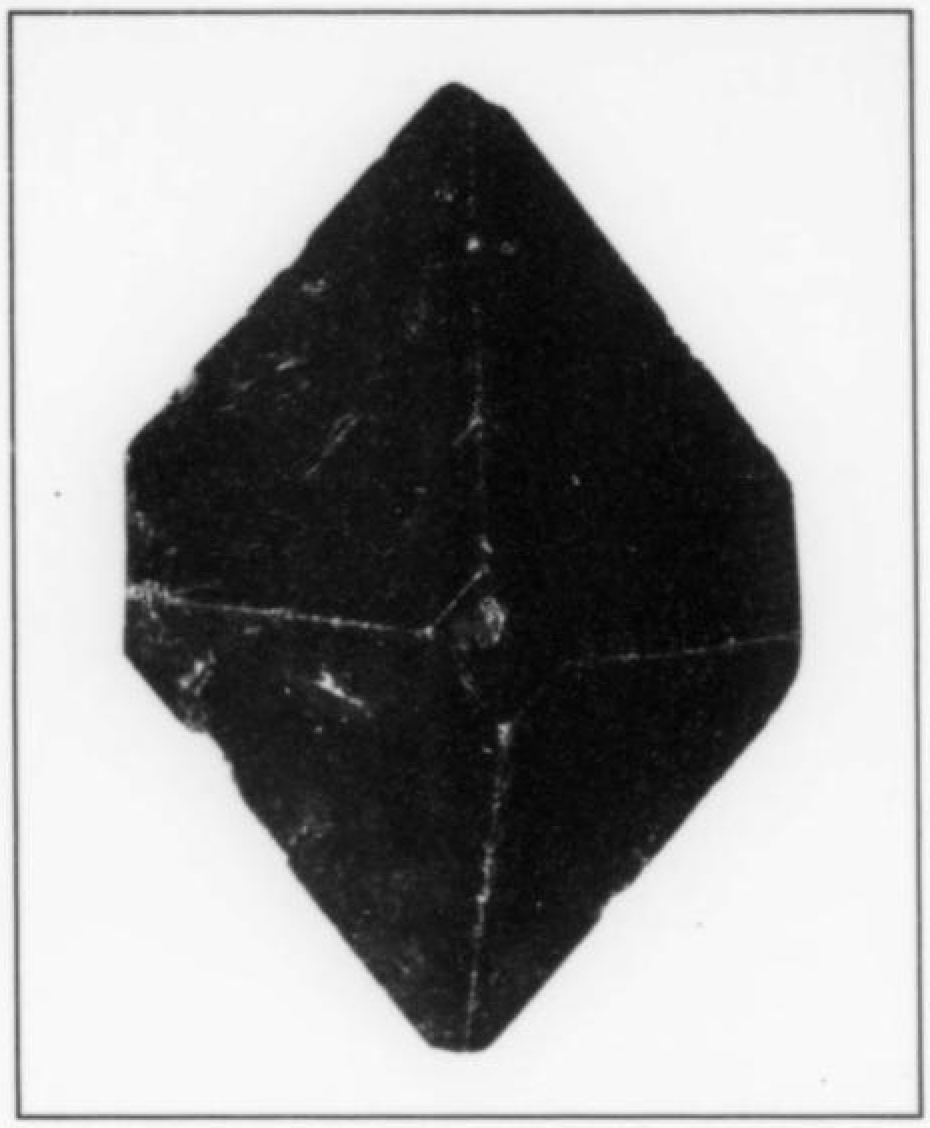

Figure 39. **Cumengite single crystal, 2 cm, from the Amelia mine, Boléo. Sorbonne collection; photo by Nelly Bariand.**

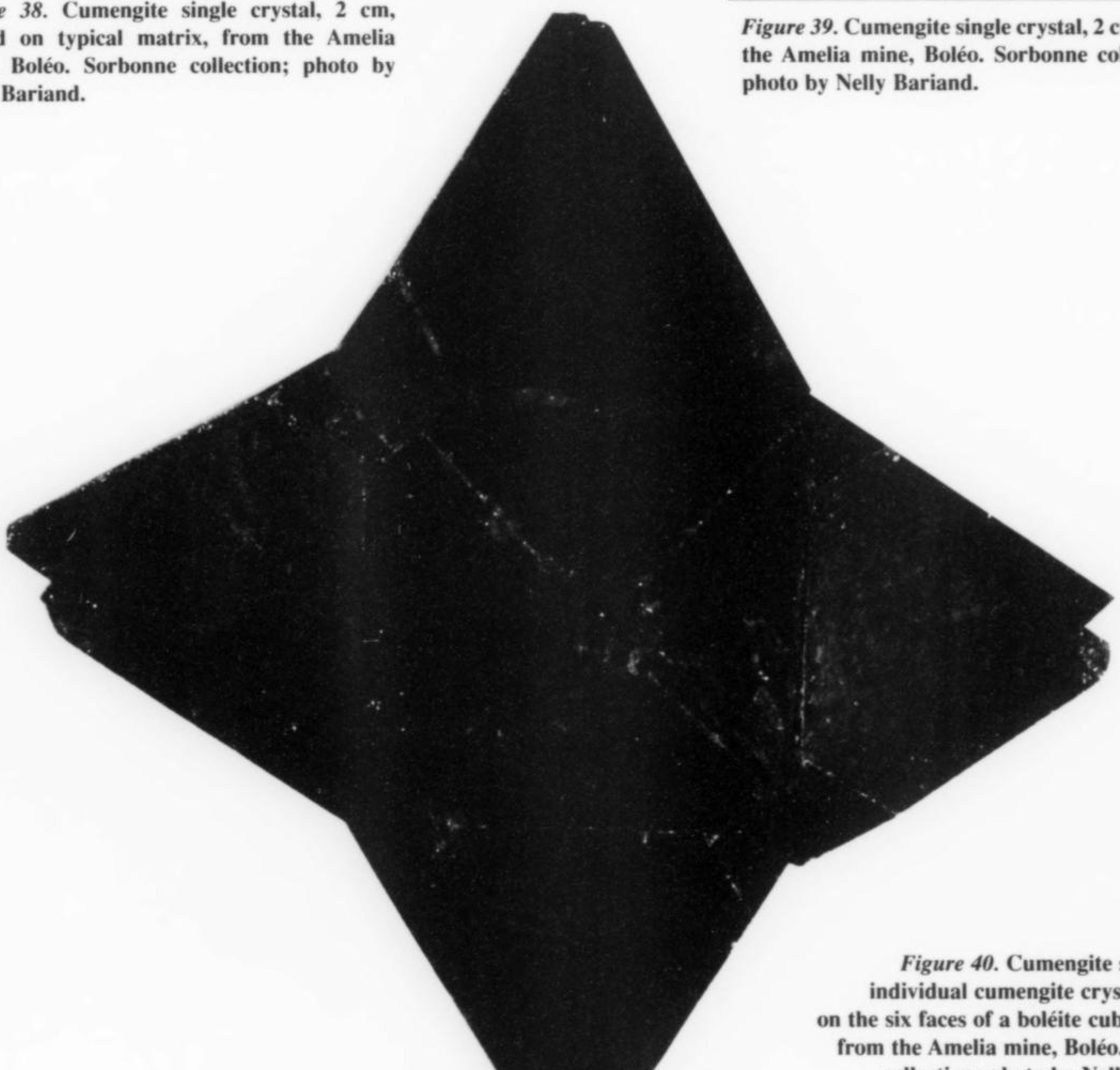

Figure 40. **Cumengite sixling (six individual cumengite crystals grown on the six faces of a boléite cube), 1.5 cm, from the Amelia mine, Boléo. Sorbonne collection; photo by Nelly Bariand.**

Figure 41. **Some of the largest known cumengite-on-boléite sixlings, measuring 3 to 3.5 cm. Now in the Sorbonne collection; photos by Nelly Bariand.**

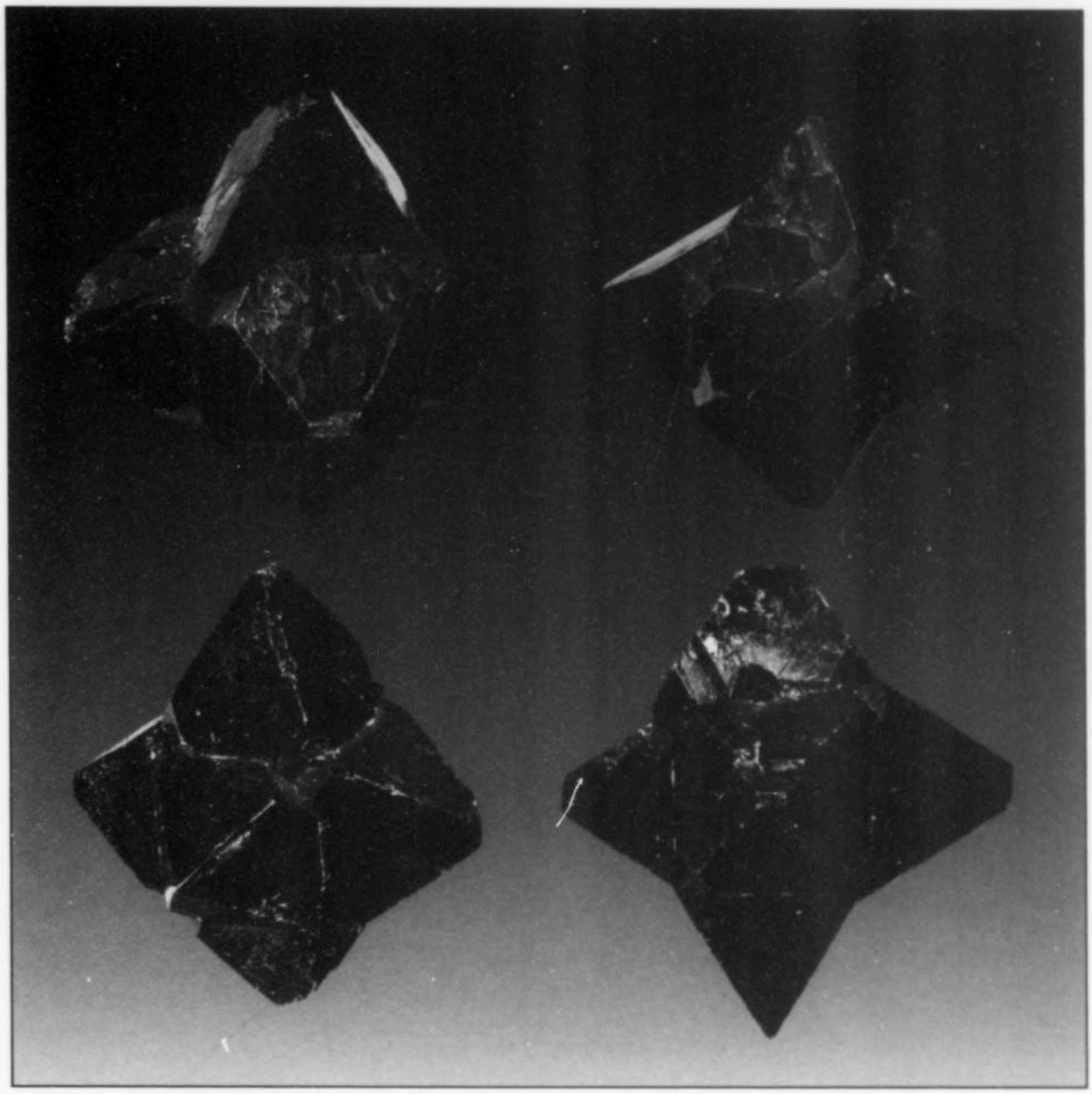

Figure 42. **Cumengite-on-boléite sixling, about 2.5 cm, from the Amelia mine, Boléo. Sorbonne collection; photo by Nelly Bariand.**

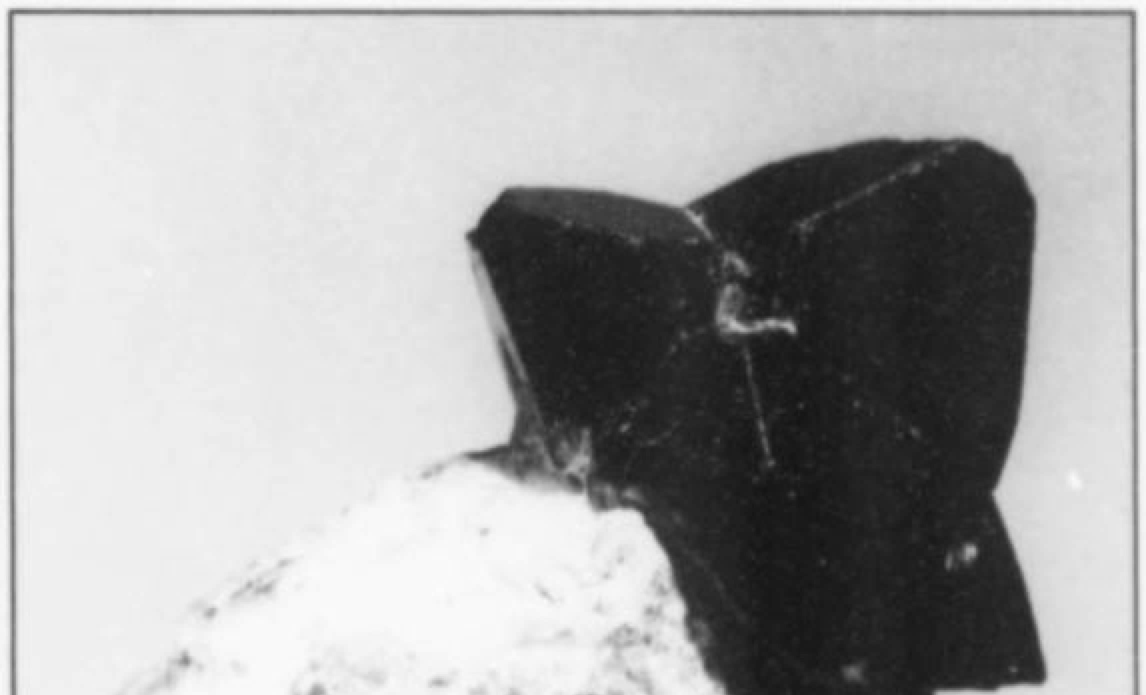

Figure 43. **Cumengite-on-boléite group on an anglesite (once called *bouglisite*) crystal, about 2 cm. Sorbonne collection; photo by Nelly Bariand.**

of them, and it is to be feared that we are dealing here with an error. Whatever the case, the ten largest examples known and accessible to the public are on exhibit in the collection at the Sorbonne (Pierre and Marie Curie University, Paris).

Cuprite Cu_2O

Cuprite crystals have been found on sheets and plates of native copper. They are octahedral or cubic in form, with brilliant, smooth faces. They range from transparent to translucent and are of a dark red color. Their size sometimes approaches 1 cm. Cuprite also appears in powdery form, associated with oxidized minerals (carbonates, chlorides, oxides). In the early period of exploitation, Lacroix (1898) reported two kinds of crystals in the argillaceous gangue. He described, first, perfect little cubes of no more than a millimeter in size that could be isolated by washing. He described the second habit more precisely:

> The octahedral crystals are of a most curious nature. They reach 1 cm in size and reveal the various special characteristics of the well-known Chessy crystals. They differ from them, however, in their freshness, the absence of the covering of malachite that is so characteristic of the crystals in this last deposit, and the frequency of the faces of the cube. The rhombododecahedron also occurs in the form of little facets. As is the case in Chessy, there are twins with parallel axes, symmetrical in relation to one face of the cube, with the twins being produced in all cases by regular penetration. Each octahedral ridge is then replaced by the groove that is so common in diamond octahedrons displaying this same twin. What gives the twinned crystals in the Boléo deposit their special interest is the frequent occurrence of cubic faces with two grooves parallel to their diagonals, indicating the junction planes of the individual elements making up the complex. These grooves are particularly clear on a crystal showing *p*{100}, *al*{111}, *bl*{110}, in which the faces of the cube dominate.
>
> Again like those in Chessy, the cuprite crystals in the Boléo deposit frequently present hollow faces. Some are made up of an open framework that is completely hollowed out and reduced to octahedral ridges. In addition, one also finds extreme habits in which the octahedron is defined by the intersection at 90° of three thin plates, each of them parallel to one face of the cube. When one holds these thin plates up to sparkle in the light, they themselves can be seen to be made up of piles of even thinner plates. The edges of these plates are sometimes jagged and irregular. In other cases, the edges reveal little bevels corresponding to the faces of the octahedron. There are passages between all the octahedrons with hollow faces, with or without *p* faces; on these elementary frameworks one can sometimes recognize the twin described above.

Galena PbS

The galena was locally concentrated in certain parts of the deposit (Carmen mine in the Providencia group, Wilson, 1955). It is probably the primary source of the secondary lead minerals in the oxidized zone (Cumenge, 1893).

Gypsum $CaSO_4 \cdot 2H_2O$

Gypsum, although not found in well-formed crystals, is widely scattered throughout the oxidized zone, mixed with the argillaceous gangue of the complex chlorides at the Amelia mine (Cumenge, 1893). It accompanies boleite and the related species, and it covers and is mixed with the variety of anglesite once called *bouglisite*. It is also a mineral in the gangue, where it appears in little veins and as distinct crystals (Lacroix, 1898). It also appears in fibrous masses covered secondarily by paratacamite (Wilson, 1955).

Magnesite $MgCO_3$

Magnesite was mentioned by Krusch (1899) as a secondary mineral in the gangue. Krush (1899) showed that it contains strontium, calcium and copper.

Malachite $Cu_2(CO_3)(OH)_2$

Malachite is an alternation product often found as coatings on azurite and native copper.

Montmorillonite $(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot Nh_2O$

The greater part of the gangue at Boléo is made up of argillaceous minerals formed by the weathering of tuffaceous rocks. Wilson's work (Wilson, 1955) did not offer any definitive conclusion about the mineralogical nature of the dominant argillaceous mineral believed to belong to the montmorillonite-saponite or montmorillonite-beidellite series. For convenience, the term montmorillonite is widely used to designate the dominant argillaceous mineral in the gangue.

Paratacamite $Cu_2Cl(OH)_3$

For a long time, the green copper chloride found in the Boléo deposit was identified as atacamite. The findings of paratacamite varied as a function of the status accorded this mineral, which was viewed for a time as a twinned form of atacamite (Dana, 1976). At the beginning of our century, Ungemach (1911) drafted a synthesis pertaining to atacamite based exclusively on goniometric measurements of the crystalline faces. Following analysis of the complex twinned crystals (maximum size of 3 mm) he asserted that the "atacamite" in the Boléo deposit was actually paratacamite. Later, Wilson (1955) mentioned only atacamite (at a time when paratacamite was not an accredited species).

The conditions for the formation of atacamite versus paratacamite depend only on the partial pressure of chlorine according to the sequence: paratacamite → atacamite → matlockite (Bariand *et al.*, 1978). Modern analyses of recently collected specimens suggest that the majority of the green copper chlorides from the Boléo deposit are paratacamite, not atacamite.

The paratacamite in the Amelia mine often accompanies boleite, pseudoboleite and cumengite (Swoboda, 1976). Wilson collected this mineral in the form of cryptocrystalline balls of a pale green color and 1-cm size; he described them as little rosettes measuring 2 to 3 mm and covering gypsum. The rosettes were black on the outside but green color on the inside. Lacroix (1898) reported the existence of assemblages of gypsum crystals colored green by this mineral.

Phosgenite $Pb_2(CO_3)Cl_2$

Phosgenite appears as overlapping short prismatic crystals that are poorly formed. The sizes observed do not exceed a few millimeters. Phosgenite has been found accompanying boleite, pseudoboleite and cumengite in zones rich in lead and poor in copper and silver. Cumenge (1893) mentioned phosgenite, but Swoboda (1976) found none when he reviewed the works on the Amelia mine.

Percylite? $PbCuCl_2(OH)_2$

This "phantom" mineral is certainly one of the most curious intellectual products of the mineralogical community (see the history of mineralogy). Its existence in nature is at the present time doubtful, since the works of Winchell and Rouse concluded that all of the samples of percylite they studied were in fact either boleite or pseudoboleite or a mixture of the two. This mineral has never

***Table* 2. Minerals reported from the Boleo district (excluding rock-forming minerals of the tuffaceous host rocks).**

Species	*Composition*	*Occurrence*	*Reference*
Allophane	Silicate	Gangue	Wilson (1955)
Anglesite	$PbSO_4$	Secondary ore	Cumenge (1893)
Anhydrite	$CaSO_4$	Stratified masses	Wilson (1955)
Apatite	$Ca_5(PO_4)_3(F,OH)$	Gangue	Touwaide (1930)
Aragonite	$CaCO_3$	?	Salinas (1923)
Azurite	$Cu_3(CO_3)(OH)_2$	Secondary ore	Wilson (1955)
Barite	$BaSO_4$	Gangue	Touwaide (1930)
Boleite	$Pb_{26}Ag_9Cu_{24}Cl_{62}(OH)_{48}$	Secondary ore	Mallard and Cumenge (1891)
Bornite	Cu_5FeS_4	Sulfide ore	Touwaide (1930)
Calcite	$CaCO_3$	Gangue	Wilson (1955)
Celadonite	$K(Mg,Fe)(Fe,Al)Si_4O_{10}(OH)_2$	Gangue	Wilson (1955)
Celestine	$SrCO_3$	Gangue, rare	Touwaide (1930)
Chalcocite	Cu_2S	Sulfide ore	Touwaide (1930)
Chalcopyrite	$CuFeS_2$	Sulfide ore	Touwaide (1930)
Chlorite Group	Silicate	Gangue	Wilson (1955)
Chrysocolla	$(Cu,Al)_2H_2Si_2O_5(OH)_4 \cdot nH_2O$	Secondary ore	Wilson (1955)
Covellite	CuS	Sulfide ore	Touwaide (1930)
Crednerite	$CuMnO_2$	Secondary ore, rare	Fuchs (1886), Saladin (1892)
Cryptomelane	KMn_8O_{16}	Oxide zone, abundant	Wilson (1955)
Copper	Cu	Sulfide ore, oxide zone	Wilson (1955)
Cumengite	$Pb_{21}Cu_{20}Cl_{42}(OH)_{40}$	Secondary ore	Mallard (1893)
Cuprite	Cu_2O	Secondary ore	Lacroix (1898)
Dolomite	$CaMg(CO_3)_2$	Gangue	Wilson (1955)
Epidote	$Ca_2(Fe,Al)_3(SiO_4)_3(OH)$	Gangue	Wilson (1955)
Galena	PbS	Sulfide ore	Cumenge (1893)
Garnet Group	Silicates	Gangue	Touwaide (1930)
Gypsum	$CaSO_4 \cdot 2H_2O$	Gangue	Lacroix (1898)
Halite	$NaCl$	In Tuffs	Wilson (1955)
Halloysite	$Al_2Si_2O_5(OH)_4$	Gangue	Wilson (1955)
Hematite	Fe_2O_3	Oxide zone	Wilson (1955)
Kaolinite	$Al_2Si_2O_5(OH)_4$	Gangue	Touwaide (1930)
Magnesite	$MgCO_3$	Gangue	Krusch (1899)
Malachite	$Cu_2(CO_3)(OH)_2$	Secondary ore	Wilson (1955)
Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$	Gangue	Wilson (1955)
Paratacamite	$Cu_2Cl(OH)_3$	Secondary ore	Ungemach (1911)
Phosgenite	$Pb_2(CO_3)Cl_2$	Secondary ore	Cumenge (1893)
Pseudoboleite	$Pb_{31}Cu_{24}Cl_{62}(OH)_{48}$	Secondary ore	Friedel (1906)
Pyrite	FeS_2	Sulfide ore	Touwaide (1930)
Pyrolusite	MnO_2	Oxide zone	Wilson (1955)
Pyromophite	$Pb_5(PO_4)_3Cl$	Secondary ore	Lacroix (1898)
Quartz	SiO_2	Gangue	Wilson (1955)
Silver	Ag	?	Salinas (1923)
Smithsonite	$ZnCO_3$	Oxide zone	Warren (1898)
Sphaerocobaltite	$CoCO_3$	Oxide zone	Lacroix (1898)
Sulfur	S	Oxide zone	Krusch (1899)
Tenorite	CuO	Oxide zone	Krusch (1899)
Zeolite Group	Silicates	Gangue	Touwaide (1930)

been found in the Boléo deposit. It is only mentioned here because following his crystallographic analysis, Mallard (1893) concluded that there were twins present in the boleite, and he suspected that the crystalline unity of the boleite revealed by the epitaxial growths on what is now regarded as pseudoboleite could be percylite, although this latter species was only poorly described at that time. Lacroix (1895), for his part, gave this name to certain octahedral crystals (of boleite) which because of their feeble birefringence and their density seemed to him distinct from boleite.

Pseudoboleite $Pb_{31}Cu_{24}Cl_{62}(OH)_{48}$

Pseudoboleite is always associated with boleite. Each individual pseudoboleite (in the frequent form of a flattened truncated tetragonal pyramid) is epitaxially grown on the face of a cube of boleite. Unlike cumengite, pseudoboleite has never been found in isolated crystals. The pyramidal groupings of cumengite often contain pseudoboleite (Friedel, 1906). Its color, brilliance and transparency are similar to those of boleite. The crystals of pseudoboleite often resemble boleite at first glance, but along the ridges of the cube, they invariably reveal reflex angles bounded by faces that are almost parallel to the faces {210} of the cube, and sometimes, when these grooves are very deep, by faces parallel to the cube as well. Pseudoboleite is tetragonal. It has a perfect dominant basal cleavage, which is thus parallel to the cleavage

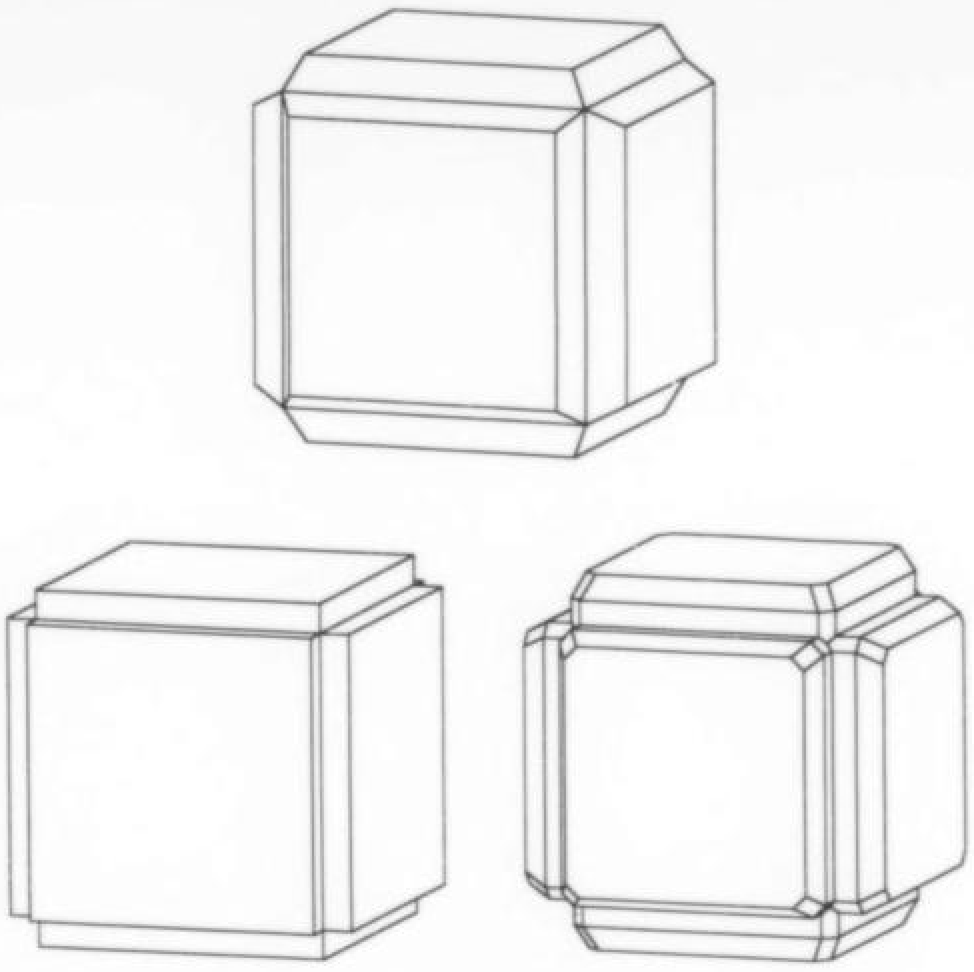

Figure 44. **Pseudoboléite crystals. Drawings by R. Peter Richards.**

{100} of boleite, and it has octahedral cleavages parallel to the tetragonal faces that invariably appear on each crystal (faces {101} almost parallel to the faces {210} of the cube). Because of the absence of isolated crystals, the studies of the chemical and crystallographic characteristics of pseudoboleite were difficult and have proven contradictory (see the history of the minerals in the boleite group).

The groups of pseudoboleite crystals generally have dimensions (including the nucleus of boleite) of several millimeters, sometimes reaching 5 mm. Few specimens exceeding 1 cm are to be found today in the collections open to the public. The largest specimen on exhibit, collected by Cumenge, is at the National Museum of Natural History in Paris. It is a cubic crystal with grooves, measuring about 1.5 cm on an edge. The thickness of the pseudoboleite crystals surmounting the boleite cube is about 2 mm. The faces are irregular.

Figure 45. **Pseudoboléite on boléite, 1 cm, from the Amelia mine, Boléo; collected by Ed Swoboda in 1973. Pala Properties International specimen; photo by Harold and Erica Van Pelt.**

Pyromorphite $Pb_5(PO_4)_3Cl$

Only Lacroix has mentioned the presence of pyromorphite in the Boléo deposit. In an 1898 memorandum, he described two specimens. The first was made up of a clay speckled with atacamite on which the pyromorphite formed millimetric bunches of acicular hexagonal prisms. The second was made up of a chrysocolla gangue on which a large number of gypsum crystals (of 1 to 2 mm) grouped along parallel axes were implanted. The intense orange color of the gypsum was considered to be due to numerous included pyromorphite microcrystals.

Quartz SiO_2

Opal partially crystallized in quartz is mentioned as a secondary mineral in the gangue. Chalcedony is one of the most abundant minerals in the gangue, after the argillaceous minerals and the oxides of manganese and iron. Like calcite, it appears in little veins and also as an alteration of the enveloping tuffaceous material (Wilson, 1955).

Remingtonite

This mineral was given hasty mention but was not described by Ungemach (1911) in his work on atacamite. The species, considered to be a hydrated carbonate of cobalt, has now been discredited. It is certain that the material is sphaerocobaltite (Wilson, 1955).

Smithsonite $ZnCO_3$

Warren (1898) reported the presence of particles of a delicate pink included in the gypsum and associated with "atacamite" (paratacamite) in the oxidized zone. This mineral was given the name *cobaltsmithsonite* by Bilibin (1927) and *warrenite* by Boldeyrev (1928). These last two names were not accepted; the mineral appears to be a cobaltoan smithsonite.

Sphaerocobaltite $CoCO_3$

Lacroix (1898) mentioned this mineral among the oxidized minerals. According to him, it was this mineral which gave certain groups of gypsum crystals their "peach-petal pink" color. A sample of this type, rather unspectacular, is on exhibit at the National Museum of Natural History in Paris.

Venerite

This substance, which was mentioned by Fuchs (1886) and described as a cupriferous chlorite in the oxidation zone, was subsequently deemed to be a heterogeneous substance (Dana's *System of Mineralogy*, 6th edition) and was discredited.

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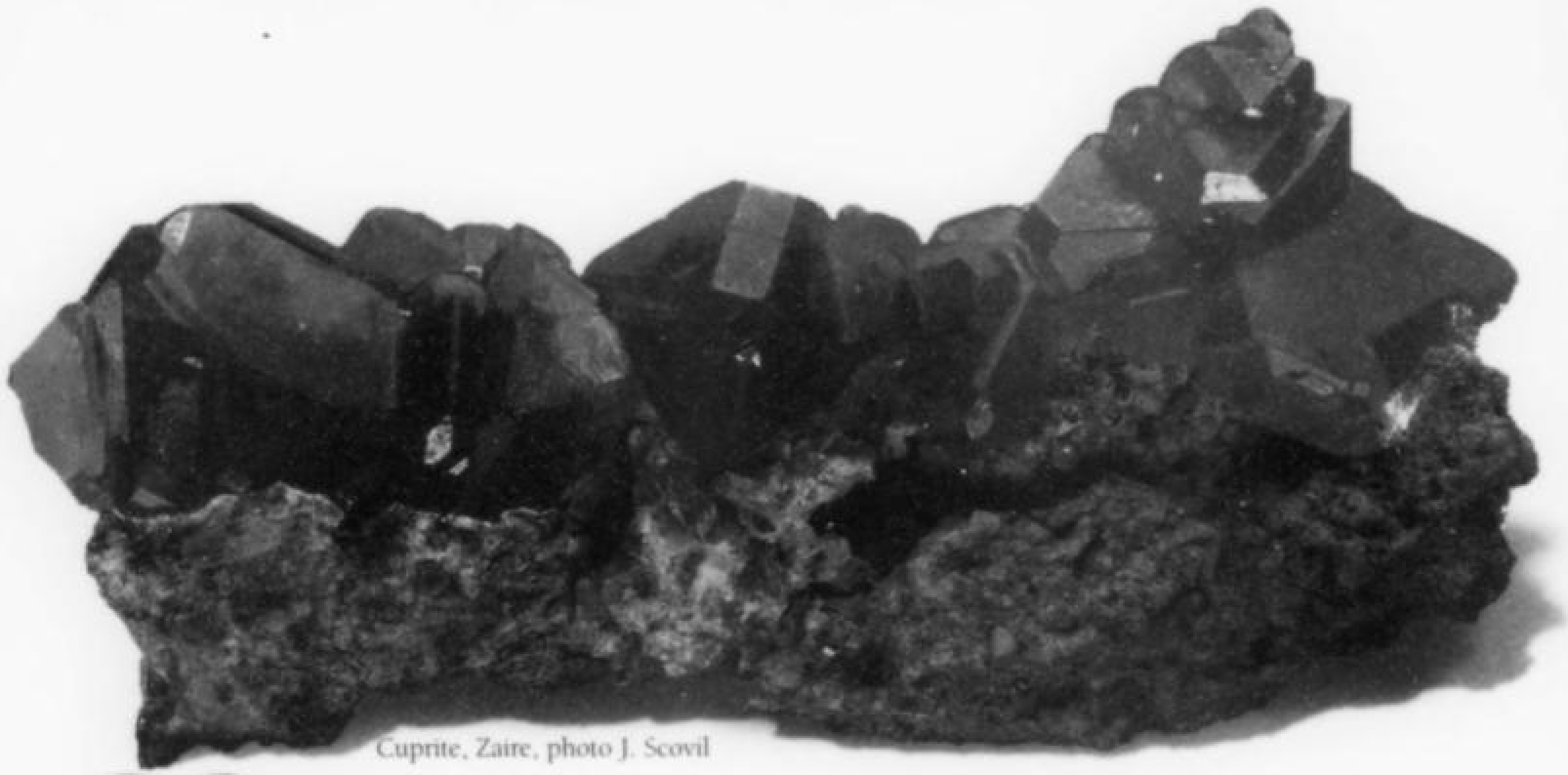

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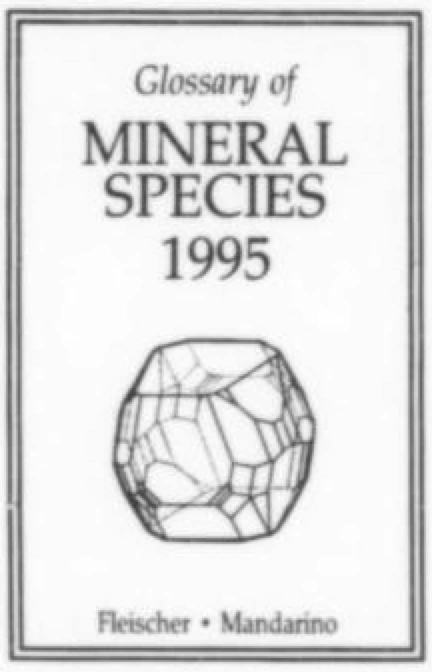

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Boléo—A Classic Locality Reworked

Edward Swoboda
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EDITOR'S NOTE

In 1959, 1969, and again in 1973, mineral collector and dealer Ed Swoboda visited the Boléo district. His extensive work there at the Amelia mine resulted in the discovery of the greatest batch of Boléo specimens to come out since the days of Cumenge. Here is his story, reprinted by permission from the January 1976 issue of Lapidary Journal.

INTRODUCTION

BOLEITE! PSEUDOBOLÉITE! CUMENGITE!—exciting minerals in beautiful, sharp, azure blue crystal forms of unbelievable size and structure—what collector or lover of natural beauty wouldn't lust for them!

A few major museums throughout the world and a very few private mineral collections sparingly display the super crystals found only within the Boléo copper district of Santa Rosalia in Baja California Sur, Mexico. All of these fine specimens were removed from the Amelia mine which is situated about six miles inland from the shore of the Sea of Cortez up the Arroyo del Boléo Canyon and in the general area of Curuglú Canyon and the Cumenge ventilating shaft. The French mining company, Compagnie du Boléo, from 1886 until abandoning the Amelia in 1919, removed copper ore from a network of interconnecting tunnels and stopes for a total length of 30 miles of underground workings just in this area, and near the Cumenge shaft, at distances from 260 feet to 340 feet below the surface.

From the time of the discovery of copper in the district in 1868 up to the French company's involvement, only the richest sections of the ore beds were worked, producing hand selected high-grade ore. The ore concentrate was sold to German buyers who loaded the sacked up cargo on sailing ships at the small port of Santa Maria, a place long ago abandoned and forgotten, up the coast about eight miles from Santa Rosalia. Miners using a *tenate*, a rigid, tough rawhide bag supported by a wide headband, lifted their 60- to 85-pound loads of copper ore step by step up a pathway of footholds cut into the steep footwall of a near-vertical 80 degree incline shaft from depths to 250 feet below the surface. The high-grade ore was then sacked up, loaded on burros and transported down the canyon about three miles to the shore and then up along the coast to the small loading dock at Santa Maria.

Old Santa Rosalia was first located on a beach terrace facing the ocean five miles north of its present location and scarcely two miles down the coast from Santa Maria port. After the Compagnie du Boléo was formed in 1885 to mine copper in the district, an

Figure 1. **Approaching Santa Rosalia on the shore of the Gulf of California.**

outcome of the report presented in Paris by Messers. M. E. Cumenge and G. de la Bouglise, who had visited Boléo in 1884 to investigate the ore reserves, they relocated Santa Rosalia at the mouth of the Arroyo de la Providencia, convenient to the newly constructed port, the mines and the new smelter. From this point, a network of tracks was laid out to form four main lines converging at the smelter that serviced five or six of the largest mining camps ever established by the company back in the canyons close to the active mines. The powerful little Baldwin locomotives hauled up supplies for the company stores plus timber and other materials from the port and brought back on the downhill run, up to 15 or more loaded wagons of ore to the mill for treatment. As production increased, thousands of miners and their families crowded into town and the outlying camps, many being recruited from foreign lands. Hundreds of pigtailed, long mustached Chinese miners dressed in loosely fitting blue slacks and canvas shoes worked and lived mostly apart from the others, together in large wooden-framed boarding houses in several of the camps, preparing and preferring special meals to their taste. Two hundred Japanese arrived by ship to work in the Providencia mine but quit after two days work and left, probably on the same ship they arrived on. One hundred Italian miners lasted about a month before they left.

Today, only a few fragments of wall can be found marking the rock foundations of the houses that made up the old camps. The wooden parts were reclaimed by the company or pirated long ago and the summer rainstorms and the sand and dust have destroyed or covered the remains. Since the mines started working, three or four violent summer cloudbursts, called *chubascos*, are recorded that inundated the canyons with flood waters, pouring down the incline tunnels, drowning people and washing out whole rows of houses. The most durable remnants of these once bustling mining camps are the abandoned cemeteries where tilted and fallen headstones of naturally formed rock slabs, some scarred with crude handchipped crosses, mark the untended mounds of rounded boulders.

FIRST VISIT—1959

The lure to visit the source of these exciting crystals led me to first visit the locality in 1959 when the French mining company still operated the mill. Highway No. 1, stretching from Tijuana south through Santa Rosalia to Cabo San Lucus at the southernmost tip of the Baja peninsula, for most of its length, was a joltingly tough trip at that time, along an unpaved road used mainly by trucks distributing food and supplies in both directions. An unpaved airstrip was available at Santa Rosalia for private and small commercial planes.

Comparing 600 miles of slow driving over jagged rocky grades, through dustchoked flats and dry lake beds, and miles of bumpy, sand- and rock-filled washes, I chose without hesitation to make the trip by plane. There was a direct flight from Tijuana by a DC4, and in a few short hours a giant wind-swept column of white smoke marked in the clear atmosphere, the copper smelter at Santa Rosalia. Circling the town in our approach to the airstrip, the plane descended alarmingly close onto a rough network of steep rock-filled gorges that dissolved, just at the last moment, into an isolated tight little mesa for a breathtaking landing. It was just another routine landing for the Mexican pilot.

A taxi delivered me from the airstrip on the mesa, down along the shoreline, passing through the lower end of town where a massive system of glassy, pockmarked walls assembled from giant rectangular blocks of slag were laid in the late 1800's by the company to create the port of Santa Rosalia. Adjacent to the northern edge of the low-lying town, we climbed a narrow road entering upon a sloping mesa occupied by a variety of French-built frame buildings with corrugated metal roofs and broad shaded verandas positioned to face both sides of an unpaved, tree-lined avenue. The view seaward extended to distant islands and covered the entire port, with the mill site and its smoking stacks; while inland could be seen steeply eroded, barren canyon walls, forming a natural barrier to limit the expansion of the mine town to a corridor of growth up the canyon from the port. We stopped in front of the mine office and I entered, soon to be courteously received by the French mine manager.

After explaining to him the purpose of my visit to Santa Rosalia, I requested permission to visit the old Amelia mine where the famous crystals were discovered and described from. He was sympathetic to my desires but explained that the Amelia, being one of the oldest mines in the area, was for the most part completely inaccessible underground. Extensive cavings through the years had sealed off all of the entries at or near the surface. When I added that I would have a three-day wait in the area anyway to make my return flight to Tijuana, he kindly offered me the facilities of the company boarding house and arranged also for me to meet an old miner the following morning in the mine office who was one of the few surviving workers who knew the underground in the Amelia from years before.

At 7:30 the following morning, we had met and were already discussing the Amelia. The miner reaffirmed that the workings were all caved but offered, nevertheless, to go with me to the area to point out the surface features and to describe what he remembered of the underground. It seemed that my only hope, at this point, was to find something in the dumps.

A mine truck, shortly thereafter, trundled us up the coast for a few kilometers and then inland up a broad valley that soon tapered into a narrow canyon that had been cut through an immense bed of gypsum, exposing some giant crystals of selenite in the steep canyon walls. Soon we arrived at the end of the road at one of the working mines, not too far from the Amelia.

A forty-minute hike over a narrow, sun-scorched foot trail through arid, steep hills and canyons brought us to the crest of a slope overlooking the Amelia workings along the side of Curuglú Canyon. I began to realize the magnitude of this mining operation upon viewing the gigantic dumps stretching side by side for hundreds of yards up and down the canyon, spilling their enormous loads of waste down into the gulch, and extending outward to contour with their smooth, steep slopes, the whole east wall of the canyon.

Surface probing in the dumps, under a very hot sun, yielded a variety of minerals: attractive botryoidal masses of iron and manganese oxides, chunks of transparent selenite, dendritic opalite and chalcedony in various ochre shades with occasional tints of green, sparse coatings of brochantite on iron and manganese oxides, some very friable chrysocolla, a few antlerite stains and small amounts of crudely crystallized anglesite, but none of the sharp azure-blue crystals that I had come so far to find. On one side of the canyon, positioned above an enormous dump, we examined one of the old haulage tunnels. A series of cave-ins had closed the passageway just a few yards inside the entrance. It faced, across the canyon to the west, the step-like remains of a mortered stone abutment that once supported a wooden trestle. No trace remained of the timbered span over which loaded ore had cars crossed the canyon to be connected five or six together for the long mule haul through the Amelia tunnel to the ore chutes in Arroyo de la Soledad Canyon to the east, where the trains picked up the ore for the smelter. Further search led to other mine entries carved into pastel layers of volcanic tuff but severe collapsing of the formation had sealed off all the openings.

Proceeding up the steep slopes of Curuglú Canyon, working our way over jumbles of rounded boulders that had accumulated from the weathered conglomerates, we passed through a heavy covering of thorn bushes and cactus to arrive on top of a gently contoured summit. Following this low crest to the south, we spied through a stand of saguaro-like cactus trees, a low-profiled mound of light colored dump material that surrounded the old Cumenge ventilating shaft. In its aged condition, the shaft opening had developed steep slides forming a rim several feet back from the vertical walls of the cut. The weathered remnants of the timbered headframe had long ago lost out to the pressure of the thinly cemented surface conglomerates. Rounded boulders that had worked loose from their matrix had battered jagged holes through the timber sidings and poured inward to fall to the floor of the shaft, three hundred feet below. Examining the meager contents of the dump only verified information given in the report: the shaft was dug principally to create a much needed natural ventilating system in the Amelia workings to alleviate an excessive heat problem underground, and bottomed out about 20 feet above the ore bed, connecting through gentle incline tunnels to the workings. No trace of copper minerals could be seen in the dump.

SECOND VISIT—1969

Ten years later, in 1969, a particularly cold and rainy January in Southern California offered sufficient reason for me to again visit this locality that continued to occupy my thoughts. Through the help of Roger Bostard, a California mineralogist with an encyclopedic memory of the Boléo Copper district report, we reviewed the underground maps of the Amelia mine. A tunnel was shown in Curuglú Canyon that entered the volcanic tuffs at the level of the river bed and extended inward for over 700 feet to meet a connecting tunnel that led to the Cumenge shaft. It was an entry I had not seen during my prior trip when examining the Curuglú Canyon area.

Searching out this opening, among the trees and boulders of the dry watercourse, revealed a sparse, narrow dump that blended into the rocks of the gorge. The stream-eroded dump gave no hint of the extent of the workings that I found within the portal. Passing by two or three small cave-ins within the first 300 feet, I came upon the edge of a winze that occupied all of the tunnel floor and descended thirty feet below to connect with lower level tunnels. Passing carefully over the thin connecting strip that bordered this deep hole, I encountered a large cave-in a few steps beyond with just enough space at the top of the collapsed mound to allow me to barely crawl through. Inside this barrier, which was over 400 feet from the entrance, the air in the tunnel became oppressively hot, and at the deepest point of my entry some 600 feet in from the canyon bottom, stagnant hot air made breathing extremely difficult.

The next day, I tried to penetrate even deeper into the same tunnel that seemed so close to offering me an entry into the Amelia underground. I had rented a tank of air from a scuba diver in town to give me a supply of fresh air underground, but out of the water, it proved to be too heavy and much too unwieldy. Deeper in the tunnel, over the cave-ins, I hollowed out shallow grooves by scraping handfuls of dirt and rocks to the side, allowing my body to pass through. I twisted and squirmed my way over the tight roof openings in the repressively hot atmosphere, enveloping myself in a muddy layer of sweat, as I struggled with the extra burden of the bulky air tank. I was gulping in huge mouthfuls of the rapidly diminishing supply of air, and not knowing how long the tank would sustain me, decided to turn back rather than risk running out of air.

It was a discouraging retreat, crawling and walking out through the tunnel, past the entrance into the glare of the afternoon sun. Standing at the portal in the refreshing warm air of the canyon bottom, my thoughts centered on a method to reopen this tunnel to provide the entry into the Cumenge shaft area that I sought.

THE AMELIA PROJECT BEGINS—1973

Four and a half years later I finally was able to put into work a plan to penetrate the underground. Many things were happening during this time span important to the transformation, unconsciously, of the Boléo dream into reality. Most important of all, I had met Bill Larson and soon thereafter, we were planning the formation of Pala Properties International. Mainly due to the relentless drive of this individual, together with the able backing of his wife Karla, Pala Properties International was soon in the enviable position of being able to take on the Boléo program. During this same period, a new development was also taking place on the Baja peninsula. The remaining stretches of the tortuous old grinding dirt road were being replaced with a shiny asphalt highway. In the coming months, this was to facilitate tremendously the smooth flow of equipment and supplies necessary for our project.

By 1973, three possible methods of entry into the Amelia were being considered: (1) through the haulage tunnel that I had partially explored with the scuba tank, beyond which a dangerous caved area of the old mine could stop us short of our goal with complete blockage from major cave-ins; (2) by erecting a new headframe over the Cumenge shaft, timbering off the first thirty or forty feet near the surface to hold back the dangerously loose conglomerates, and installing a hoist to lift out 150 feet of jumbled loose boulders and debris that choked the shaft, or (3) waiting for some old connecting tunnel to be uncovered by the new truck tunnel being driven at this time by the company, on the same third ore bed, from the San Luis mine towards the Cumenge shaft area, 3,500 feet to the west.

Driving for the first time on the new paved highway to Santa Rosalia, on a trip to decide which would be the best method of approach to the Amelia underground and how it could successfully be accomplished, for miles and miles I passed hundreds of busy construction workers. They were making a tremendous effort during the day and on through the night under Coleman lamps to finish the last minute details of the highway and the tastefully designed way stations and hotels prior to the passing of President Echeverria's inaugural caravan up the new highway. Pemex, the government-controlled national oil company, through the busy highway modernization program taking place, contributed heavily to this tremendous transition, overcoming the Baja Peninsula. Luxurious havens at frequent and selected intervals, each with its self-sufficient diesel generating plant to supply the electricity needed for lights, equipment and appliances, were installed to offer round-the-clock service of food and drink along with automotive supplies and quality fuels, and, for the more wary traveler, camper hook-up facilities in formidable wire fence enclosures to ward off the dangers of the night.

Those colorful stopping places on the old dirt roads are and were owned and maintained by unusual characters, conditioned to cope with the hardships of their desert habitat, many of whom are descended from the early settlers and pioneers of the region. Before the coming of the paved highway, these lonely oases were so spaced out along the peninsula and so meagerly supplied with automotive parts, that carrying reserve gas and spare parts was a sensible precaution for all travelers through the area. A stop then meant more than the impersonal refueling and departure of today. Wonder and surprise sometimes greeted one's arrival, as if some near-impossible task had been attempted and accomplished. Friendly conversations on the happenings of the area or on the road ahead could stretch into hours and sometimes revert into interesting

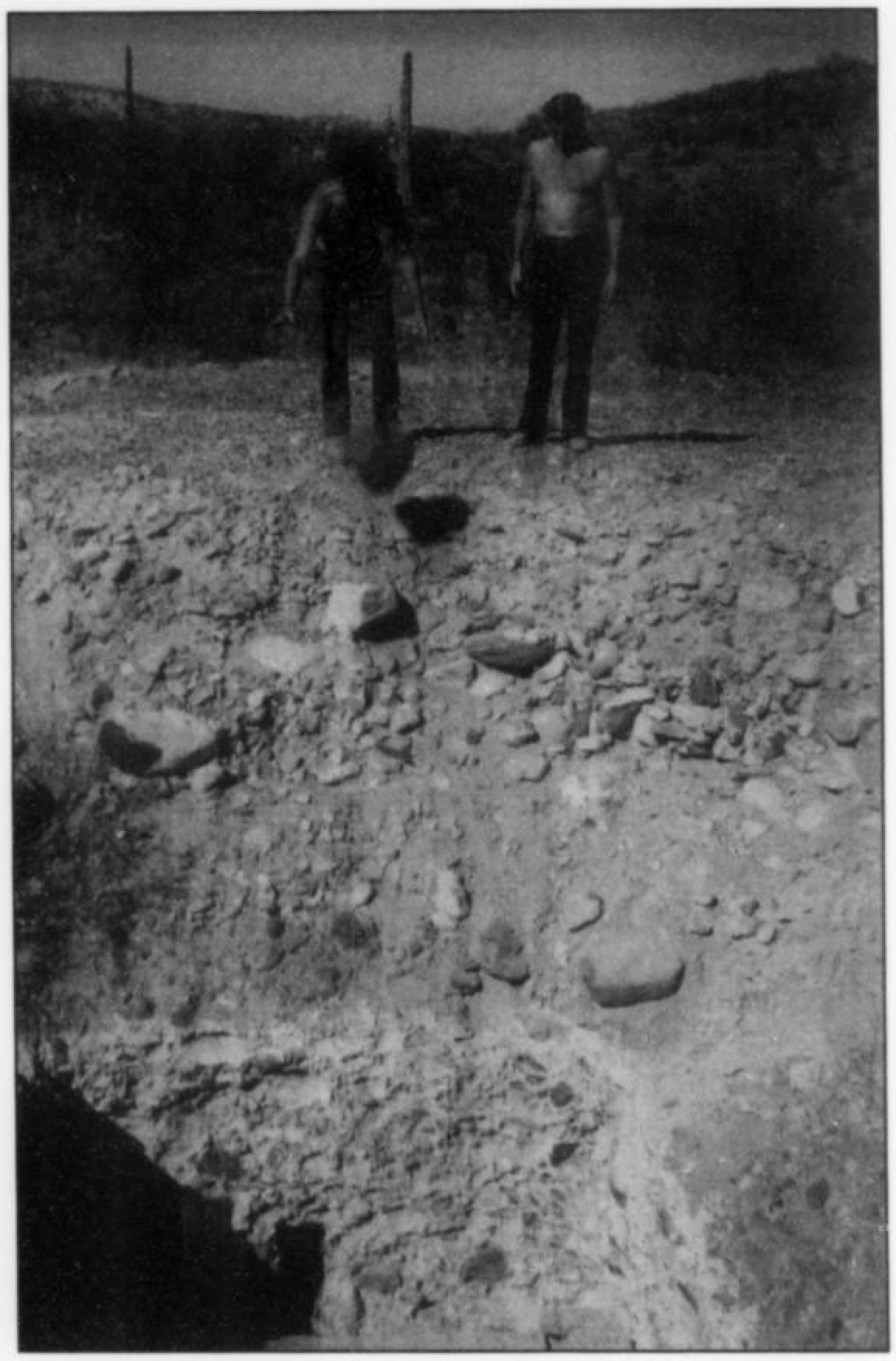


Figure 2. **The Cumenge shaft.**

reminiscings on pioneering forefathers. If good fortune favored one, an occasional meal of outstanding rarity and quality could be obtained, tastefully prepared with meat and produce of the area. The excellent Mexican beer was most often *al tiempo*, room temperature, which takes a bit of conditioning to appreciate. Near empty tanks could be refilled with the low octane gas siphoned from a 50-gallon drum by a gas-spitting attendant who was lucky to start the flow on the first try. Most of the carburetor-fouling contaminates were held back by filtering through a chamois or a piece of cloth.

Today, faced with the competition of the modern roadside facilities, but at the same time favored with the swelling surge of tourism attracted to the easily obtainable scenic wonders of the Baja peninsula, some of the old places that were not completely bypassed by the new highway are striving for a share of the action. Improvements are being made, such as graded rock-lined entries landscaped with rows and plots of attractive desert plants and cacti, including occasionally the luxury of a colorful flower patch alongside the modest structures to add cheer to the desert environment. Butane-burning refrigerators and stoves along with fresh supplies of food and drink contribute to better and more efficiently prepared meals, rivaling or surpassing those offered in the more expensive and modern string of President Hotels. Customers include loyal friends from the locale and truck drivers who prefer the ambience, the food and the prices, and now and then, a nostalgic traveler bringing warm memories of some past trip or the occasional traveler who only stops for an emergency.

Eleven hours of driving brought me from Tijuana to the first view of the inland Sea of Cortez from a vantage point the highway crosses on a sloping mesa. Closer to the waters of the Gulf, the mesa breaks down into eroded, steep-walled, barren yellow canyons opening onto the shoreline. Here for several miles north of Santa Rosalia, the highway follows a gently curving bay rimmed with beaches of well-rounded rocks and pebbles until, on the approach to town, it passes through a small community of miners' homes and then within the property of the mill, through a maze of metal forms on both sides of the road in advanced stages of deterioration; twisted tanks, pipes, ore cars, track, cable, steam engines, hoists, etc. etc., abandoned by the mining company.

After signing the register in the lobby-restaurant of the two-storied French-built Hotel Central, I carried to my room upstairs a few articles of travel in order to spare them the dusty ride I was planning up Canyon Boléo. Downstairs and behind the wheel again, I soon reached the turn-off and headed up the mine road in the direction of the Amelia mine.

An event occurred, shortly thereafter, that was to fill in the missing parts necessary for our mining program to actually get into work. A couple of miles up-canyon, I stopped at the foot of an ochre-stained mound of mined out material to chat with a sun-bronzed Mexican mine boss who was directing a few miners on a small open pit project. He introduced himself as Simón Navarro, a friendly man with the experience of having worked 25 years of his life in the district, first with the French Compagnie du Boléo for 15 years and thereafter with the present Mexican company. He invited me to his home after work that afternoon where we would talk about the Amelia mine. Later on as evening fell, I, for the first time, knew that I had found a man with the ability to manage our Amelia project.

A few days after returning to Los Angeles, I flew to Mexico City to join a friend, the amazingly well-relationed Sylvan Marshall, an attorney of distinction from Washington, D.C., to meet and to talk with Mexican government officials regarding permits and contracts necessary to work the Amelia mine. Months later, with official permission and contracts in hand, I was back again in Santa Rosalia engaged in long talks with Simón about finances, equipment and supplies.

After all the preliminary investigations I had involved myself in,

Figure 3. **Old adit in Curuglú Canyon.**

searching for a way of entry, Simón proposed a fourth and completely different plan to reach the third ore bed of the Amelia from his valuable experience of the underground peculiarities of the district, that turned out to be the safest and most practical approach. We were to sink a new inclined tunnel in from the slopes of Curuglú Canyon. Pacing the distance from the Cumenge shaft opening that lay hidden from view over the top of the hill, we walked back down the side of the canyon and chose for our entry pad, a natural basin that had been eroded into the slope, roughly midway between the dry stream bed and the top of the hill. Down-canyon, a half-mile from this spot, the dirt road ended on the flat top of a mine dump. Starting from the end of this road, with a full bucket and a can, we climbed up through rocks and cactus dousing here and there on prominently outcropping boulders, cans full of limewater that marked upon drying, a whitewashed line of rocks along the slopes of Curuglú Canyon that guided the bulldozer in cutting the connecting road to reach our new mine. Before returning to Los Angeles, I asked Simón to have the surveyor check our surface location to tell us what angle to descend and what point on the compass we must follow to touch down at a particular place I had selected on our tracing of the old French map of the underground.

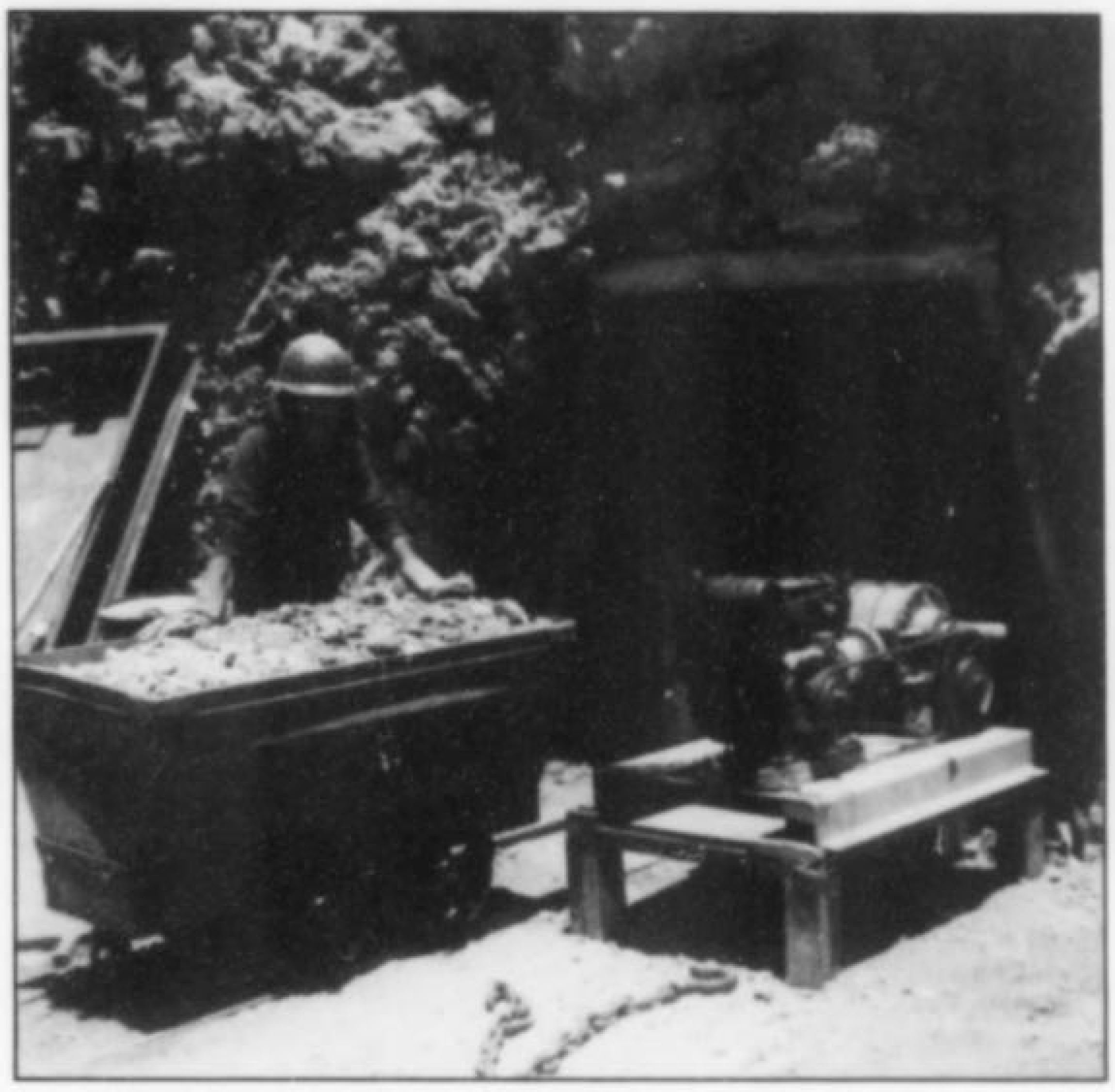


Figure 4. **Air compressor and ore car at the entrance to our new inclined shaft.**

TUNNELING BEGINS

In the space of two weeks, a tunnel was started in a vertical face cut out by the company dozer, and at an inclined angle of 30 degrees, Simón with his miners started down in the earth. The first few yards of descent exposed a grim hint of the problems we were to face ahead. Simón was having great difficulties making headway through a nest of large boulders, many weighing from 200 to 300 pounds apiece, an accumulation of nonmarine conglomerates underlying the slope that would plague us for the first 110 feet of descent. Before I could find and deliver to Simón the narrow gage track for the ore car, he was doggedly lifting out 300 pound boulders by brute strength, forcing them up the 30 degree slope in a wheelbarrow, with his helpers pulling from the topside on a rope attached to the wheelbarrow frame. Expertly placed timbering was necessary through these surface conglomerates, adding extra costs and loss of time we hadn't counted on. Meanwhile in Los Angeles, I had finally located 800 feet of narrow gage mine rail and a barrel of rail spikes and contracted for a Mexican trucker for the pick-up, along with 500 feet of four-inch diameter sheetmetal duct and a forced air-ventilator. Three days later, out of Los Angeles, the

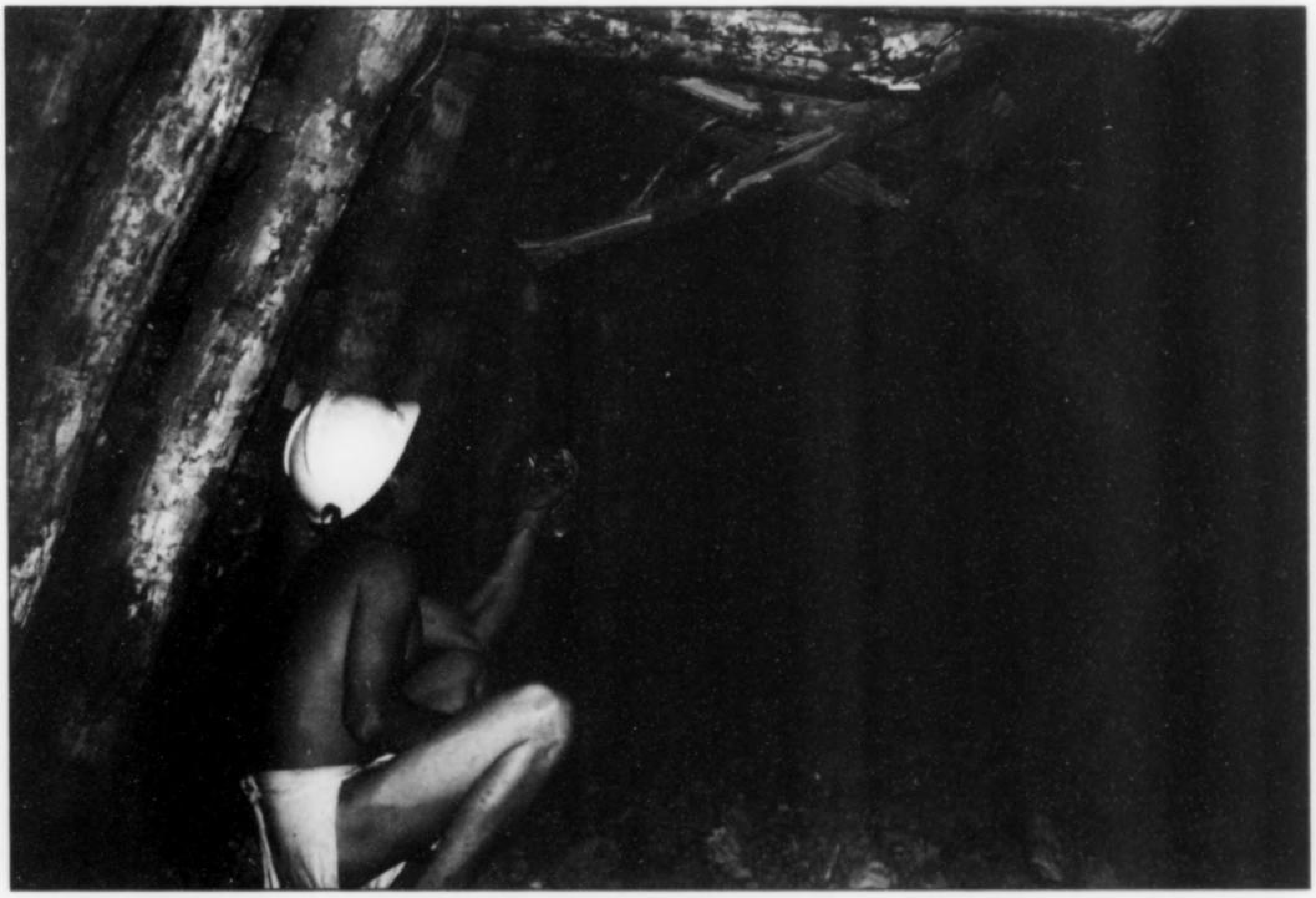


Figure 5. **Old workings slowly collapsing in the Amelia mine.**

trucker had arrived at our mine entrance and Simón was unloading the much-wanted cargo.

The donkey engine promised us by the mine engineers never quite made it to our diggings; the spare winch was occupied with emergency duties in other places and couldn't be loaned to us. With great resourcefulness, Simón anchored an upright pipe into the ground outside the entrance and attached a pulley through which he threaded a half-inch cable, connecting the ore car to his pick-up. Slowly driving down the road with his truck pulling on the cable, he lifted the loaded ore car to the surface where a helper disconnected the cable and hand-pushed the 1,000-pound load to the end of the track and spilled the waste onto the dump. For the next nine months, we poor-boyed the loaded cars up our seesaw, Simón going down and the ore cars coming up. In this manner, Simón mined for the incredible distance of over 500 feet. Beyond the 300-foot mark, it became a real problem when the cable behind the truck would swing out over the canyon and entangle itself in rocks and cactus, as Simón rounded an inside curve of our access road 300 feet down-canyon. He then installed a vertical roller at each of two inside curves by placing a greased larger pipe over a smaller inner pile that was anchored vertically on the canyon edge of the road. As he rounded the curve on his downhill pull, the cable would run against the upright pipe and start it noisily spinning on its axis, keeping the cable in line behind the truck.

Month after month of hard work passed by. Below the surface conglomerates, we encountered layer upon layer of hard sandstone-like volcanic tuffs. Driving downward through these tough beds with hand tools was a slow, tedious job that tended to affect us all with discouragement. Tools were being sharpened twice a week and wore down to frail remnants of their former strength. Eventually, with depth, the color of the formation began to change and the buff-toned layers gave way to a band of tuff the color of baked brick, and then farther down, changing again into shades of gray and tan. One angular piece of black basalt that Simón saved to show me that was removed from the beige tuff, upon being broken showed most of the angular vesicules filled with snow-white crystals of some zeolite.

After several months of tunneling, in the course of a casual conversation with Simón, I learned, to my horror, that an engineering survey I had requested months earlier to give us a location on the underground had never been made. My apprehension increased upon our passing through two very prominent down faults about 250 feet from the surface that meant we would have to dig deeper than expected to make up the vertical distance lost by the displacement. The Amelia ore bed tilted slightly upwards toward the west (the side we were coming in from) and the down faults cutting through the bed would section off the ore bed in giant shingle-like blocks that tilted as shakes on a roof, without overlapping. Consulting with Simón, I decided we should steepen our angle of descent from 30 to 35 degrees, thereby shortening the distance to reach our goal. I could hardly wait until the next trip to bring the Brunton compass down to Santa Rosalia to check our position underground.

A month later, back at the mine again, the first priority was the Brunton traverse and, after noting our tunnel direction, I ran the same point on the compass from our workings up the steep canyon slope and over the top to within sight of the Cumenge shaft, our surface reference to the place we wished to reach underground. The plan was to drive our incline down to the ore bed and then onward straight ahead within the near-level old workings to reach a point approximately 50 meters north of the Cumenge shaft. After projecting over the surface this line of direction of our tunnel to within measuring distance of the shaft opening on top of the hill. I found to my amazement that Simón had chosen, without instruments, a direction for our tunnel that (when eventually extended the full distance of nearly 800 feet) would pass in the ore bed within three feet of that point vaguely described as the discovery location of cumengite, pseudoboléite and boléite! I had nothing but admiration for this man as I told him he was way off course, by 36 inches! His poorly concealed concern transformed instantly into a proud explanation, of which I was in warm agreement, of the innate abilities of an experienced miner.

Recalculating our vertical position, I realized we were in for a much longer dig than I had originally surmised. Months later at around 400 feet from the surface we ran out of track, then cable and finally out of ventilating duct. We scrambled to keep reserves of these supplies on hand and luckily obtained some rails from the mining company who, from the start of the operation, had been most cooperative and helpful in supplying us with much needed materials and supplies.

Finally, towards the end of the tenth month of continuous digging, the signs started to look more encouraging. We were digging beyond the 475-foot mark and poor Simón was practically driving his pick-up out of sight down the canyon road to lift the loaded ore car out of the hole. We had plans to eventually install a winch, but I think we all wanted to see what would show up at the bottom before getting into that expensive detail.

THE ORE BED!

In our downward progress, we passed over an old tunnel, nicking the upper corner where the loose dirt funneled through the tiny opening into the old digging below. Soon thereafter, we penetrated a tenacious bed of red argillaceous tuff containing thin stringers of a dull black manganese oxide and interlacing thin bands of crystal-clear selenite. Just below this red formation, at a distance of 530 feet from the surface, we finally touched down on our objective, the hanging wall of the third ore bed of the Amelia. Passing through montmorillonite clays in assorted pastel shades of yellow, tan, cream, orange and green in the hanging wall, we continued downward through a hodge-podge of compressed backfill materials that supported a stoped out area that had been mined 60 years before, reaching the underlying footwall, a slickensidelike smooth-faced horizontal bed of dull red volcanic tuff.

The two miners first saw them when loading the ore car underground but when I saw them in the light of day, in that first load of backfill that came to the surface, those first sharp, bright little blue cubes, I wanted to make love to them. They were the most powerful medicine I had ever held in my hand. Feelings of joy and gratitude and relief pervaded my senses. After twelve months of tough digging, twelve months of total immersion in the project and seventeen trips later, twelve of these by consecutive monthly drives, there they were in my hand! Excitedly, we screened and searched by hand through each ore car load that surfaced. Loose boléites began to appear, with now and then a piece of montmorillonite showing a single cube or rarely a cluster of crystals. One screen load contained several clean-edged quarter-inch cubes but mostly we were picking up one-eighth inch sizes and under. By the end of that memorable day, we had picked out a nice little selection of boléites, loose and in matrix.

Later that evening, after having happily celebrated with the miners on the finding of the crystals, I contemplated the significance of our discovery. Actually, the real surprise was to find boléites in backfill at a point about 225 feet to the west of where they were supposed to be, according to the location given in the reports I had studied. After the mine was electrified in 1905, endless belts were used in the Amelia to transport backfill from

Figure 6. **Old workings collapsing in the Amelia mine.**

distances up to 60 and 80 feet, according to the old miners who had worked there during that period. In its completely caved-in condition, there would be no way to know where the crystals were coming from in the backfill, until we could examine some unmined remnants of the ore bed.

During the next few weeks several improvements were in progress around the mine. While the miners began tunneling along the level ore bed, laying their track and placing square sets of timber across the roof every four feet or so for safety, we put up on the pad facing our opening, a palm-thatched ramada. It was open on four sides, shading us from the debilitating heat of the summer sun and was high enough to cover our little Airflow camp trailer that had been serving as my headquarters in Simón's backyard.

We learned that a sample of backfill given to the mill assayer showed a high percentage of copper, which delighted no end, Simón the miner. Within a few days, a couple of the company engineers visited us to study the problem of putting up an ore chute to efficiently handle our copper ore production. A bulldozer appeared up our canyon and cut a lower road, branching off of ours down canyon, to carve out a pad at the base of our ore dump. Two company men arrived on a mine truck loaded with long timbers and a barrel of lag bolts and spikes and for two weeks worked mightily to construct a solidly built two-story ore chute. With a simple but efficient heavy six-foot iron bar with over-size notches at one end, placed over a section of the loosened mine rails just outside the entrance, Simón and his two sons coaxed the rails into a nice smooth curve to relocate the track towards the new ore chute. An end dumper was attached to the track just over the bin so that loaded ore cars could be flipped up by two men, and dumping directly into the chute, where the ore trucks loading from underneath hauled their eight-ton payloads to the mill.

Figure 7. **Digging for boléite in a promising part of the third ore bed, Amelia mine.**

Most important to our mining operation at this time was a diesel generator that was to power a winch and the ventilator. John McLean took time off from working the Tourmaline Queen mine in the San Diego back-country to make the long trip down, bringing

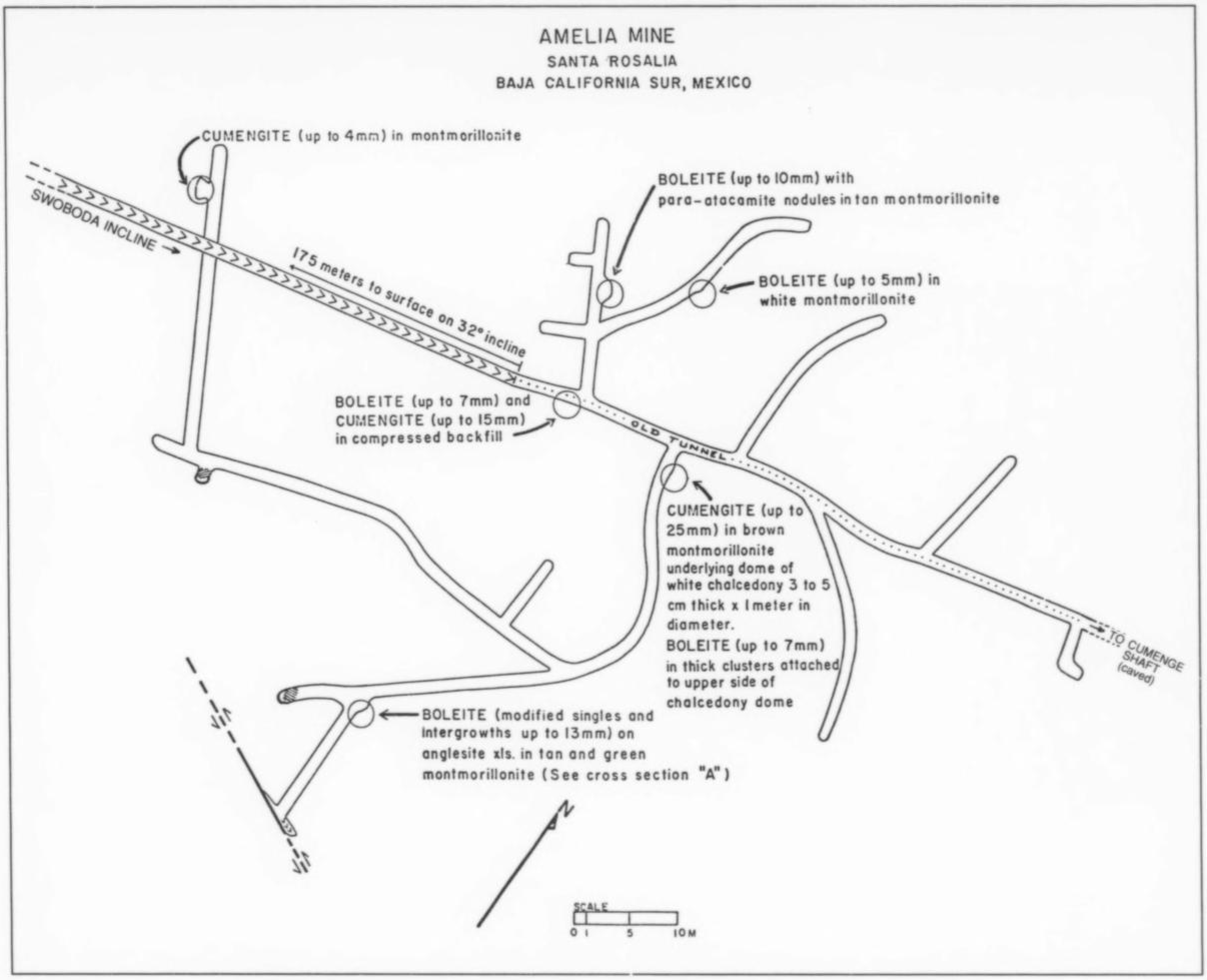


Figure 8. **Our workings in the Amelia mine. Our 175-meter incline happened to intersect an old, partially caved tunnel which we cleaned out; then the exploratory drifts were dug as shown.**

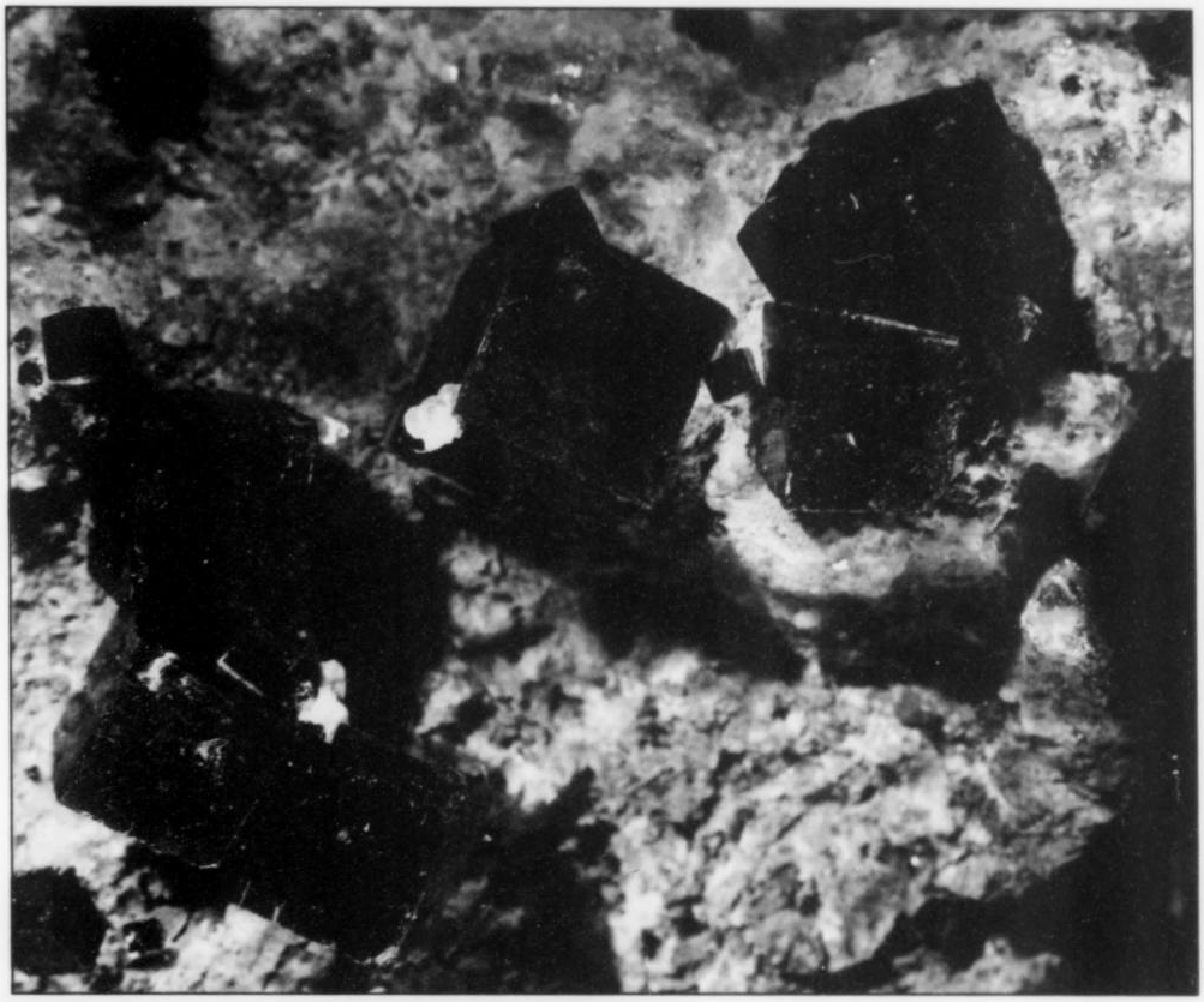
to us this much needed equipment plus the know-how to put it together. For several days, John was fully occupied with the installation and wiring of these units, after which we all appreciated the look of pure joy on Simón's face as he operated his new playthings. On an earlier trip, John had brought up to the mine a solidly welded iron door frame with door, plus a few bags of cement. The miners did a professional job at the tunnel entrance building up a thick enclosure of reinforced concrete to encase the iron frame, from which they hung the massive door.

Our present plan is to develop the several exposures of copper ore we have already uncovered that contain no crystallized minerals, selling the ore to the company to help defray our running expenses and possibly to recover some of our investment. For the moment in a precautionary way, we are flushed with success on the discovery of the rare minerals, but much remains to be done in the development and control of the mineral collecting. We will continue to advance along the ore bed in a straight line almost due east, a delicate procedure that requires an experienced miner's hand at timbering, through collapsed tunnels, fragmented old timbers and the once loose backfill that has been welded into durable conglomerate-like masses from the intense pressure of the crushing weight of the overburden.

The most meaningful discovery of boléite we have made since the initial excitement of entering the third ore bed of the Amelia mine, verifying that some of these rare minerals still existed underground, was when we were removing a small portion of unmined ore bed, probably a support pillar left in place as a safety precaution by the miners who were digging out the copper ore years ago.

Extending our tunnel eastward through the caved-in hazards of the old workings, we entered into this unmined bed of grayish tan montmorillonite from which we uncovered some lustrous, well-formed boléite crystals of unusual size and beauty, embedded at random distances in a thin layer of the pocket clay. This narrow band of montmorillonite, containing the crystals, was carefully worked out section by section and brought to the surface for wrapping.

The better specimens from this important find are now being carefully trimmed and cleaned for the coming Tucson mineral show in February, where they will be exhibited as a special display. They are the most outstandingly beautiful matrix specimens we have ever seen. What a pleasure it is indeed, to be involved in one of nature's beautiful products.



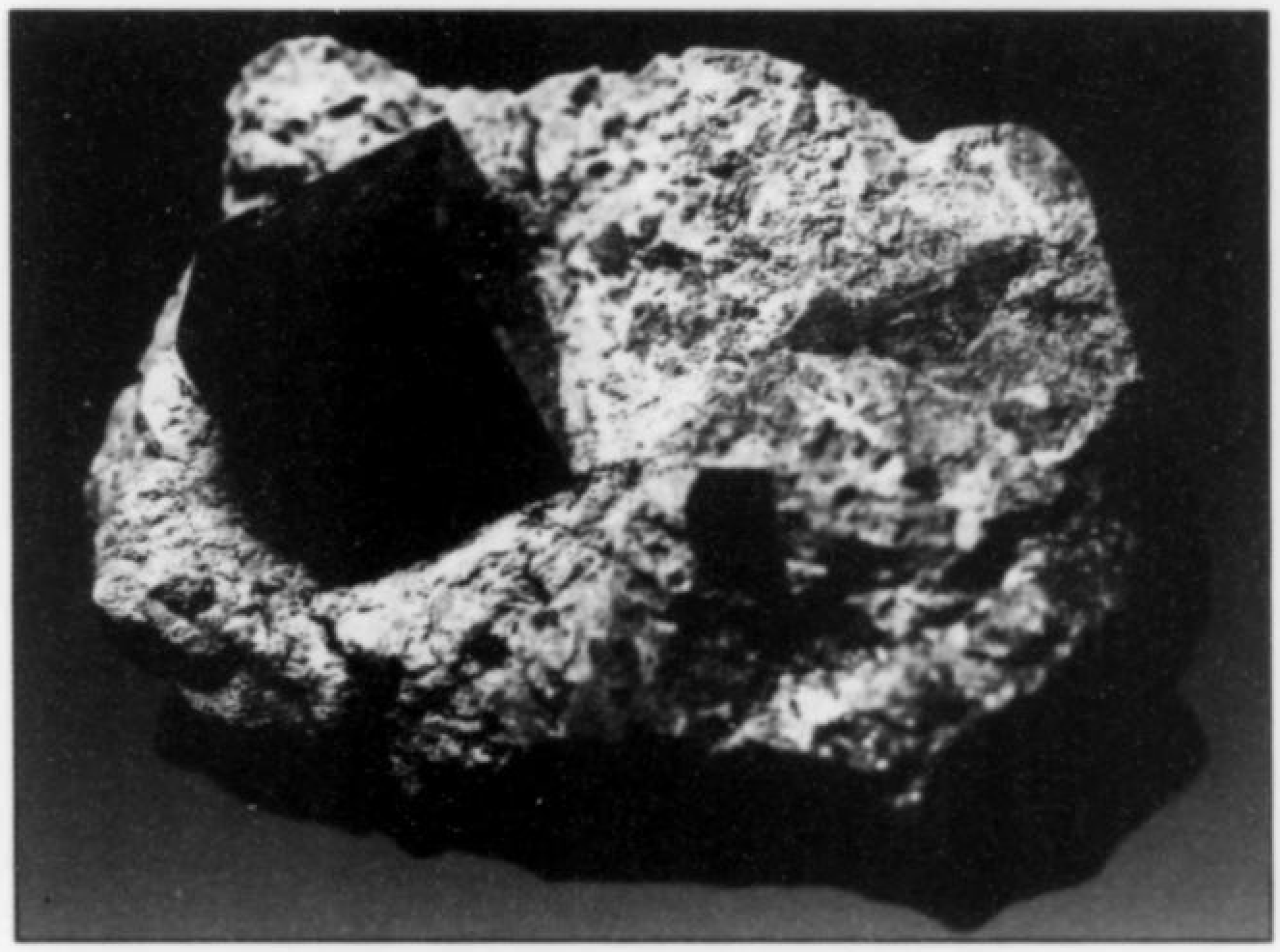


Figure 9. (above) **Boléite crystals to 1 cm on matrix, from the Amelia mine. Pala Properties International specimen; photo by Harold and Erica Van Pelt.**

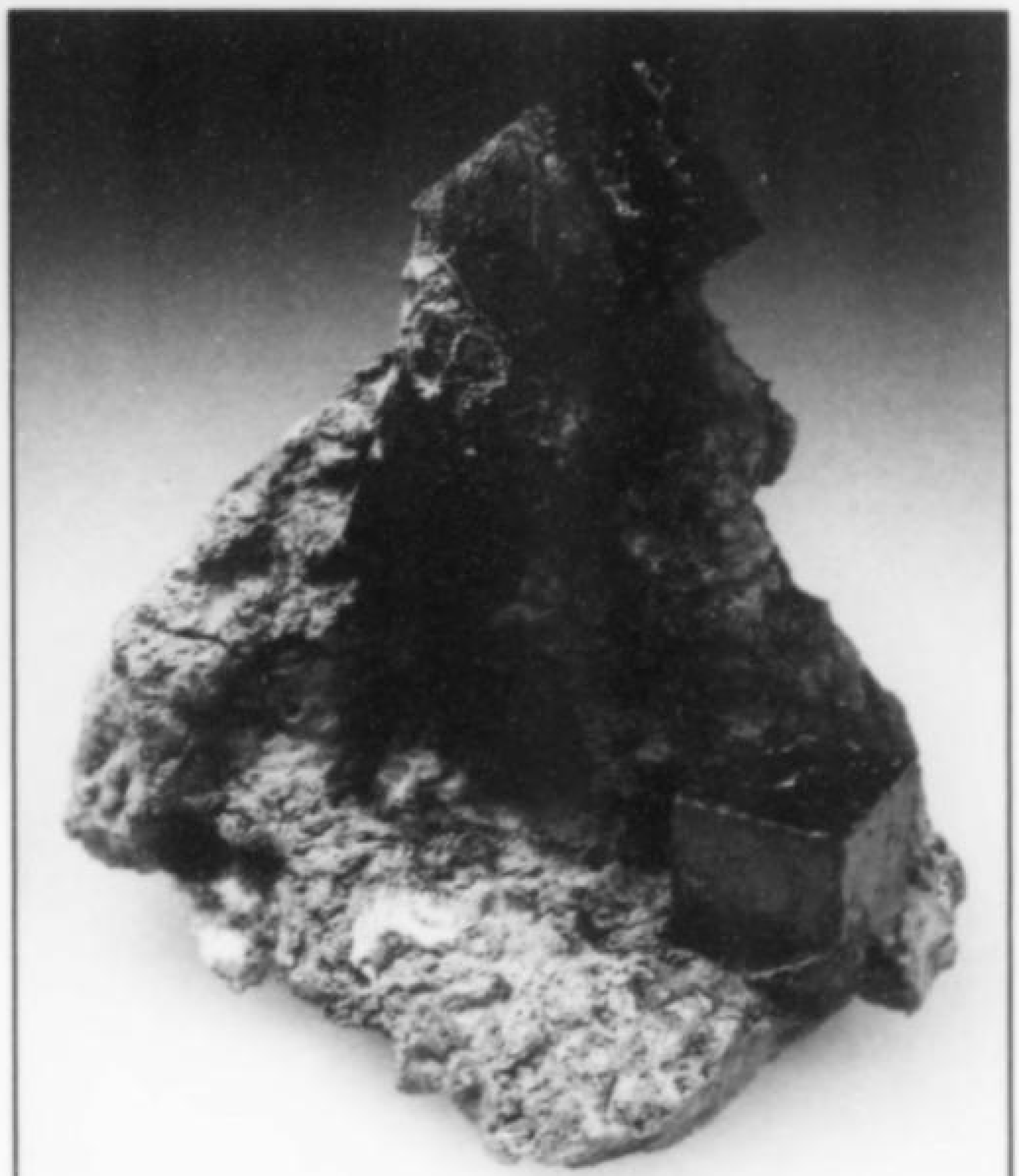


Figure 10. **Boléite crystal, ca. 2 cm, on stabilized matrix; one of the largest crystals collected at the Amelia mine. William Larson collection; photo by Wendell E. Wilson.**

[Editor's Note: That's where the story ended in Swoboda's 1976 Lapidary Journal *article, with work just getting started. But what happened then? We contacted Ed, who is currently involved in exploratory work at the Tourmaline Queen mine in California, and asked that he finish the story. He graciously sat down and wrote out the following notes on what they later found.]*

Reminiscing on events that brought me to willingly endure the oppressively hot environment of the Amelia mine, I remember

Figure 11. **Boléite crystals to 1.8 cm, on stabilized matrix. Cal Graeber specimen; photo by Wendell E. Wilson.**

Figure 12. Boléite crystals recovered in 1973; the largest one measures 1.4 cm. Ed Swoboda collection; photo by Wendell E. Wilson.

Figure 13. Boléite crystals to 6 mm on white anglesite. Ed Swoboda collection; photo by Wendell E. Wilson.

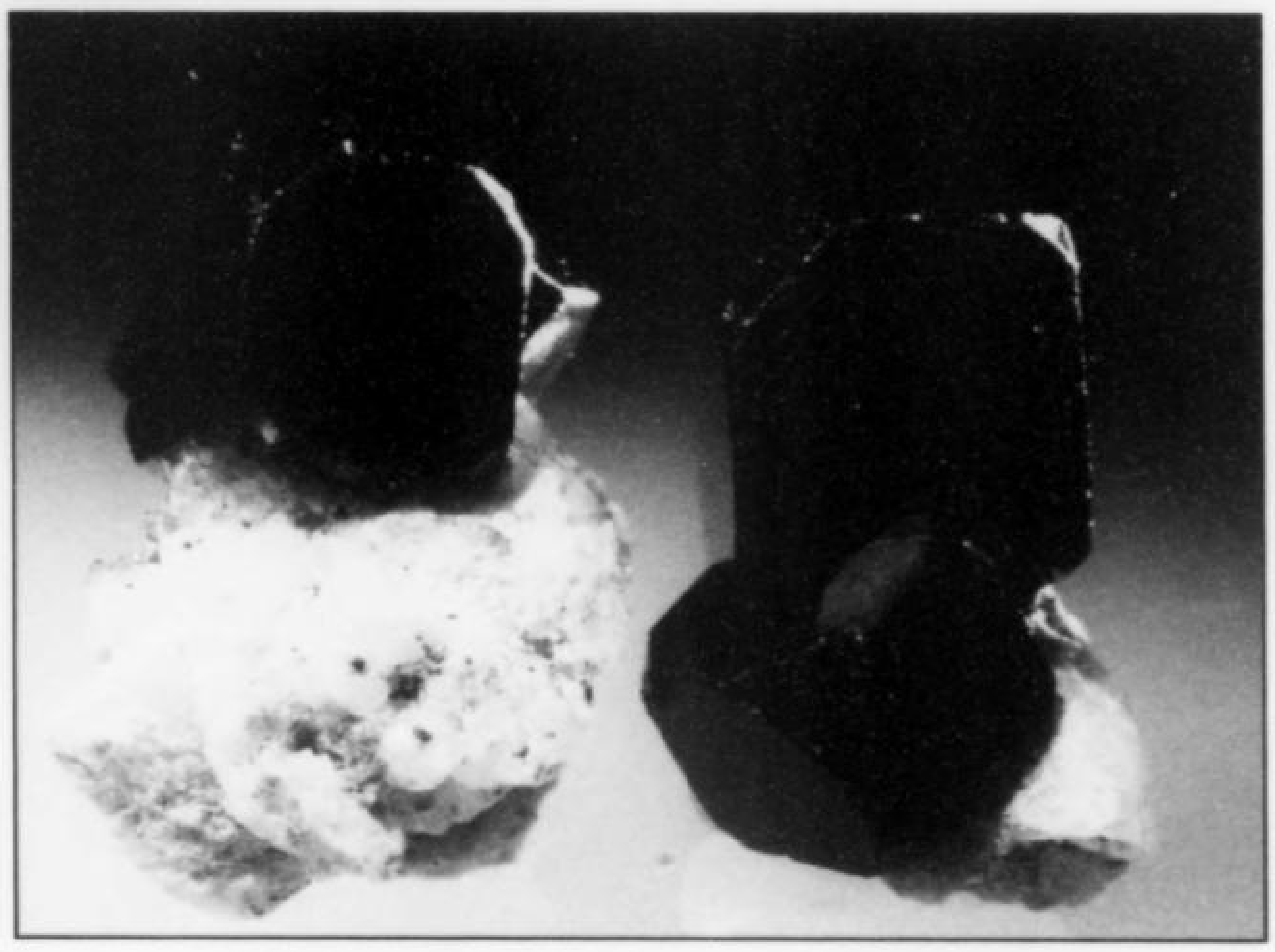


Figure 14. Boléite crystal, 6 mm, on anglesite. Ed Swoboda collection; photo by Wendell E. Wilson.

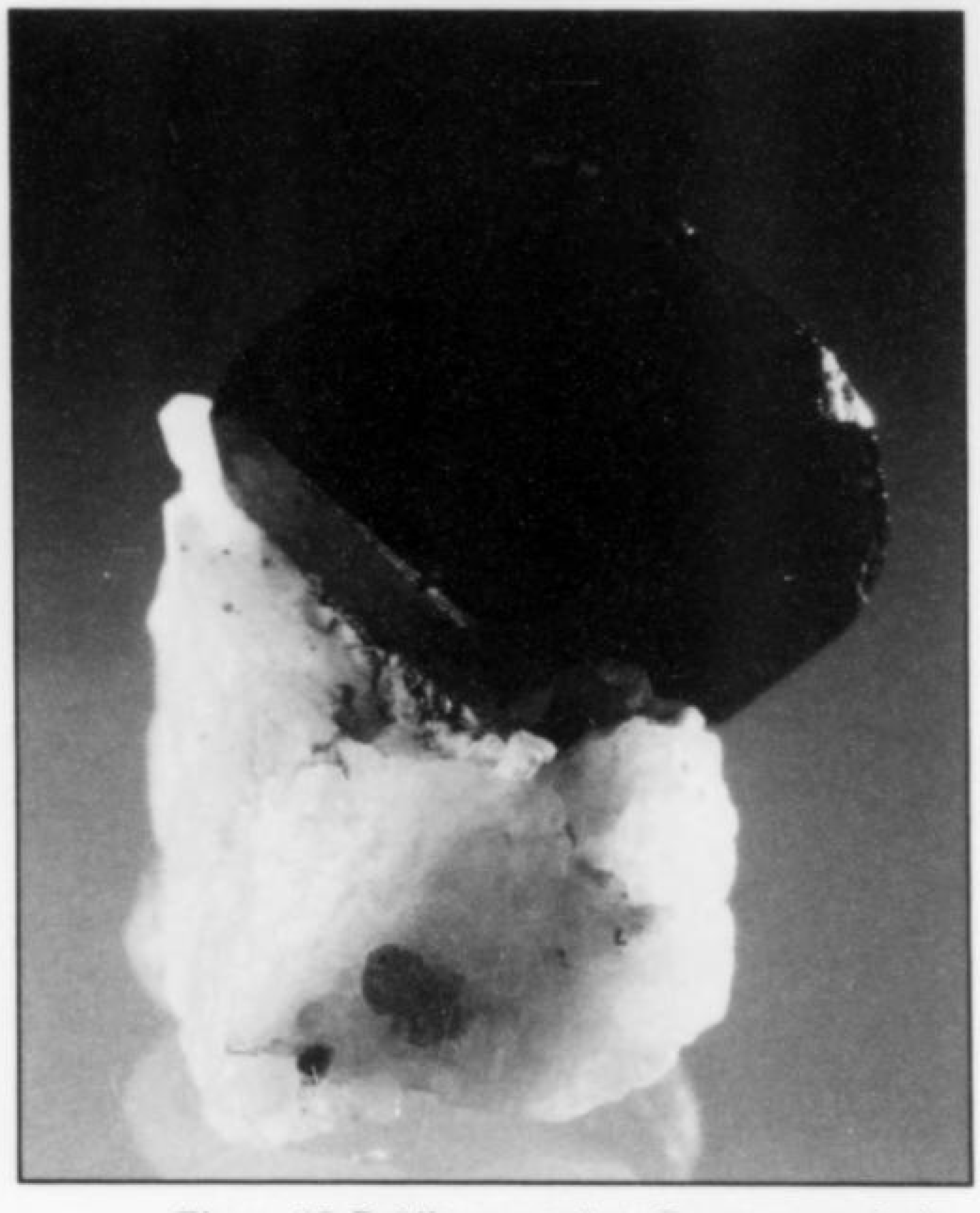


Figure 15. Boléite crystals to 7 mm on anglesite. Ed Swoboda collection; photo by Wendell E. Wilson.

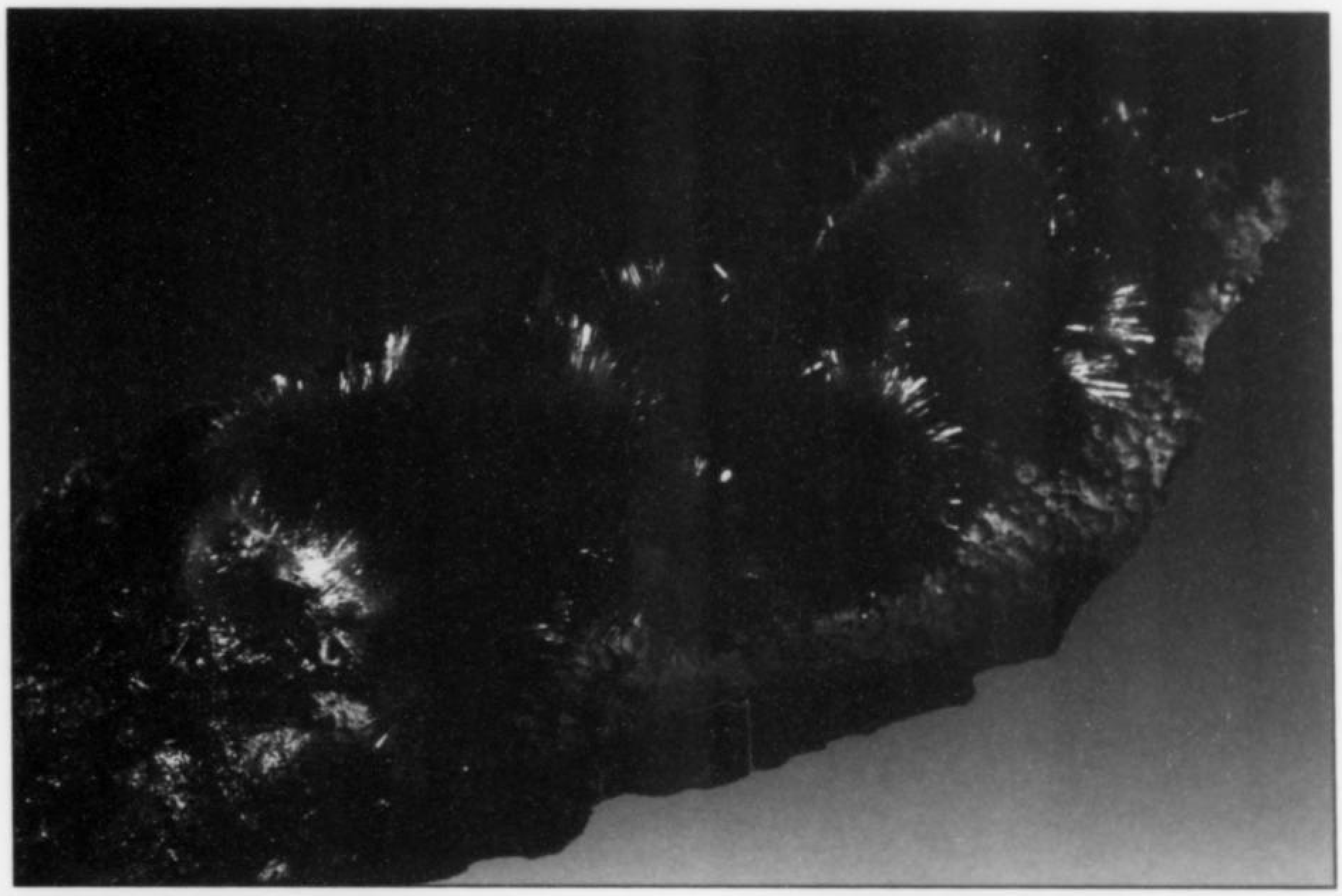


Figure 16. (above) **Brochantite tufts (or possibly aurichalcite?) on matrix, about 6 cm, from the Amelia mine in 1973. Ed Swoboda collection.**

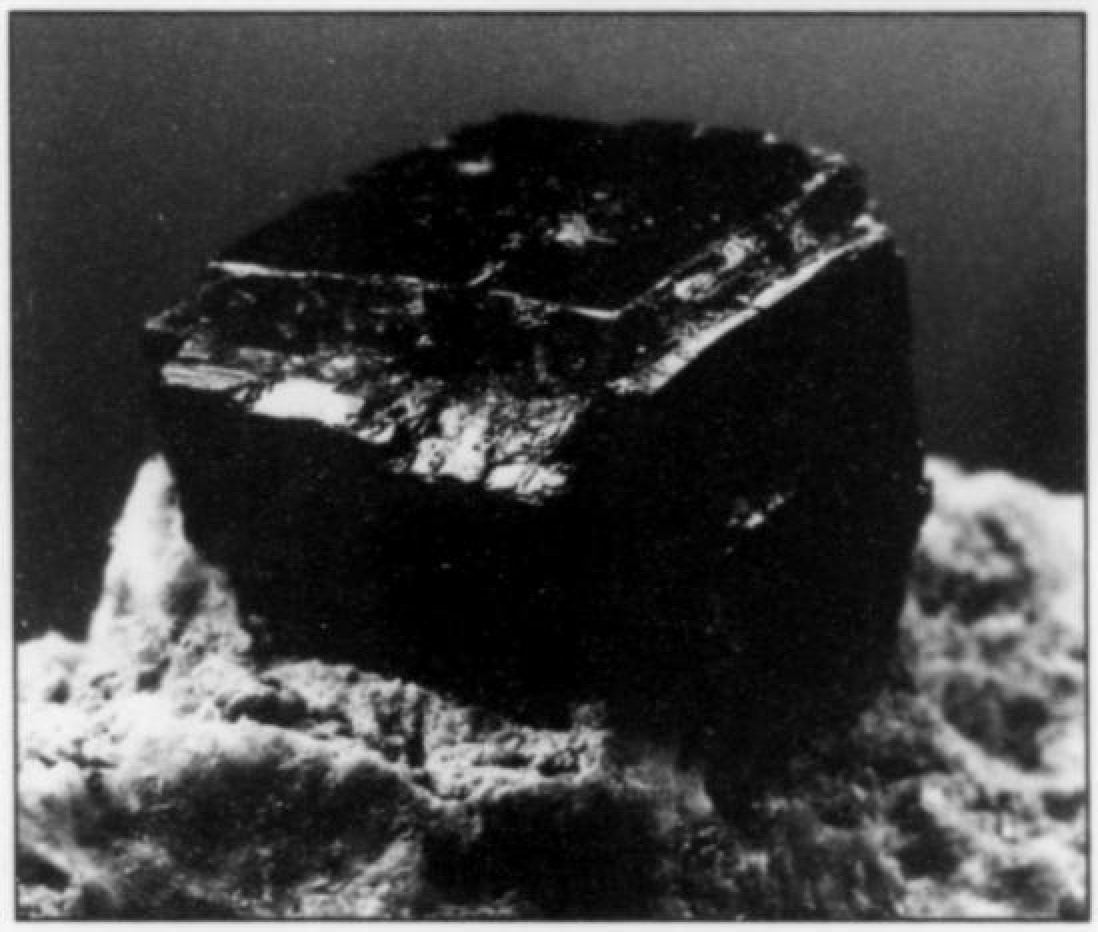


Figure 17. (left) **Pseudoboléite crystal, 1.1 cm, collected at the Amelia mine in 1973. Ed Swoboda collection; photo by Wendell E. Wilson.**

Figure 18. (right) **Paratacamite pseudomorph after anglesite, 2 cm, from the Amelia mine. Ed Swoboda collection; photo by Wendell E. Wilson.**

clearly being entrapped by the late mineral dealer Martin Ehrmann's enthusiastic description of the three giant cumengites that he had just seen at the Sorbonne in Paris. With trembling fingers he showed me their dimensions, and I was hooked. Anyway, to continue the story . . .

There I was, finally having reached the third ore bed, the origin of those fabulous crystals Ehrmann had seen in Paris. Unfortunately there was no accurate record of exactly *where* in the third orebed workings those crystals had been found. So I proceeded to have exploratory tunnels driven from the haulage tunnel touchdown outward in several directions within the friable six-foot stratum of mineralized clays. This work ultimately covered a haphazard area of about 200 x 300 feet. The digging was pretty much a blind grope through the soft clay, and it was clear that, although we did run across some very nice specimens, we could easily have missed other fine material.

Most of the matrix specimens recovered consisted of boléite crystals embedded in soft, pale gray montmorillonite-like clay. Occasionally we also found pseudoboléites, with their characteristic notched edges showing where the pseudoboléite had overgrown the faces of a boléite cube. Rarely, very rarely, we found a

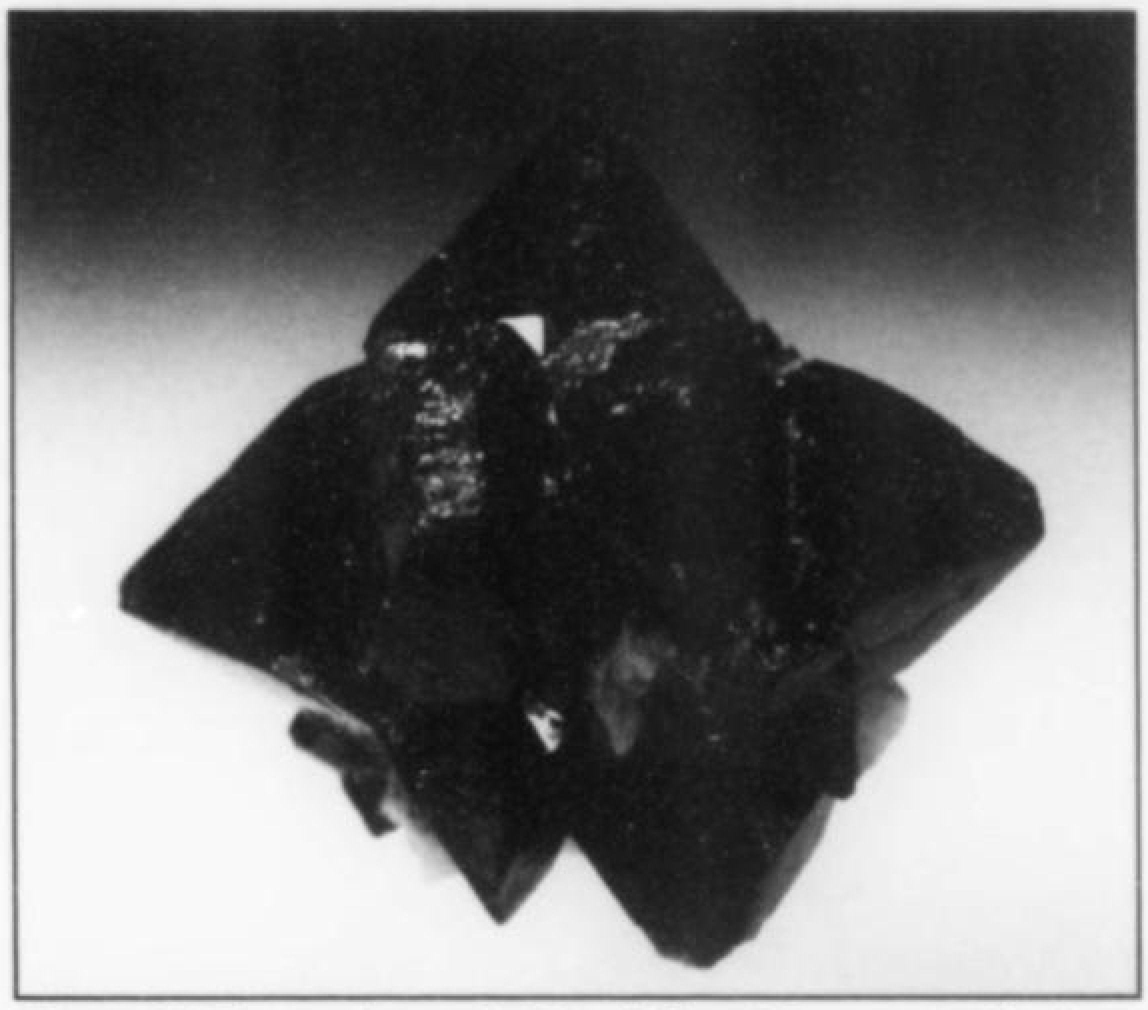


Figure 19. **Cumengite-on-boléite sixling, 1.2 cm, actually showing seven crystals grown on the six faces of a boléite cube. Ed Swoboda collection; photo by Wendell E. Wilson.**

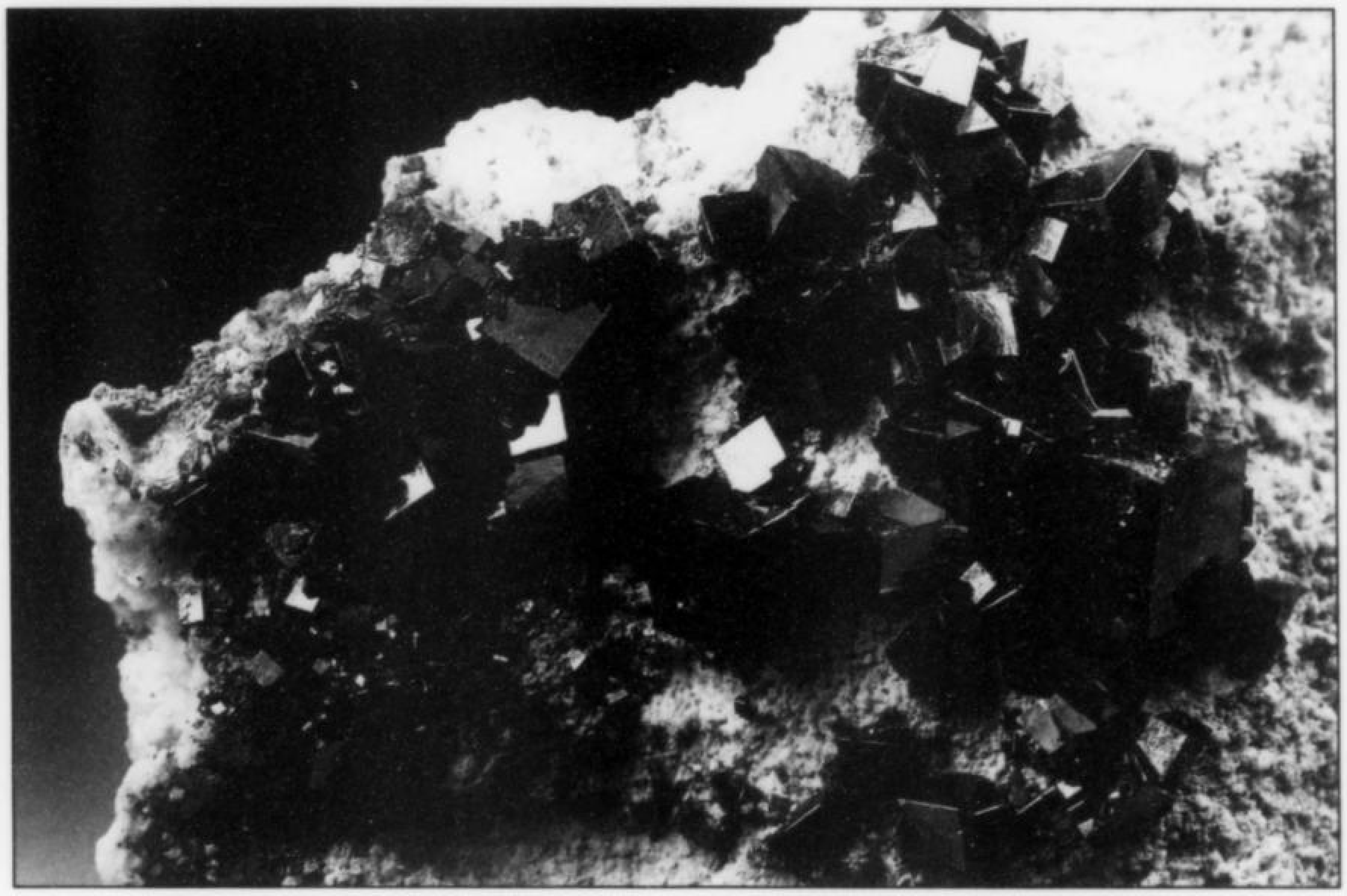


Figure 20. **Boléite crystals to 5 mm covering chalcedony, from the Amelia mine. Martin Zinn collection; photo by Wendell E. Wilson.**

cumengite in matrix. These bright blue crystals were associated mainly with boléite, perched on or embedded within transparent masses of gypsum attached to dull green nodules of paratacamite, or even more rarely on hard chert-like masses of opaque white chalcedony.

With great care we extracted the matrix specimens from the ore bed, but once exposed to the arid desert atmosphere the clay began to dry, crack, and crumble away before my very eyes. I quickly developed a preservation technique whereby each chunk of damp clay showing signs of blue crystals was immediately wrapped in cheesecloth and immersed in a solution of water and Elmer's Glue. After soaking a while the specimens were removed from the solution and allowed to surface-dry in the fierce desert heat, then were wrapped in newspapers and left to dry slowly and completely over several weeks. The newspaper and cheesecloth were then removed, and the crystals exposed through the use of hand tools.

Some layers of clay were so loose and friable (such as the brown bands that yielded occasional cumengite crystals) that even when mined carefully with small hand tools they would collapse and disgorge their crystal contents in a flow of loose, wet powder. In digging through this clay I recovered three remarkable loose crystals of cumengite in the classic six-pointed aggregates of cumengite-on-boléite. Two of them, almost identical in size and perfection, measure 1.6 cm in size; the third, with some underdeveloped points and lightly touched by pseudomorphism on one point, measures a full inch, 2.54 cm!

By this time I was feeling absolutely certain that the "Big Ones" were within my grasp, but, as it turned out, those three specimens were the best cumengites to reach our hands. A single 1.8-cm cumengite crystal, *not* overgrown on boléite but replaced by chrysocolla, is in my pseudomorph collection.

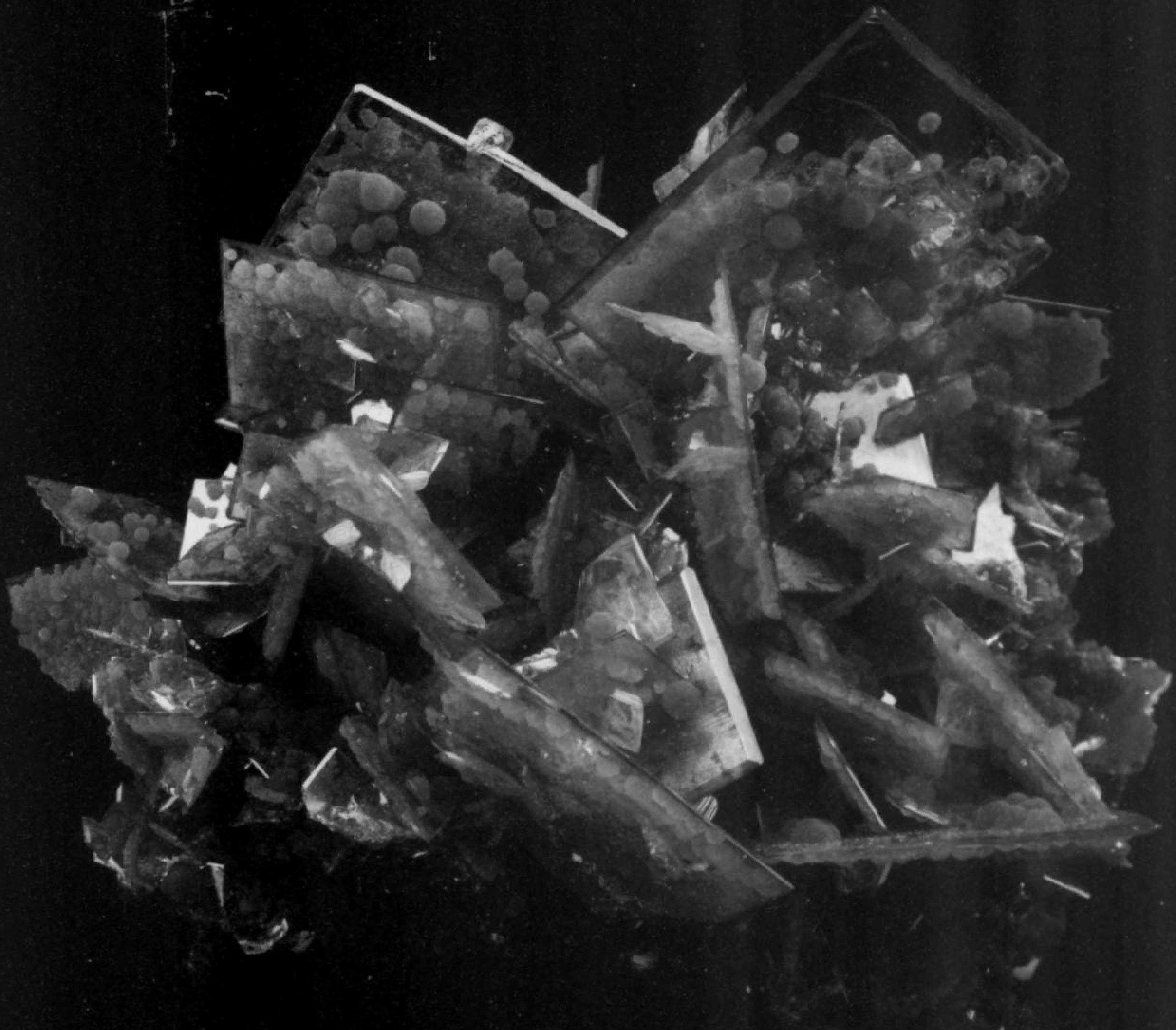
One sad incident involved a unique 20 x 30-inch slab of opaque, milky white chalcedony. An old miner had been left underground alone to drive a tunnel and remove ore for processing, and it was he who came across the rare piece. When I arrived that Friday after a six-hour drive across the hot desert, the first thing I saw on the sorting table was a small chunk of hard, white, cherty matrix with boléite crystals. It had just come up in an ore car. I raced down the incline to the working face, but it was too late. The rest of the big plaque had been completely destroyed. The miner had methodically pulverized it into small fragments, each piece showing smashed blue scars where perfect boléite crystals to 7 mm once stood. The total upper surface of the plate had been covered thickly by lustrous blue crystals. The crystals now lay scattered in broken pieces across the tunnel floor. What a heartbreaker! Three or four small pieces of matrix were all that survived with good crystals intact from this magnificent sheet nearly a meter across.

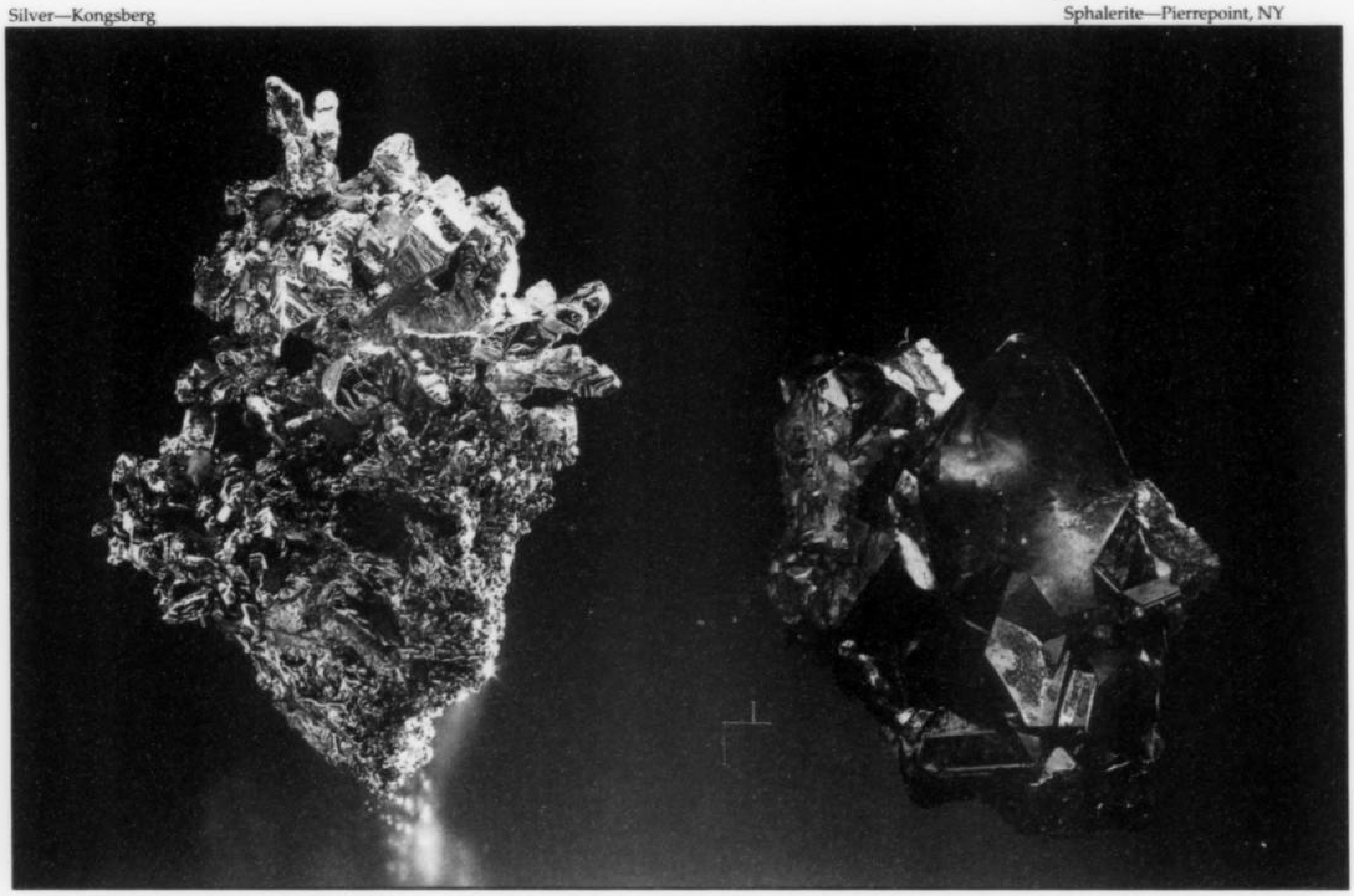
Different locations in the ore bed each produced boléites of a distinctive habit. One area yielded plain cubes, another produced modified cubes, another only intergrowths, another with pseudoboléite overgrowths, etc. In each case the surrounding clay gave no indication whatever that crystals were near.

Months of painstaking labor produced for us what were probably the finest matrix boléite specimens ever recovered, although the best *loose* crystals found by the early French miners were far superior to any we encountered. The same could be said of our cumengites, which, fine as they were, did not reach the size of the huge examples in Paris. Nevertheless, we liberated some wonderful specimens that otherwise would still remain in the ground. It was a great experience.

In the end, we shut down the operation because it just wasn't paying for itself anymore. Our workmen left for other jobs, our equipment was cannibalized, and our site finally abandoned. But the big steel door set in concrete is probably still there to this day. Perhaps some day another collector, with plenty of financial backing, will decide to re-enter the old Amelia workings through our shaft and try his luck. He had better be prepared to suffer, though. If he fully realized what we went through in our quest, he would probably give up and look for easier pickings somewhere else.

Editor's Note: In 1993 a hiker named Bonnie Thoresen (not a mineral collector) stopped at a dump in the Boléo district, just to kill some time. She sat down and casually sifted out *hundreds* of cumengite sixlings (up to 1.3 cm) from the muck. She later sold them all wholesale at the Tucson Show. Being unfamiliar with the district, she has no idea *which* dump she was sitting on at the time.





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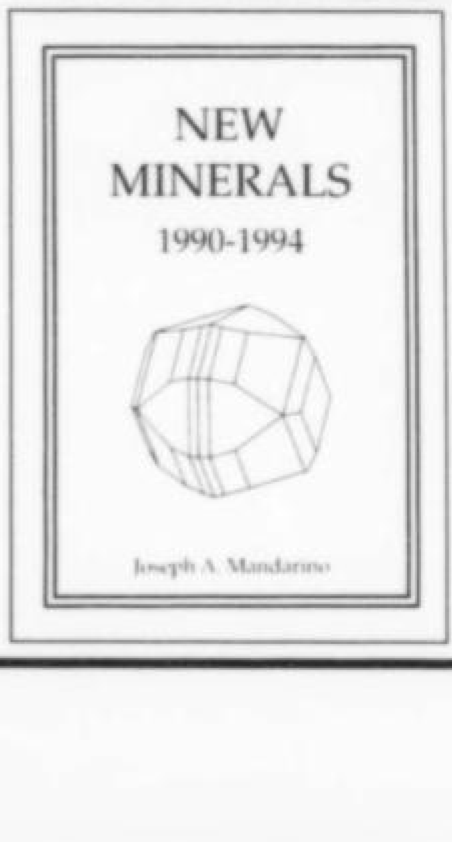
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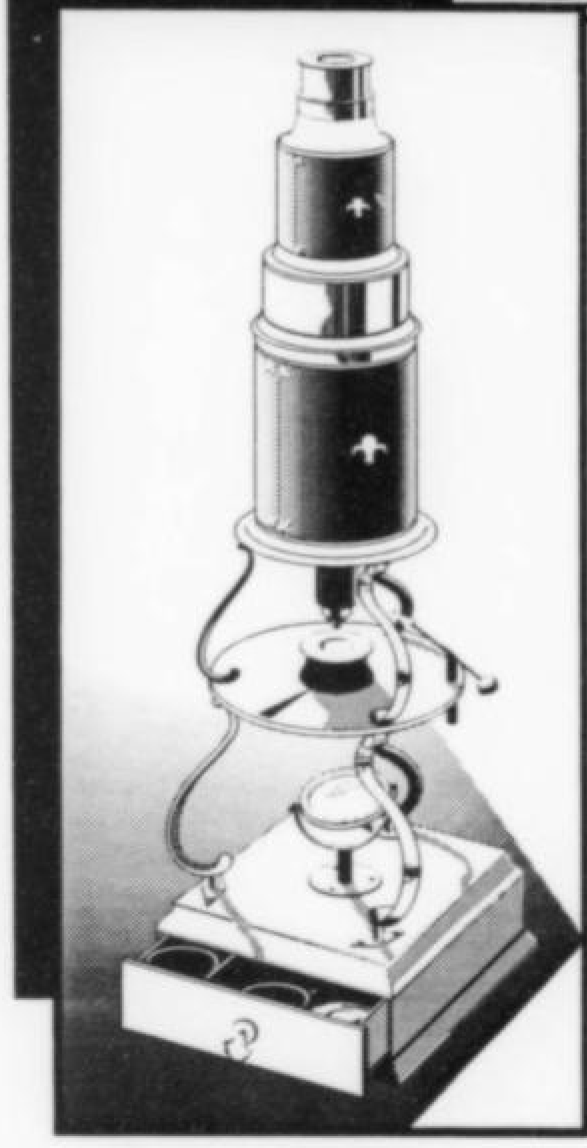

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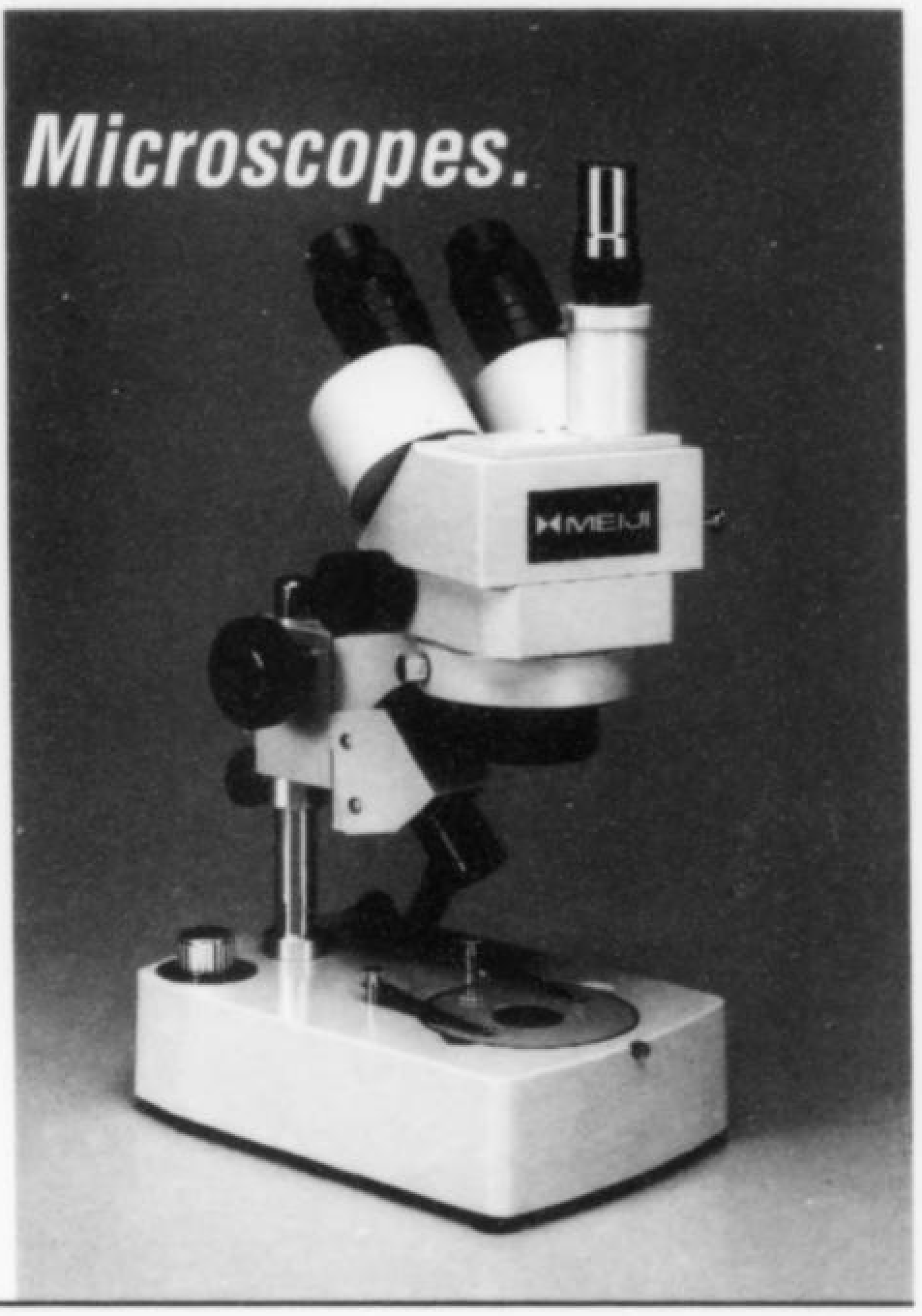

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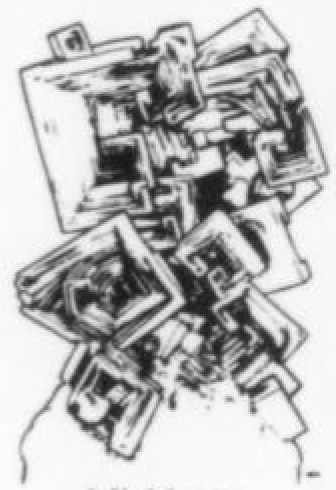

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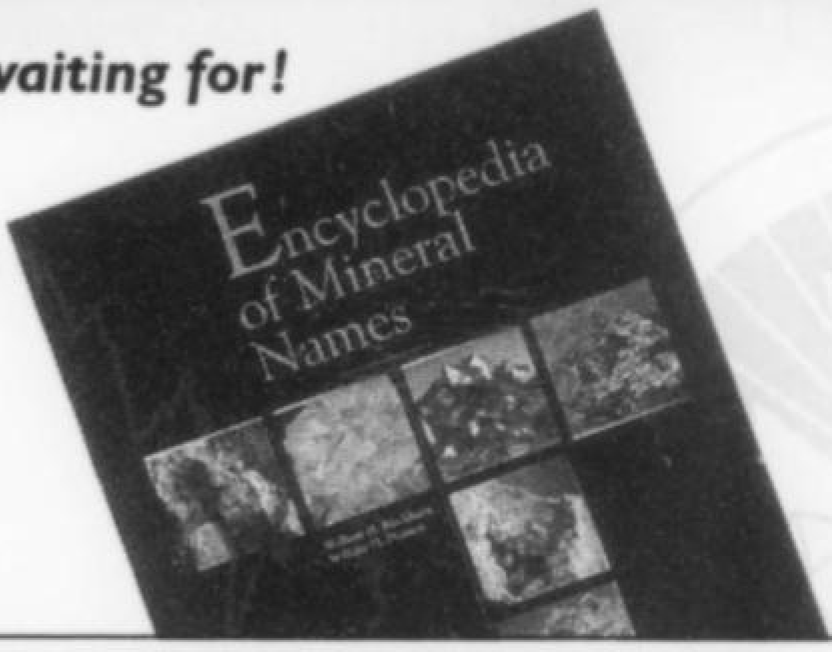
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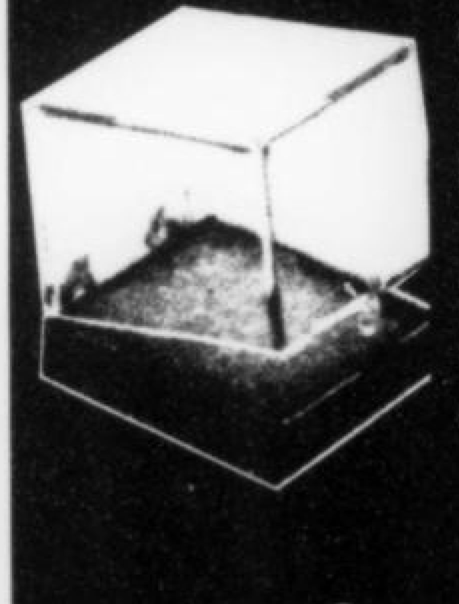

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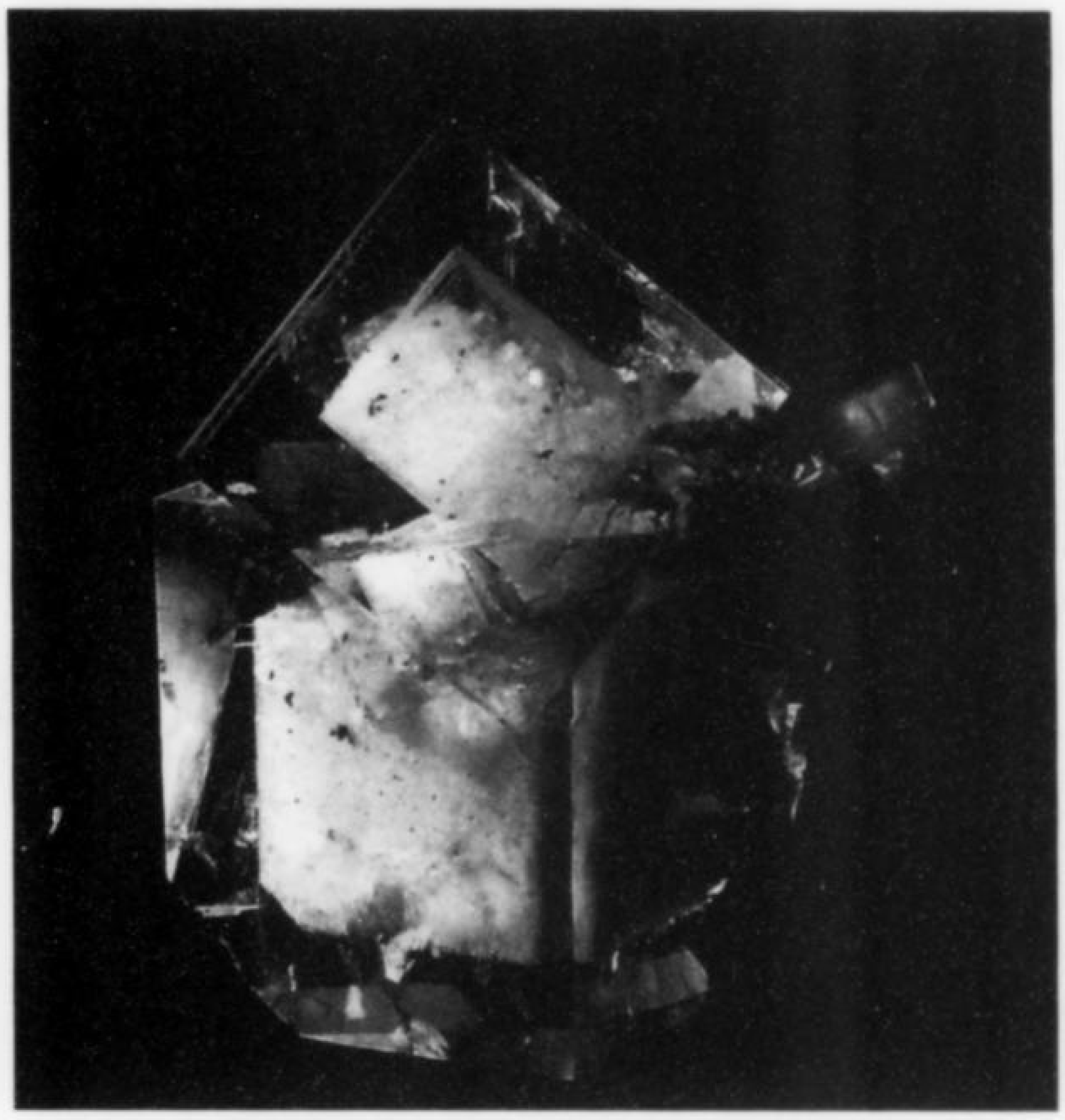

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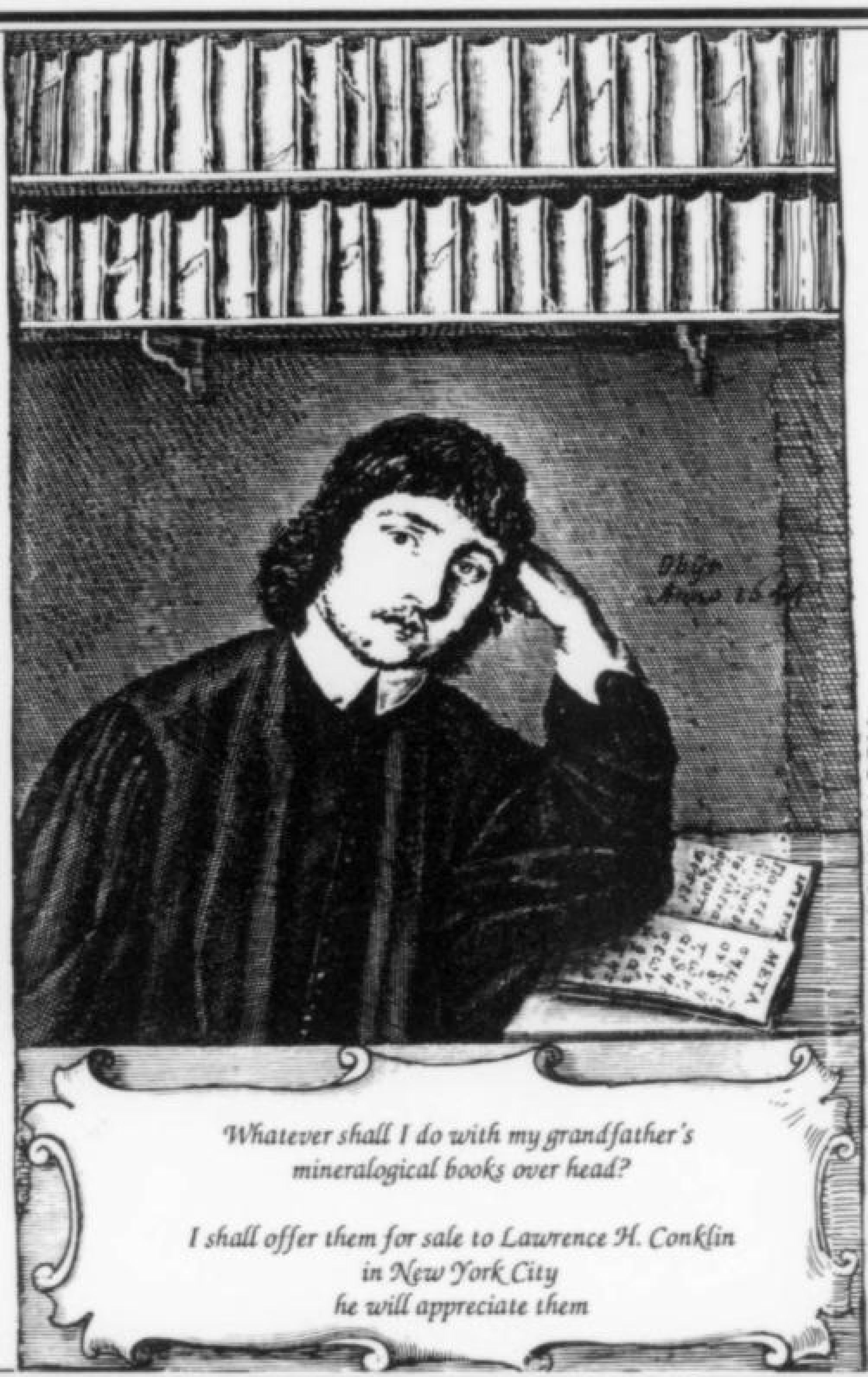

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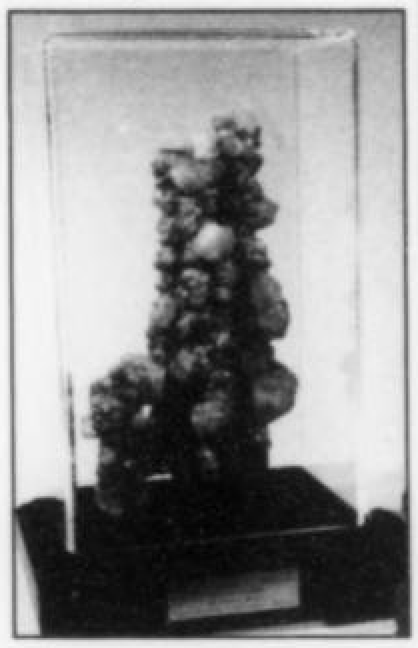

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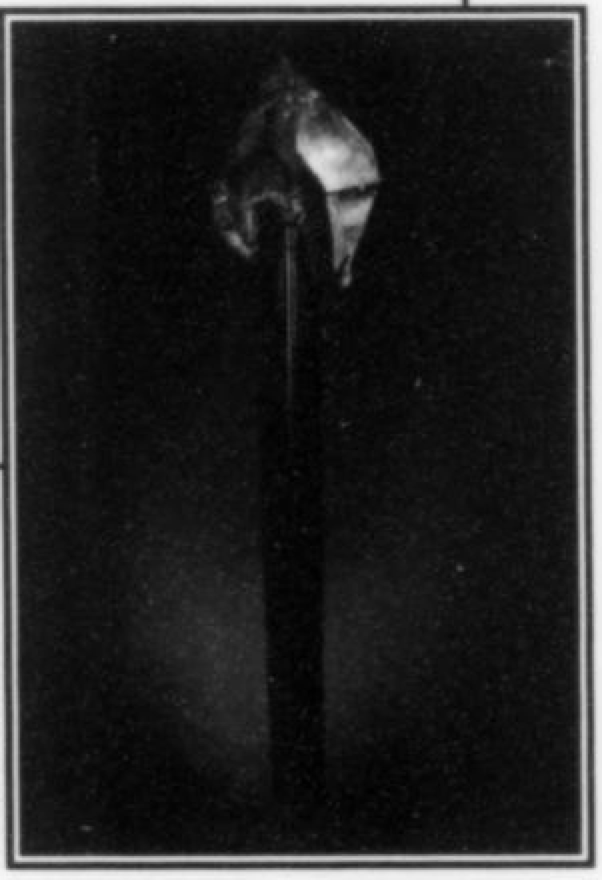

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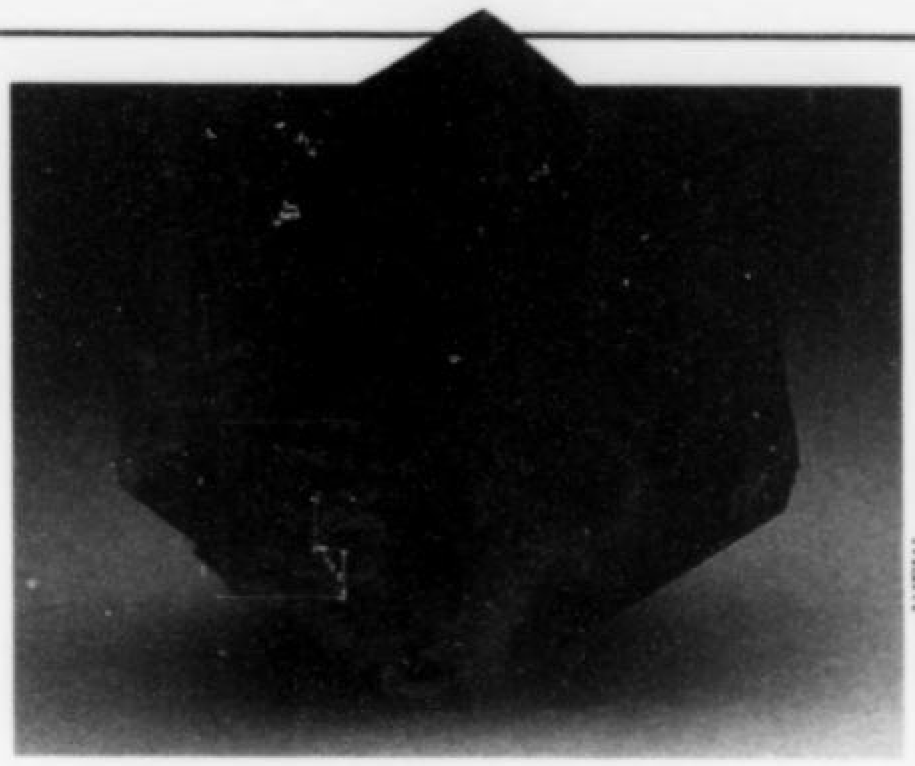

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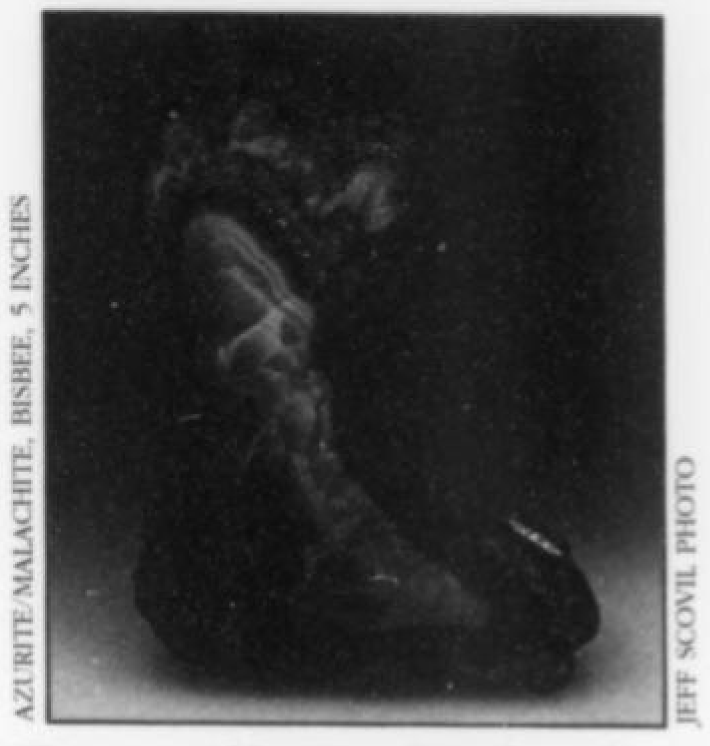
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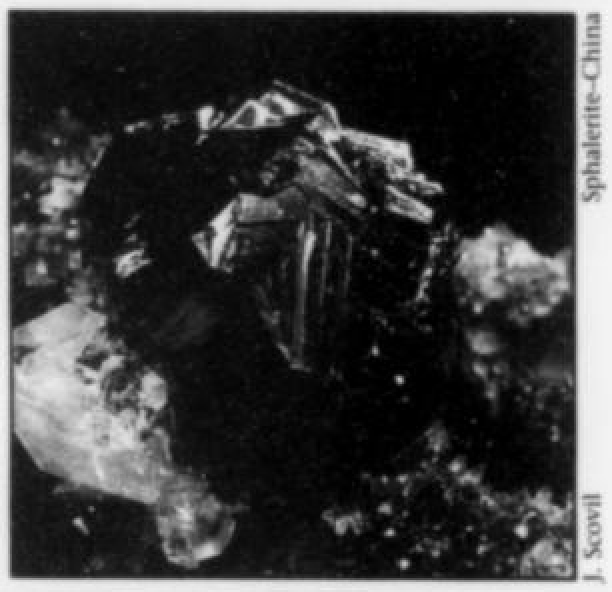
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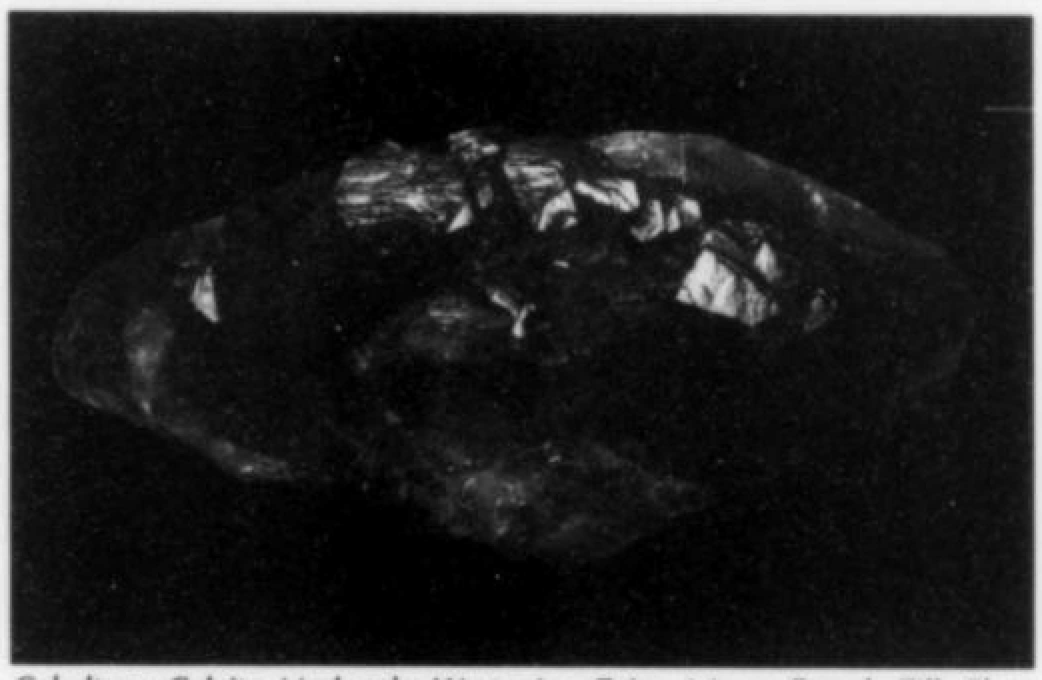
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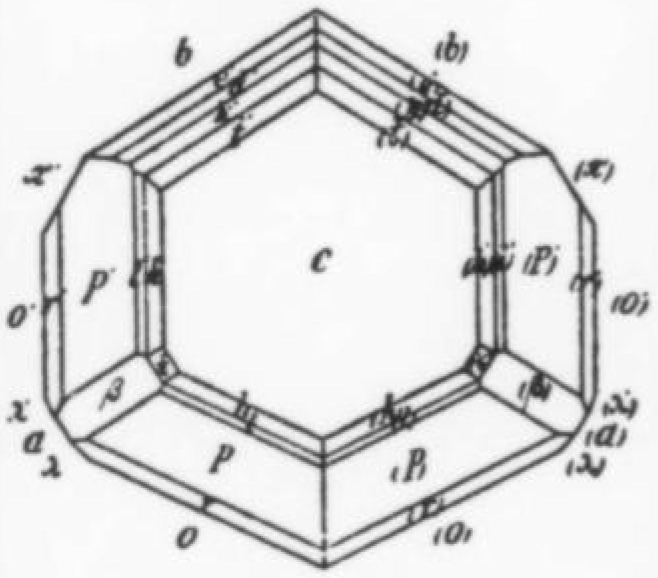

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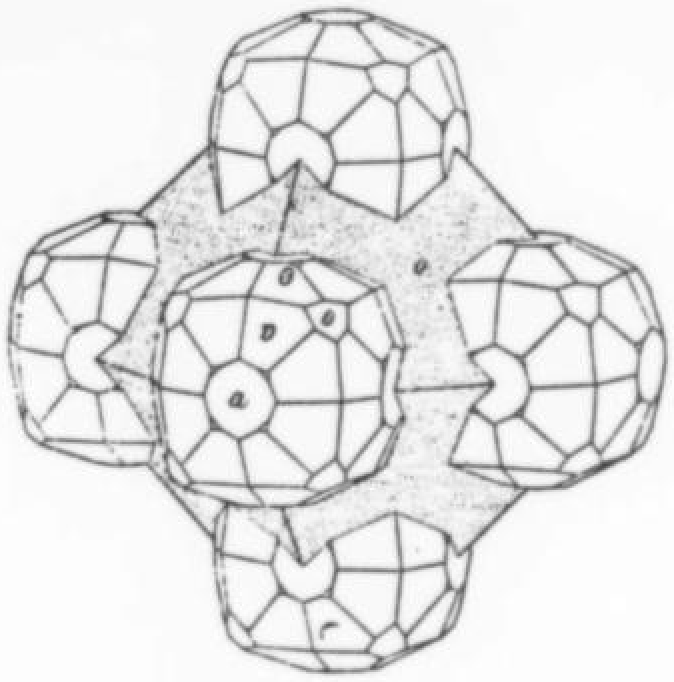

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SYMPOSIUM ON FLUORITE AND RELATED ALPINE CLEFT MINERALS

19TH ANNUAL MINERALOGICAL SYMPOSIUM

10:00 A.M. – 12:00 A.M.
Saturday, February 14, 1998

PROGRAM

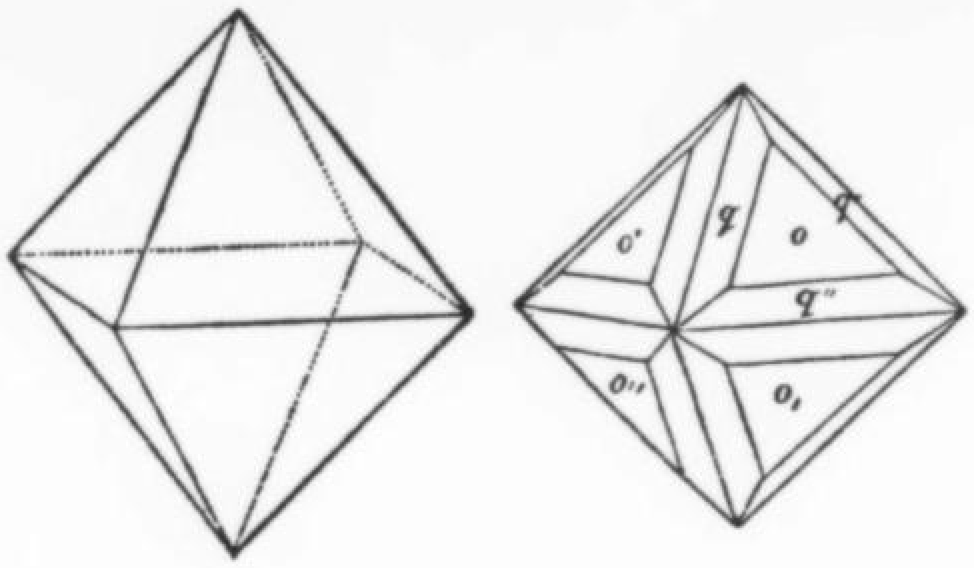
10:00-10:20	Introductory Remarks—Symposium Co-chairperson *Dr. Robert B. Cook*
10:20-10:40	Fluorite from Akchatau and Karaoba, Kazakhstan *Dr. John Rakovan and* *Dr. Christian Schmidt*
10:40-11:00	Pink Fluorite *Mr. Eric Asselborn*
11:00-11:20	Quartz Gwindels *Mr. Eric Asselborn*
11:20-11:40	Highway 51 Quarry, Magnet Cove Arkansas: an Alkali intrusive equivalent of alpine mineral veins *Dr. Henry Barwood*
11:40-12:00	Fluorite in the Upper Midwest, USA *Dr. N. R. Shaffer*
12:00-12:20	Open discussion-nontraditional Alpine cleft-type mineral occurrences—Symposium Co-chairperson *Mr. Beau Gordon*

INTRODUCTION

The 19th annual Tucson Mineralogical Symposium, sponsored by the Friends of Mineralogy, the Tucson Gem and Mineral Society, and the Mineralogical Society of America, is to be held in conjunction with the 44th Tucson Gem and Mineral Show on Saturday, February 14, 1998. Fluorite and related Alpine cleft minerals are the featured minerals at the 1998 Tucson Show and are the subject of the 1998 mineral symposium.

Alpine cleft minerals have been highly sought after by mineral collectors for at least two centuries. The structural environment in which these fascinating specimens formed is related to openings produced by the plate tectonic forces that shaped the Alps themselves. The widely variable chemistry of cleft minerals is thought to be due to their origin from metamorphic fluids derived from the cleft host rocks, which can range from granitic to mafic. Magnificent rutile, brookite, anatase, adularia, sphene, epidote, fluorite and quartz specimens from Alpine cleft occurrences are familiar to most mineral collectors, and the list of associated though less spectacular rare species is impressively long. Pockets of unusually large dimensions (measured in meters) have been found which have produced some of the largest and finest quartz crystals known, many in almost impossible-to-reach sites high on mountain cliffs. One of the most popular and expensive of the Alpine cleft minerals is pink octahedral fluorite, particularly when perched on smoky quartz. Outstanding fluorites of this type were found in Switzerland during the construction of hydroelectric tunnels during the 1950's and 1960's; more recent finds have been in the Mont Blanc region of France.

The papers submitted for this year's symposium describe both the better known, classic Alpine cleft minerals as well as recently described occurrences thought to be geologically equivalent. The concluding open discussion will allow audience input into the generation of criteria for distinguishing Alpine cleft-type mineralization elsewhere and the compilation of a list of other world-wide, probable Alpine cleft-type occurrences. R.B.C.



Pink Fluorite

Eric Asselborn
6 Pavillon
Attignat
F-01340 Montrevel, France

Rose-pink to red fluorite has indisputably been the mineral most sought after throughout the Alps since it was first remarked upon by Father Ermengildo Pini (1739–1825) in the Swiss Alps toward the end of the 18th century.

Pink fluorite crystals are nearly always of octahedral habit, occasionally showing modifying trisoctahedon faces. The rose-pink color, which is due to the existence of YO_2 color centers, disappears upon heating.

A range of colors exists, from brownish pink to carmine-pink, red and violet; some crystals have pink centers and a colorless outer zone, or green cores surrounded by pink. Rarely specimens will show a green/red alexandritescence.

Pink fluorite is not common in the Alps; it occurs almost exclusively in fissures (Alpine clefts) in granitic rocks. Some specimens show individual crystals up to 10 cm, but most crystals measure around 1 cm. The principal Alpine occurrences include the Grimsel and Göschenen regions in Switzerland and the basin of the Argentière Glacier near Chamonix, France.

Pink fluorite is a late-stage mineral of the Alpine clefts, where there has been little oxidation or weathering. Associated minerals are mainly quartz, sometimes also with paper-thin sheet-like crystals of calcite and blocky crystals of adularia. The fluorine necessary for the formation of fluorite has apparently originated from the breakdown of biotite in the surrounding granite (which contains an average of 500 to 1000 grams F per cubic meter of rock).

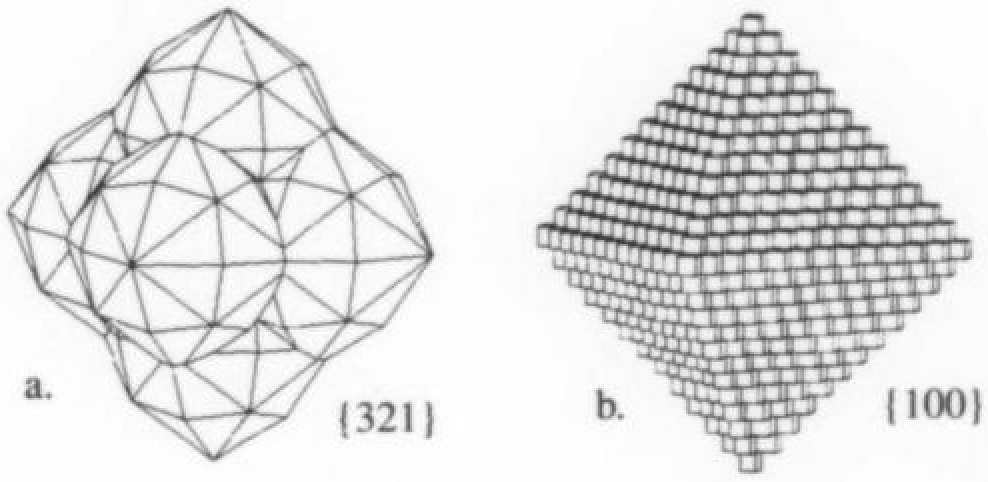
Fluorite from Akchatau and Karaoba, Kazakhstan

John Rakovan
Dept. of Geological Sciences
Virginia Tech
Blacksburg, Virginia

Christian Schmidt
Geo Forschungs Zentrum
Potsdam, Germany

Two granite-hosted, metalliferous W-Mo vein deposits in central Kazakhstan, Akchatau and Karaoba, have produced a wealth of unusual and interesting fluorite specimens that have appeared more prominently on the specimen market since the opening of mineral export from the former Soviet Union.

Several generations of fluorite, often identifiable by color, are found in both deposits. Morphologies include single-form crystals and combinations of the cube {100}, octahedron {111}, dodecahedron {110}, tetrahexahedron {210}, and hexoctahedron {321}. Most examples show some variation on the octahedron. Interesting crystals found in both deposits are made up of multiple crystals of different forms in parallel growth simulating an octahedral morphology. Groups from Akchatau show complete hexoctahedral crystals at the six octahedron corners, with a rough octahedral outline. Similar groups of multiple small cubic crystals are found at Karaoba. The individual cubes are often modified by the octahedron and dodecahedron.



Fluorite colors include brown, pink, blue, green, violet, purple and colorless. These colors have been attributed to trace metals, such as REE's and Mn, defect sites, and combinations of the two. Some of the lavender-colored samples from Karaoba are light-sensitive and will fade with exposure (personal communication, Marc L. Wilson). Beautiful examples of optically visible sector zoning are seen in cuboctahedral crystals from Karaoba. These show green {100} sectors and blue {111} sectors. Particularly striking are samples exhibiting the unusual morphology described above with sector zoning in each individual cuboctahedral crystal. Pronounced concentric zoning in octahedral crystals is also found, typically with dark purple cores and colorless outer rims.

The veins of both Akchatau and Karaoba have complex mineralogies and fluorite is found in association with many other minerals including wolframite, apatite, creedite, bertrandite, rhodochrosite, quartz, pyrite, etc.

Quartz Gwindels

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6 Pavillon Attignat
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Alpine cleft deposits occasionally yield specimens of quartz of a particular habit characterize by a twisted shape. They are known as *quindels* or *gwindels* by the Swiss strahlers, and as quartz *tournés*, *peignes* or *sucres* in France.

A gwindel consists of a parallel aggregate of prismatic quartz crystals repeated in the direction of an *a* axis, and with their *c* axes rotated progressively about the *a* axis. The trapezohedral face is almost always present, and is found highly developed. These crystal aggregates occur with clockwise (right) and with counter-clockwise (left) twists, and consequently are called *dextrogyres* and *lévrogyres*, respectively. Some gwindels are characterized as being *closed*, that is they appear to consist of a single flattened and twisted crystal (called *sucre* in Chamonix), whereas others are considered *open* because they appear more like a stack of subparallel individual crystals, each one turned a bit more than the last so as to approximate an overall twist of the aggregate. In this latter habit the termination points of the component crystals are all separate, unlike in the *closed* habit wherein they may be imagined as having merged to form a composite edge. The intermediate, *semi-closed* habit is the most common.

Gwindels range from colorless to smoky to very dark *morion* color, and very rarely amethystine purple.

Deposits yielding gwindels are found mainly in the Swiss, French and Austrian Alps, in the granitic central massifs, and more rarely in other metamorphic rocks. They are relatively common in the Alpine-type fissure deposit in the Dodo region, Polar Urals, Russia, and occur rarely in fissures in the Corinto district, Brazil.

Gwindels can apparently form in two temperature regimes: an early stage characterized by the closed habit (by a mechanism not currently understood), and in a later stage, growing normal to an original seed-grain to create a *faden*-type crystal.

Highway 51 Quarry, Magnet Cove, Arkansas: An alkali intrusion equivalent to alpine mineral veins?

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Bloomington, Indiana 47405-2208

The Highway 51 Quarry, operated by Mid-State Construction, is located near the southern rim of the Magnet Cove alkalic intrusion. In recent years the quarry has approached to within 0.5 kilometer of the intrusion contact. The quarried rock at this point is a highly altered and fractured Stanley Shale that contains numerous veins, dikes and recrystallized faces along fracture zones. As the quarry has moved near to the Magnet Cove intrusion, the degree of mineralization has increased dramatically.

There are four main types of mineralization found at the Highway 51 Quarry:

(1) **Fracture fillings** and faces on open fractures that contain: quartz, hematite, amphiboles, chlorites, pyrite (octahedrons to 10mm), fluorite, sphalerite, barite, albite, anatase, rutile, micas, calcite, ankerite and kolbeckite.

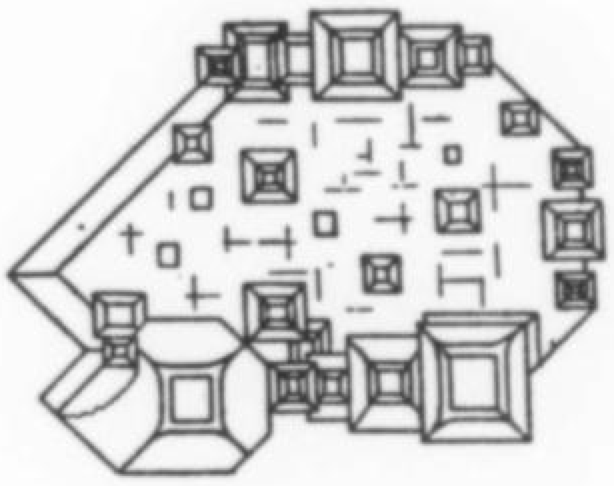
(2) **Carbonate veins**, some probably carbonatites, that contain: calcite, fluorite, quartz, micas, rutile, pyrite, barite and amphiboles.

(3) **Quartz-albite veins** that contain: quartz (smoky crystals to 6 cm), albite, amphiboles, anatase (to 6 mm), apatite, pyrite and green sphalerite.

(4) **Altered lamprophyre dikes** that contain: diopside, amphiboles, pyrite and chlorites.

The hematite/quartz/pyrite specimens with amphiboles and chlorites are particularly reminiscent of alpine veins, with the hematite forming "iron roses." Anatase in both dipyramidal and tabular crystals is locally abundant, and along with rutile forms quite attractive microspecimens. Mineralization in the quartz veins is generally embedded in massive smoky quartz, but where found in open pockets has very nice examples of anatase crystals and apatite. Smoky quartz crystals are found in pockets of iron-stained albite and, while quite clear internally, are etched on the surfaces.

The quarry will eventually penetrate the rim of Magnet Cove and begin mining the border syenites; however, the mining plan calls for operations to simply skirt the intrusion for at least several years. This means continued exposure of the altered zones and the potential for continued collection of good specimen material.



Fluorite in the Upper Midwest, USA

N. R. Shaffer
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Bloomington, Indiana 47405

The theme mineral *fluorite* occurs in all the states surrounding the Great Lakes and especially in Illinois, Ohio, Michigan and Indiana. This may seem surprising because that region has been tectonically stable for much of the Paleozoic. Previous mining in the Cave-in-Rock district of southeastern Illinois has yielded many excellent crystals that grace museums throughout the world.

An outlying region of minor fluorite mineralization is found in Mississippian age limestones in south-central Indiana and northern Kentucky. Fluorite is common as colorless to yellow and purple late-stage crystals. This fluorite often occurs with coarse pink dolomite reminiscent of that from the Tri State lead-zinc district. It is also present in fractures, in chert, and within geodes. A most unusual fibrous form of fluorite replaces calcite and gypsum at one site. Surprisingly, fluorite is rarely found in Indiana's abundant geodes. Based on geologic and fluid inclusion data, these probably result from low-temperature Mississippi Valley-type mineralization.

In northwestern Ohio, southern Michigan and northwestern Indiana fluorite is found in Silurian age dolomites. It is often accompanied by calcite, celestine and sphalerite. Fluorite-rich areas often contain high-fluorite groundwaters. Isotope data suggest that associated celestine and calcite develop from carbonate host rocks. A distinctive iridescent fluorite occurs near Auglaizc, Ohio. Ohio produces distinctive showy specimens of brilliant purple (often zoned) cubes and bright red sphalerite as well as coarse brown crystals. A distinctive gemmy pale yellow fluorite occurs in northeast Indiana. ▣

The Friends of Mineralogy

Who We Are:

Vol 1, No 1, Mineralogical Record, Spring 1970

The *Friends of Mineralogy* was founded in Tucson, Arizona, on February 13, 1970. Its objectives were to promote better mineral appreciation, education and preservation. The chief aims and activities of *FM* include:

* Compiling and publishing information on mineral localities, and important mineral collections.

* Encouraging improved educational use of mineral specimens, collections, and localities.

* Support a semi-professional journal of high excellence and interest designed to appeal to mineral amateurs and professionals, through which *FM* activities may be circulated.

* Operating informally in behalf of minerals, mineral collecting, and descriptive mineralogy, with voluntary support by members.

The Mineralogical Record has agreed to an affiliation with the Friends of Mineralogy whereby it will publish its written material and news of its activities. The *Friends of Mineralogy* will support the *Mineralogical Record*, since the aims of both are similarly educational and directed toward better coordination of the interest and efforts of amateurs and professionals.

Co-Sponsor, with the Tucson Gem & Mineral Society and the Mineralogical Society of America, of the Annual Tucson Mineralogical Symposia.

Chapter News:

Colorado Chapter: *Minerals of Colorado.*
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P.O. Box 11005, Denver, CO 80211-0005

For information about the Colorado chapter contact: Ed Raines, President, 721 Francis St., Longmont, CO 80501; 303-477-2559

Great Basin Chapter: For information about the Great Basin chapter contact: Steve Scott, President, 5690 Park Street, Las Vegas, NV 89129; 702-645-2173

Midwest Chapter: Visit out Web page at:
www.indiana.edu/~minerals

For information about the Midwest chapter contact:
Dr. Henry Barwood, President, Indiana Geological Survey,
611 N. Walnut Grove, S-409-A, Bloomington, IN 47405

Pacific Northwest Chapter: For information about the Pacific Northwest chapter contact Wes Gannaway, President,
1604 Brookwood Dr., Ferndale, WA 98248; 206-384-4209

Pennsylvania Chapter: *Reminiscences of a Mineralogist*, by Arthur Montgomery. Order from: Friends of Mineralogy, PA Chapter.

For information about the Pennsylvania chapter contact:
Roland Bounds, 315 Stamford Dr., Newark, DE 19711-2723;
302-731-8407

Southern California Chapter: For information contact:
Bob Reynolds, President, 2024 Orange Tree Lane,
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Annual Board of Directors meeting:
Friday, February 13, 1998; 8:00 am
InnSuites Hotel, 475 North Granada, Tucson, AZ

Annual General Membership meeting:
Saturday, February 14, 1998
Tucson Convention Center

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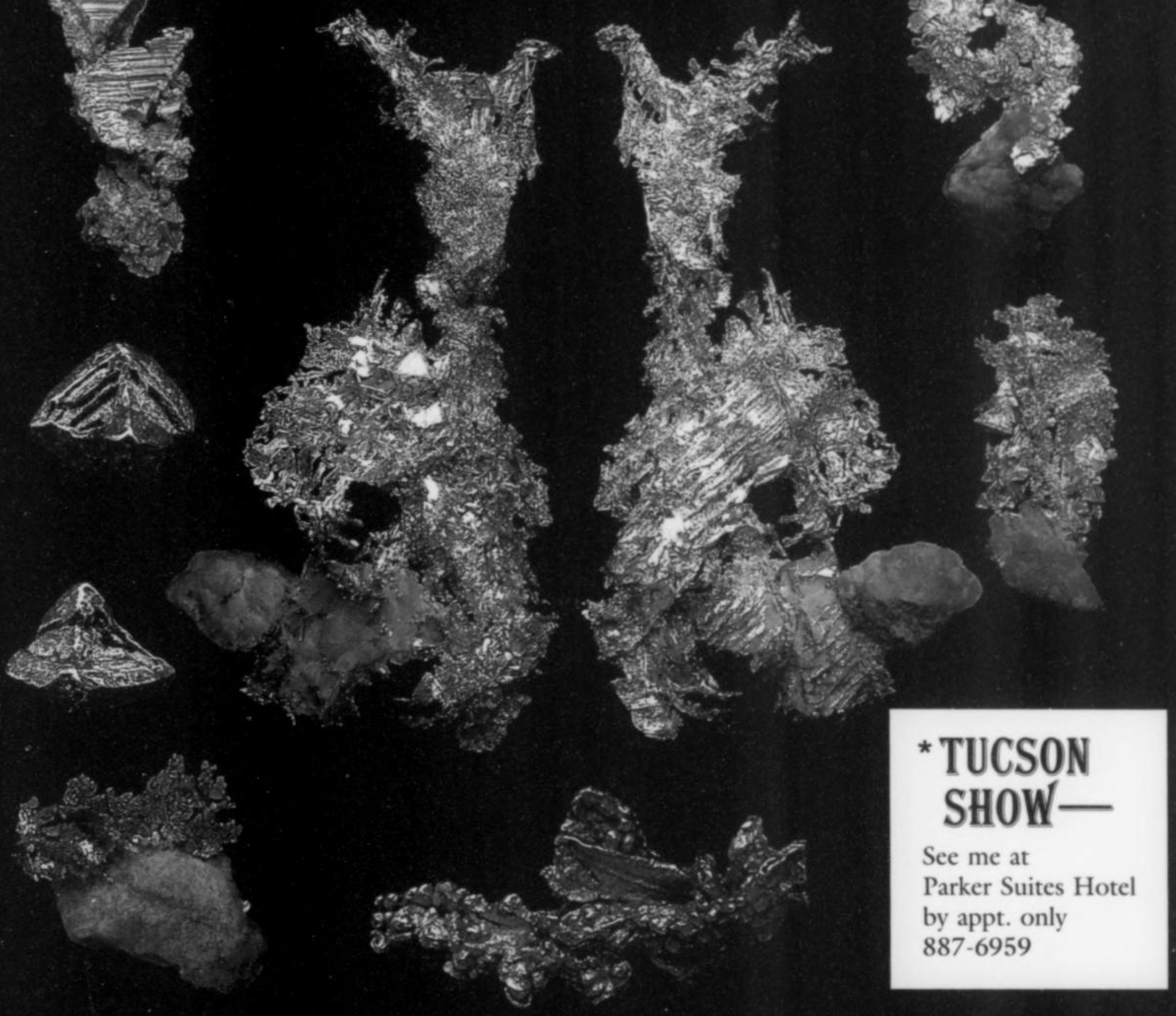

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Dr. Wendell Wilson in his video review in *M.R.*, Nov/Dec 1992, p. 504, says "The collector of aesthetic mineral specimens will find much to savor in Keith Proctor's video catalog of his collection. . . . It really delivers in terms of extraordinary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

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