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the Mineralogical Record

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Articles

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COVER: VIVIANITE, 6.8 cm, from Huanuni, Bolivia. Evan Jones collection; Wendell Wilson photo.

notes from the EDITOR

THE EDITOR ON FRAGMENTATION

As editor of the *Mineralogical Record* I am sometimes forced to serve as referee between conflicting parties. Never has this been quite so difficult as it was with respect to the recent guest editorial by Pete Dunn and Carl Francis ("Dangers to science from species dealers," vol. 17, no. 4, p. 226), and the subsequently published opposing viewpoint by Forrest and Barbara Cureton, rebutted by Dunn and Francis (vol. 18, no. 2, p. 167–168).

My inclination is to let people debate controversial topics, using the *Mineralogical Record* as an appropriate public forum, and to apply relatively limited editorial restrictions (no personal insults, factual errors, *ad hominem* attacks, legally actionable statements, etc.). However, many readers, most particularly rare species dealers, have lately indicated to me that I should (a) enforce the concept of fairness more rigorously, and (b) let the readers know where the editor himself stands on the issues.

Fairness is a rather subjective concept, but I understand what they mean. And I can see that they are as concerned with perceived implications about the support or lack of it present in the editorial office of this magazine as they are about the particular issues being discussed. Therefore, I feel obliged to offer my own commentary on the fragmentation debate.

In my opinion, the Dunn-Francis editorial hit on a very pertinent concept, but did not approach it in quite the best way. It is fairly certain that specimens too small to survive even a single analytical test for species verification, unless visually obvious and distinctive (i.e. good micromounts), have virtually no scientific value. Species collectors are, of course, free to collect as they please, but should not labor under any misconceptions about scientific value. It is worthwhile to point this out to all readers. They will be better informed, better able to fulfill their collecting-dealing goals, and less likely to unknowingly destroy specimens of scientific value through excessive fragmentation.

Where the difficulty arises is in attempting to attach blame for the *existence* of small specimens. Dunn and Francis singled out species dealers, but it is likely that non-dealer collectors and even curators and mineralogists have fragmented specimens from time to time. It can be argued that this was therefore not a fair or even-handed approach, even though some dealers have been guilty of the practice.

Dunn and Francis contended that *naturally* small specimens are irrelevant to the discussion, but in practice, a collector being offered a tiny specimen has no way of knowing how it got that way, and whether or not some human is to blame. Attaching blame is consequently impossible to do with any degree of accuracy, so from the buyer's standpoint there is no valid reason to attempt it. The only practical and fair approach to this problem is simply to question the scientific value of very tiny specimens. Once that is accepted, the motivation to fragment will largely disappear.

It should be pointed out in general that guest editorials are the opinions of the writers only and do not necessarily reflect the opinions of the editor and staff of the *Mineralogical Record*. (When the editor has something to say, he writes under his own name.) Guest editorials provide a valuable forum for divergent ideas, which commonly lead to a better overall understanding of important issues.

NOTICES

Died, Willard Lincoln Roberts, 64, of heart failure, in his office at the South Dakota School of Mines and Technology. Roberts was the Senior Curator of Mineralogy and Invertebrate Paleontology in the Museum of Geology, and a Senior Lecturer in the geology department. He was the principal author of two major books, *Mineralogy of the Black Hills* (1965) and *Encyclopedia of Minerals* (1974), and also 30 articles dealing with the mineralogy of various species. He was responsible, over the years, for identifying at least 20 new mineral species, and in 1974 a new species which he had discovered at the Tip Top mine was named *robertsite* in his honor. Roberts was founder and past president of the Black Hills Mineralogical Society, and a life fellow of the Mineralogical Society of America. A mineralogical scholarship fund at SDSM&T has been established in his name.

Who are these two guys anyway? None other than A. L. McGuinness and Mike Groben, in a photo originally planned to appear with William Henderson's *Microminerals of the Western volcanics* (vol. 16, no. 2) but cut for space reasons. I promised I'd publish it (vol. 16, no. 5, p. 501) and here it is.

The Mineralogical Museum at

◆

Marburg
West Germany

◆

Ulrich Burchard*
Schlosstrasse 6
D-8050 Haindlfing-Freising
West Germany

The Mineralogical Museum at Marburg is housed in a former granary built in 1515. Although intended primarily as a teaching and reference collection, the mineral inventory contains some outstanding specimens from European localities.

INTRODUCTION

The university town of Marburg is situated in central Germany approximately 90 km north of Frankfurt. The museum is located in the northern part of town, near St. Elizabeth's church on Firmaneiplatz. The curator is Dr. K. Schuermann. Exhibits are open to the public Wednesday-Friday, 10 a.m. to 1 p.m., and Saturday-Sunday, 11 a.m. to 3 p.m.; admission is free.

HISTORY

The Marburg mineral collection has close historic ties with the Chair of Geology and Mineralogy at Philipps University. J. G. Waldin (1728–1795) founded a "Hessian Mineral Collection," and by a decree of the Count of Hesse the local mines and smelters were obliged to send him samples of ores. On Waldin's death, his successor, J. C. Ullmann (1771–1821), took over responsibility for the collection.

A period of consolidation followed until 1853, when C. A. H. Girard (1814–1878) managed to acquire a valuable collection of about 4000 specimens formed by Herr Herz of Berlin.

Max Bauer (1844–1917), the world-famous gemstone expert, was director of the Institute from 1885–1915. His successors had no interest in the collection, which was transferred for storage to the old Kornhaus. This venerable building, which is now the museum, was built in 1515 by the Teutonic Order (of knights) as a granary and bakehouse for an estate which has long since vanished. The building had fallen into a serious state of disrepair; but at the instigation of E. Hellner, the new director of the Institute, it was completely restored between 1968–1974, with conversion and extension into a museum. It was opened to the public in 1977.

The collection contains about 105,000 specimens of rocks and minerals, of which 55,000 are cataloged.

EXHIBITS

The mineral collection is housed in two galleries, one above the other, of 426 square meters in total area. The rock collection is kept in a steep space under the roof. The unique atmosphere, not found in any other mineralogical museum, is achieved by a happy marriage of the old building with contemporary exhibition techniques. Fifty-one fitted wall-mounted and free-standing showcases blend in well with the sturdy, handcarved oak beams. Lighting is excellent.

Over 2000 specimens are arranged systematically, with more than 550 mineral species represented. This systematic display is interspersed with special exhibits of Tsumeb minerals, Indian

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*This article is taken, with minor modifications, from the book *Mineral Museums of Europe* (1986) by U. Burchard with photos by R. Bode.

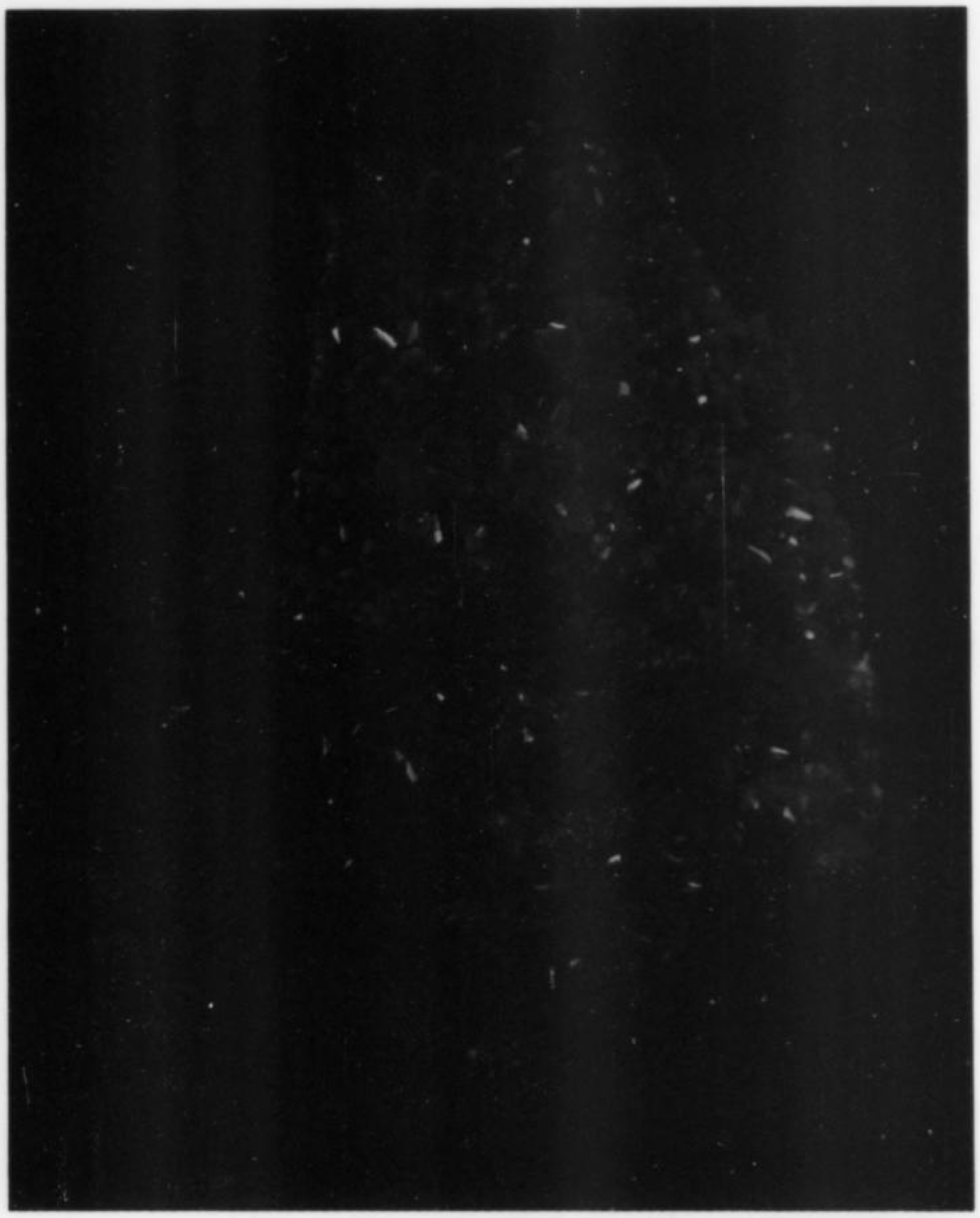
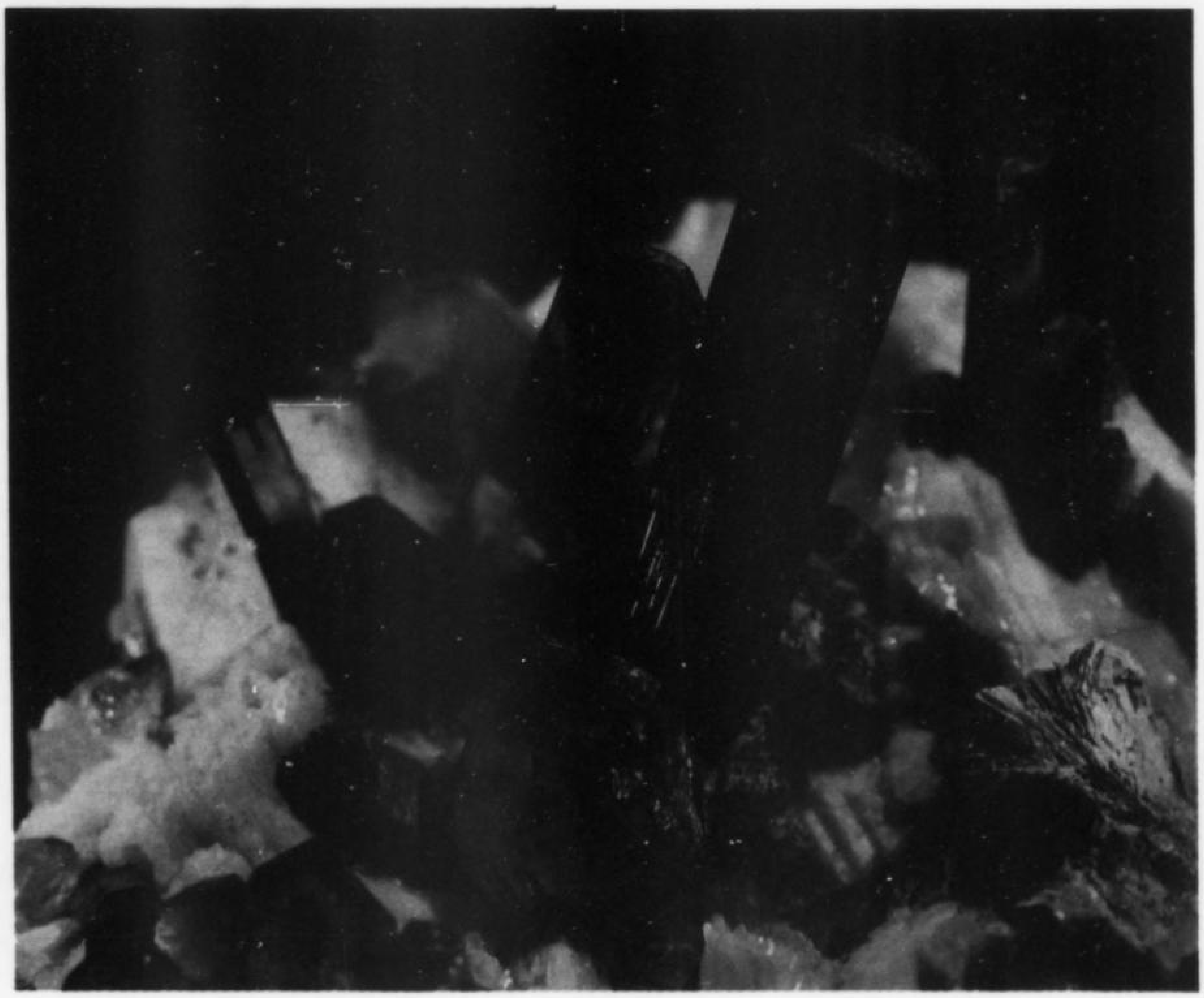


Figure 1. **Rhodochrosite crystal group, 6.5 cm, collected in 1867 at Grube Louise (the Louise mine), Bürdenbach, Westerwald, West Germany. Photo by Rainer Bode.**

BEST SPECIMENS

Excellent	
Rhodochrosite	Grube Louise, Horhausen, FRG
Very Good	
Elbaite	San Piero in Campo, Elba, Italy
Silver	Kongsberg, Norway
Pyromorphite	Friedrichssegen, Bad Ems, FRG
Vanadinite	Taouz, Morocco
Good	
Rose quartz	Brazil
Calcite	St. Andreasberg, Harz, FRG
Prehnite, Axinite	Bourg d'Oisans, France

Figure 2. **Elbaite crystals to 4 cm, on matrix, from San Piero in Campo, Elba, Italy. Photo by Rainer Bode.**



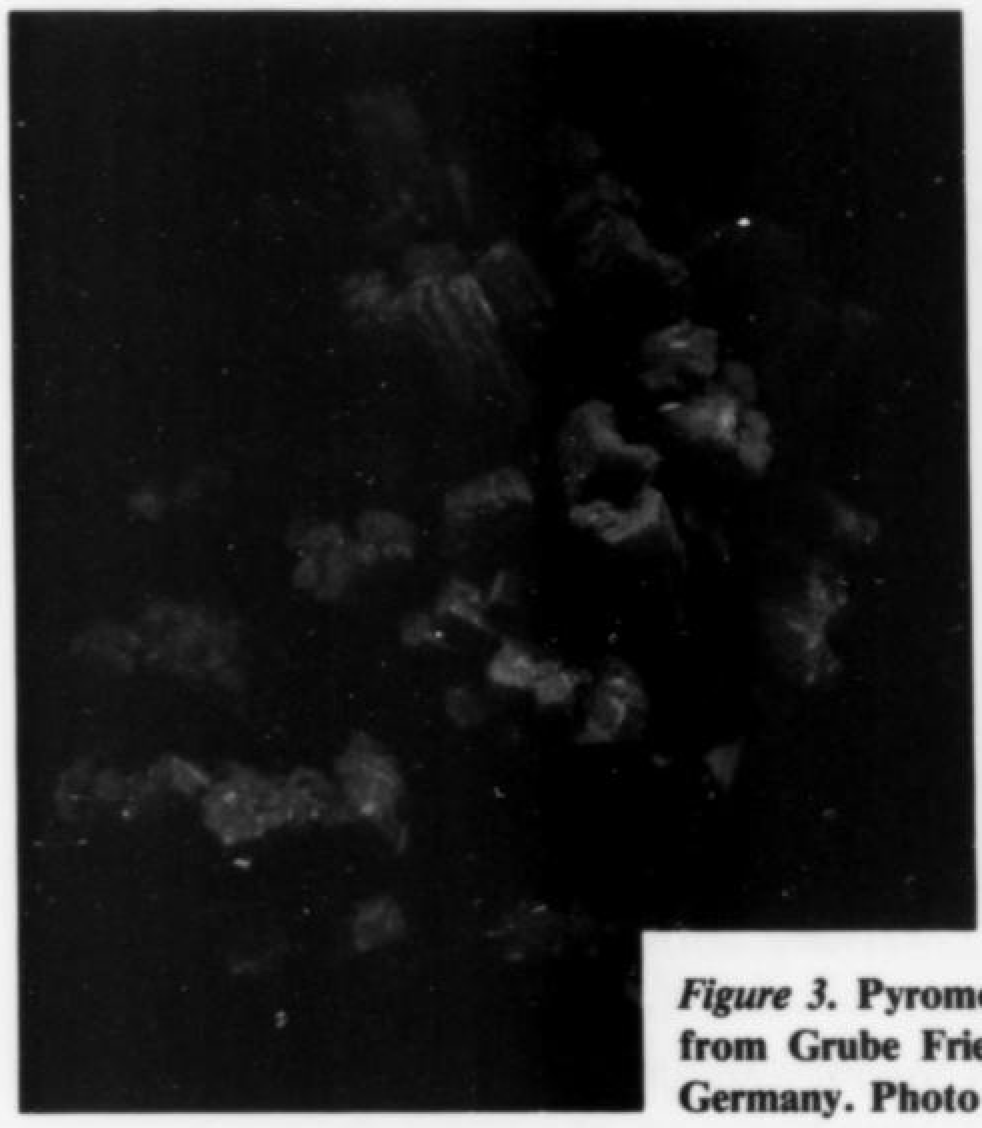


Figure 3. **Pyromorphite crystal group, 8.5 cm, from Grube Friedrichssegen, Bad Ems, West Germany. Photo by Rainer Bode.**

Figure 4. **The former granary on the estate of the Teutonic Order, built in 1515. After renovation, it was opened in 1977 as the Marburg Mineralogical Museum.**

Figure 5. **A view of one of the exhibition rooms of the Marburg Mineralogical Museum.**

zeolites, and meteorites. The collection was primarily intended for teaching, reference, and research within the Institute, and little attempt was made to obtain spectacular display specimens. The superb setting and the wealth of material alone are worth a visit.

MINERALS OF THE CARRARA MARBLE

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For two thousand years, the marble quarries near Carrara have yielded superb white marble for sculptors and a fascinating range of minerals for collectors. Research and specimen collecting continue there today.

INTRODUCTION

Since its birth under Antonio D'Achiardi in the late 1800's, the Department of Earth Sciences at Pisa University (originally known as the Institute of Mineralogy) has been a center for research on minerals of the Apuan marble.

In 1980 the authors began a project to collect and correlate all published and unpublished reports on the origins and characteristics of cavity minerals found in the marble. With the help of *Rivista Mineralogica Italiana* and its editor at that time, Natale Calanchi, a book entitled *I Minerali del Marmo di Carrara* ("The Minerals of the Marble of Carrara") was published in 1982. Some further work has been done since that time and now, with the help of Renato Pagano in rendering an English translation, the full report is ready for publication in the *Mineralogical Record.* Most of the information presented here has been distilled from the extensive bibliography compiled at the university; but a significant portion is the result of personal research by the present authors, with the help of our colleagues.

It should be mentioned that our study does not extend over the entire Apuan formation, but only its northwest portion near the town of Carrara, about 50 km northwest of Pisa in the Apuan Alps. Furthermore, we are dealing only with minerals which have been found in open cavities in the marble. It is true that the massive minerals, scattered through solid marble or forming vein fillings, crusts and veilings, are perhaps more important to a study of the overall petrogenesis. But the cavity occurrences are mineralogically more appealing and are equally instructive in their own way.

Three main quarrying basins have long been established in the Carrara area; these are in the Colonnata, Fantiscritti and Lorano Valleys.

The 24 most important quarries are shown on Figure 5. These will be referred to periodically throughout the mineral descriptions.

HISTORY

Marble quarrying in the Carrara region began over 2000 years ago, following the Roman conquest of the Apuan territories. There is no evidence for the use of Carrara marble by the Etruscans, although they were well known for their mining and quarrying activities and their use of marble and other ornamental stones, especially in Tuscany. Most likely the Etruscans did not control the territory of the fierce Ligurian-Apuan people long enough to become involved in marble quarrying.

Marco Franzini is Professor of Mineralogy at Pisa University; Paolo Orlandi is Curator of the university's Mineralogical Museum; Giovanni Bracci and Domenico Dalena wrote graduate dissertations on the Carrara marble while students at the university.

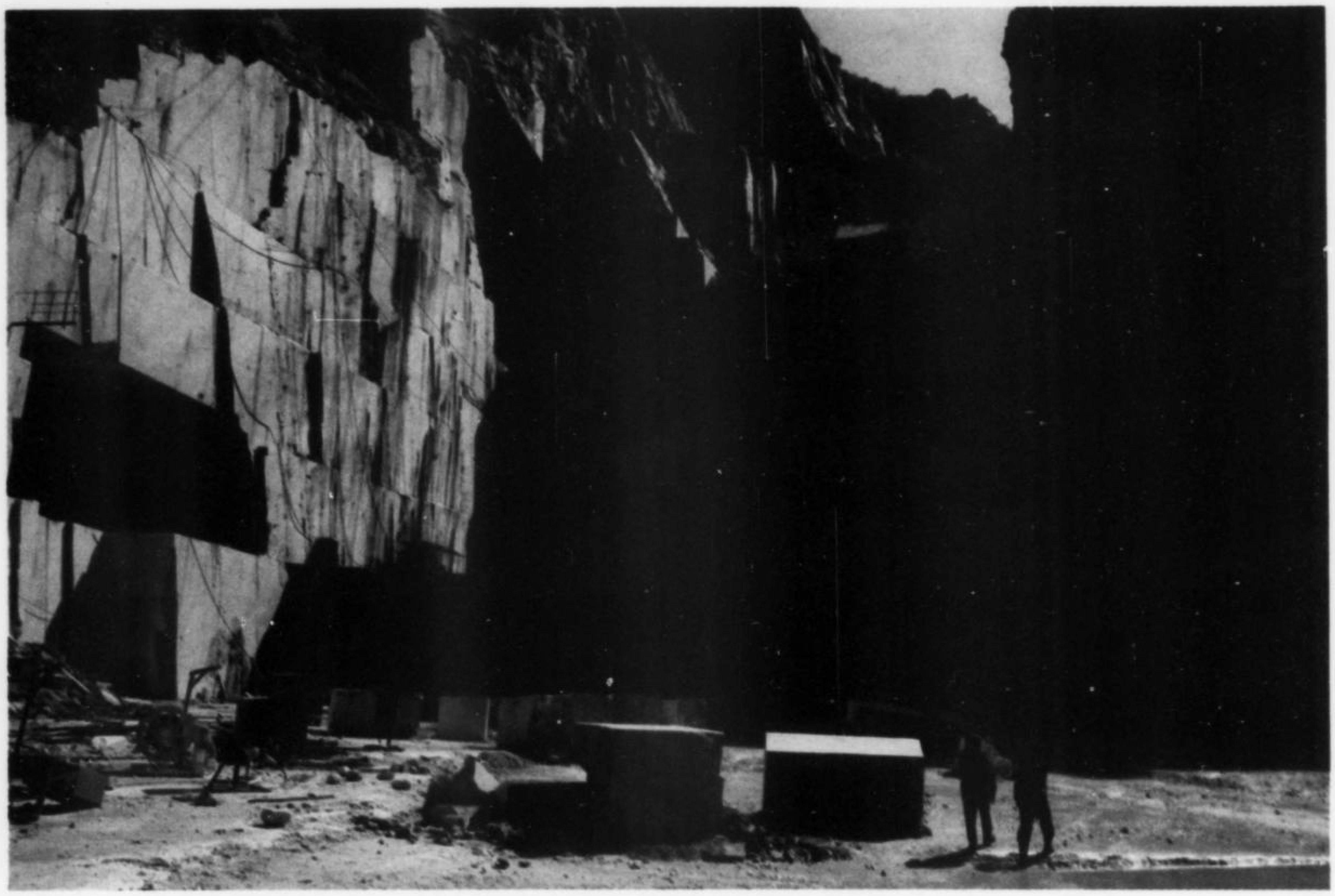

Figure 1. **La Facciata quarry. Bracci photo.**

Roman conquest of the Apuan territory in 180 B.C. did not succeed in immediately subduing the people, who remained hostile and indomitable under foreign occupation. According to one Roman historian, 47,000 Apuans were deported to an area near Naples in order to allow repopulation by friendlier people, including 2000 Roman families who settled at the new colony of Luna (now Luni).

Luna was probably erected on an older settlement, near the seashore about 8 km from the Carrara deposits. The ruins are well worth a visit, as is the neighboring archeological museum which contains displays on the history of marble quarrying and use. During the summer months, theatrical performances are given there in the ruins of the Roman amphitheater.

Because of its situation as a convenient seaport, Luna had access to a widespread market for local marble, and in time became famous throughout the Mediterranean. Classical literature always refers to Carrara marble as *Lunensis,* because it was marketed and shipped from Luna.

It is difficult to pinpoint the earliest date of quarrying at Carrara. It may not have begun until a small marble body on the seacoast about 4 km from Luna was exhausted. This deposit, Punta Bianca, supplied material used in the original Roman constructions at the Luna colony.

After 89 B.C. Rome began a "Romanization" program in all its conquered territories. To be included was the construction of a large number of magnificent public works, which were to bear witness to the greatness and power of Rome. Thus a great demand for high-quality building material, especially white marble, developed. At the same time, the austere customs of earlier years began to moderate, and private residences became more sumptuous as well.

Here we find the first written source of interest: Pliny the Elder quotes Cornelius Nepos as saying that Mamurra, First Citizen of Rome, owned a house in 48 B.C. that had marble-lined walls and monolithic columns of *Lunensis* marble. If this was indeed true, we may conclude that as of 48 B.C. the quarrying operations at Carrara were already sufficiently sophisticated to produce columns in one piece.

Under the rule of Augustus (27 B.C. to 14 A.D.) the demand for fine marble increased even more, and Carrara marble became the building stone of choice throughout the Roman Empire. The *Ara Pacis,* for example, a monument dedicated by Augustus in 9 B.C., contains huge, expertly quarried blocks of high-quality Carrara marble.

The popularity of Carrara marble was due in part to the wide range of varieties available (statuary, "flowered," veined, brecciated, bardiglio, etc.), to the constancy of its quality, scarcity of defects, large size of single blocks that could be extracted, excellent physical and mechanical characteristics, and long-lasting strength and beauty. The Romans were masters at selecting the finest and most durable marbles. Many Roman monuments still preserve their delicate bas-reliefs while the marble decorations on medieval cathedrals a thousand years younger show major deterioration.

Quantitative information on the production of marble in the Roman period is not available, but the volumes were undoubtedly high. Just to build the Trajan Column, erected in a few years, about 1500 tons of marble were used. Each block, before being worked down to cylinders having a diameter of 3.5 meters and a height of 1.5 meters, weighed about 60 tons each. And one should note that the Trajan Column is only one of the elements, rather modest in size, included in the Trajan Forum, which was erected in just six years between 107 and 113 A.D. Furthermore, the Trajan Forum is just one of the building projects using Carrara marble in which the Romans were engaged in that period. We can safely

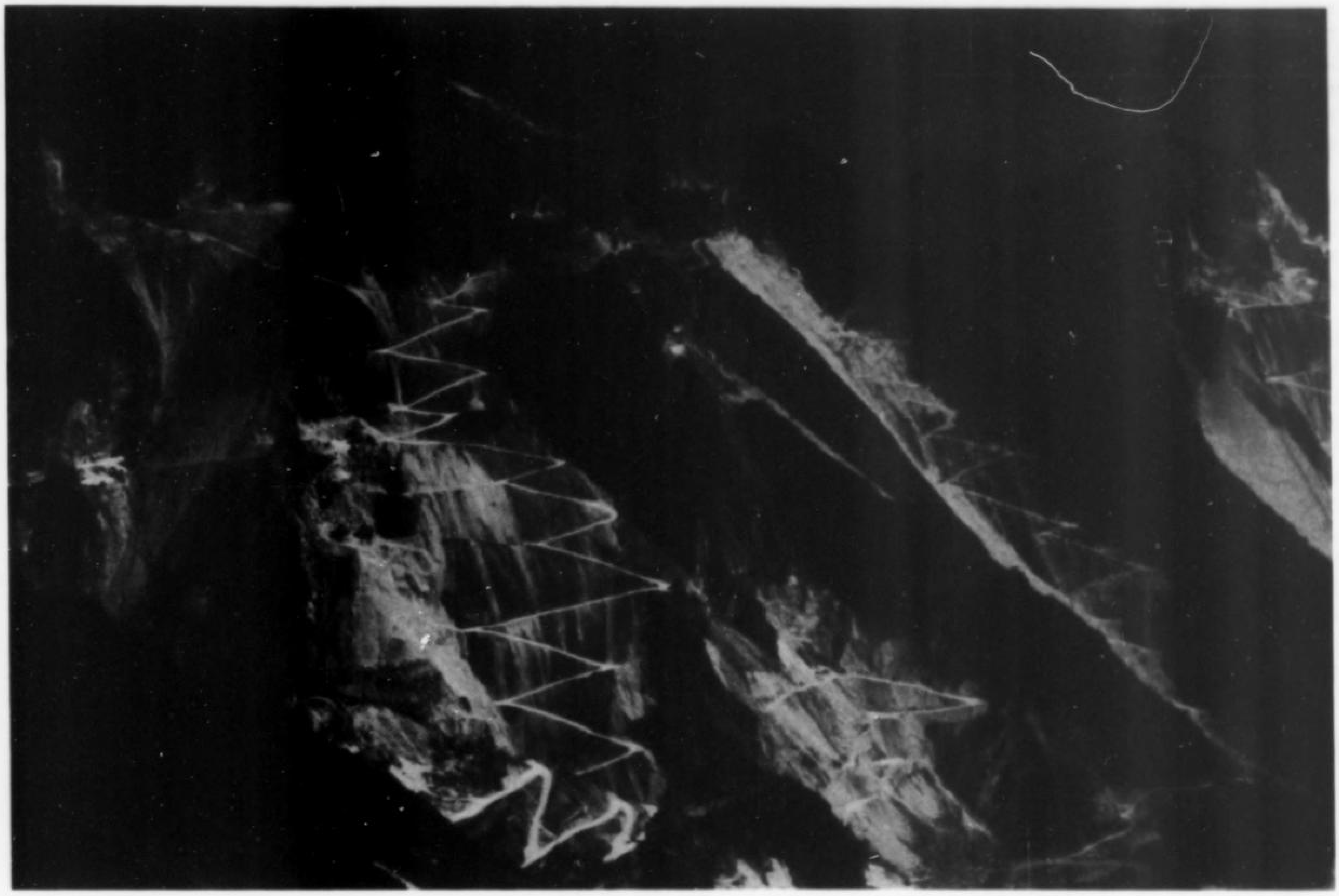

Figure 2. **Panoramic view of the quarries and dumps of Torana Valley. P. Orlandi photo.**

state, then, that the production of Carrara marble in the Roman Age was enormously larger than that, say, in the 15th century, estimated at a few hundred tons per year.

With the decline of the Roman Empire, the first period of great activity at the Carrara quarries began to decline as well, and by the end of the 4th century production had ceased altogether. Nevertheless, the concept of "Lunensis marble" survived in literary tradition well into the High Middle Ages as a symbol of wealth and power.

The Carrara deposits had to wait many centuries before becoming active again. Written records are scarce; in 963 Otto I confirmed the temporal domain of the Bishop of Luni (which included Carrara) but failed to list the marble quarries along with the other local sources of revenue. Later, in 1185, the quarries are mentioned as operational in a grant written by Frederick I, but their status during the intervening two centuries is a mystery.

A revival of architectural interest in Carrara marble in the Middle Ages was confined mostly to scavenging pre-quarried material from

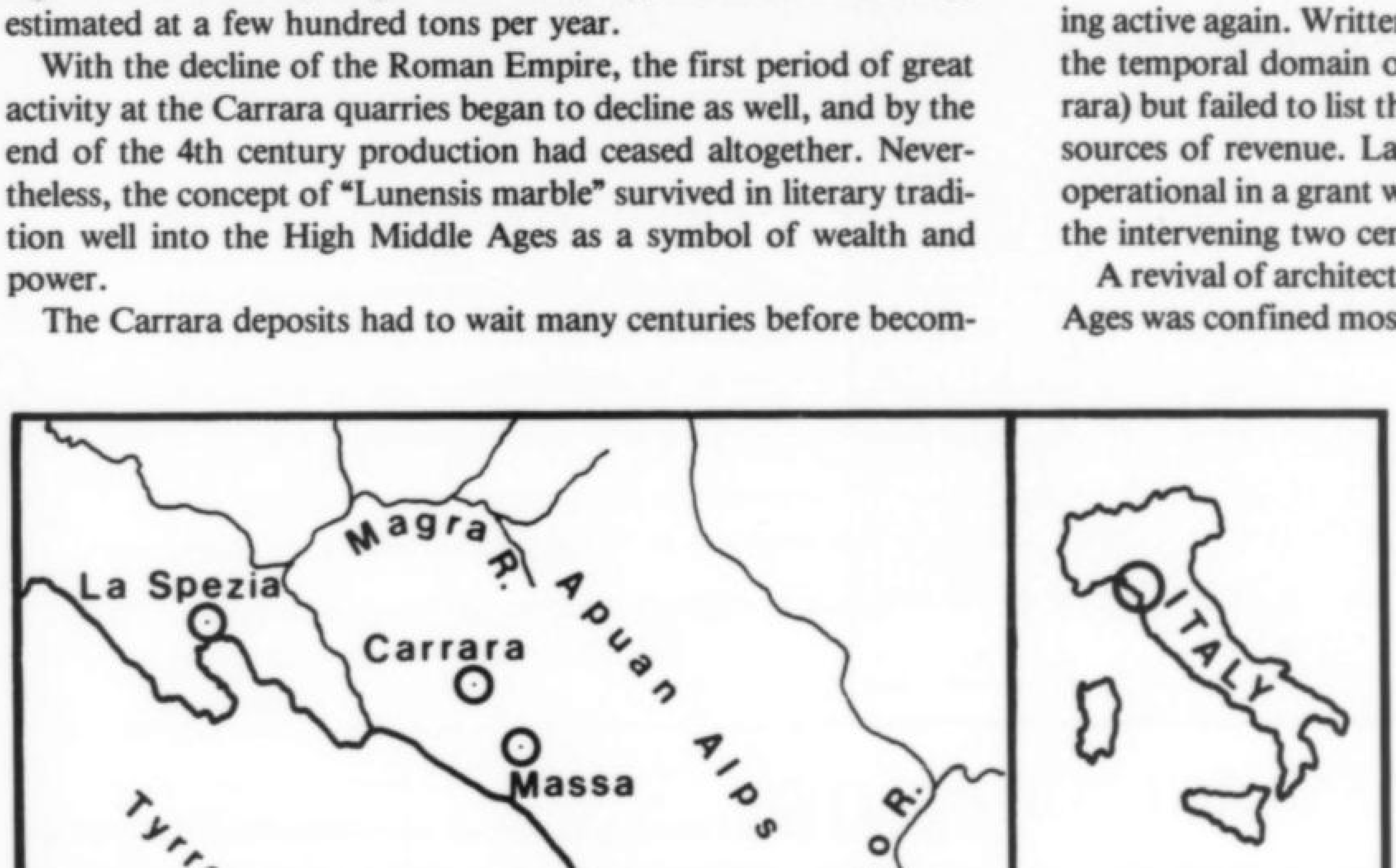

Figure 3. **Location map.**

extant Roman ruins, since the specialized skills for quarrying large blocks of marble had been lost, and the costs of cutting and transporting it from the source were considered too high. A small amount of sculpture in the 13th and early 14th centuries is, however, thought to have been accomplished with freshly quarried Carrara marble.

By the mid-14th century the renewed exploitation of Carrara marble at the quarries was firmly established, and has continued uninterrupted to the present day. Levels of production comparable to those of the Roman Age were not reached until the 19th century, when mechanical and explosives technology reached a high level.

Following the 14th century, the production and use of Carrara marble increased steadily. Great architects and artists of the Renaissance, such as Michelangelo, specified Carrara marble for their many projects. And the centuries have not diminished its appeal. Carrara marble even enjoyed widespread use as marble steps in Baltimore houses during the 1800's; this was largely because sailing ships docking at Baltimore harbor often crossed the Atlantic carrying Carrara marble as ballast.

Today, using highly advanced technology, about one million tons of Carrara marble are quarried each year and shipped around the world, making it the largest world source for white marble. It is ironic for the mineral collector that, before shipment, any and all vuggy areas in the marble which might contain free-growing crystals are meticulously cut away and discarded.

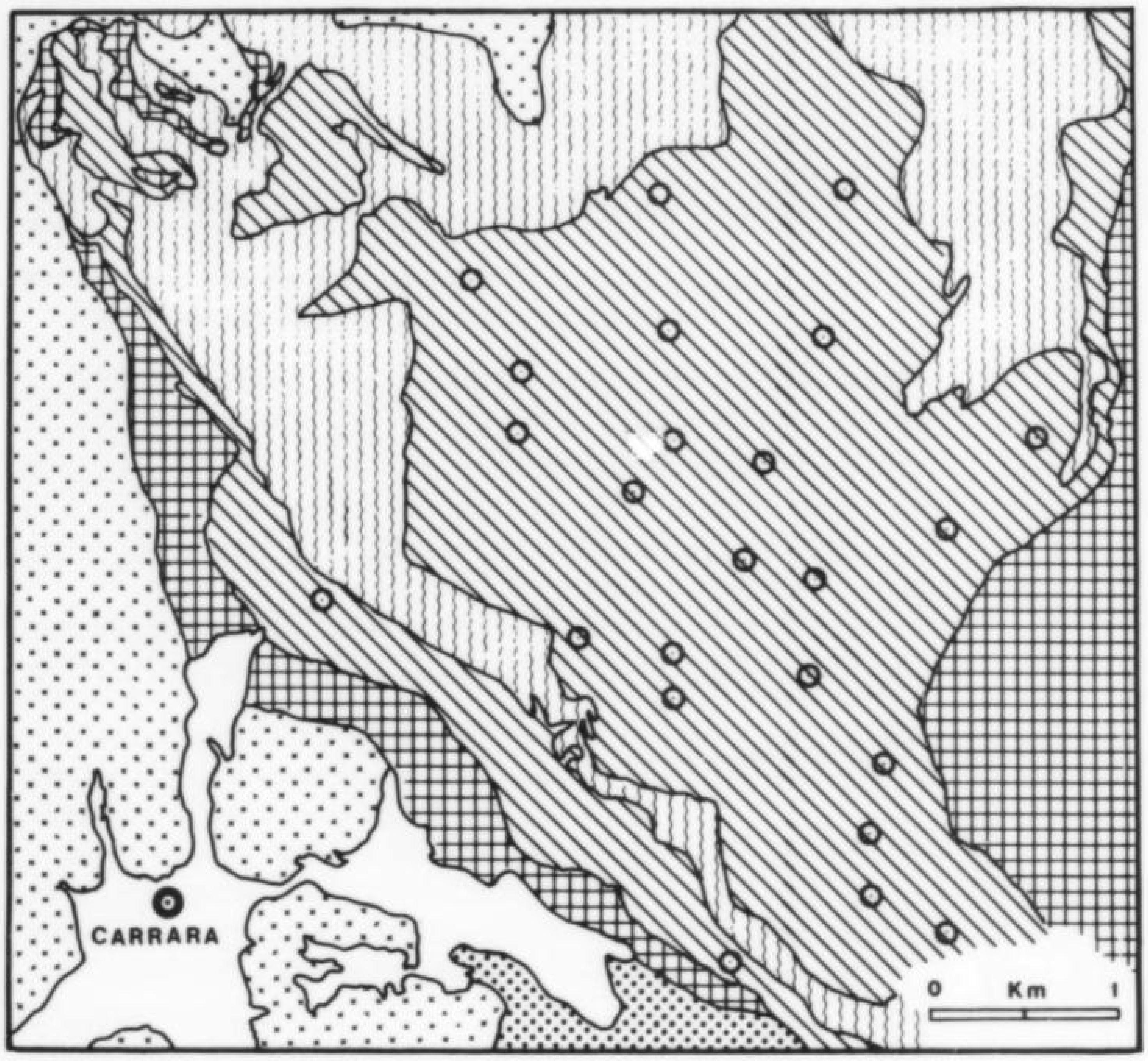

Figure 4. **Geology of the Carrara area.**

GEOLOGY

The Apuan marble formation is lowermost Jurassic in age and is composed of very pure limestone having a typically saccharoidal texture due to metamorphic recrystallization. The color is generally white but may contain variable gray banding in places. The outcrops form part of the Apuan Alps, which belong to the Northern Apennines fold-thrust belt.

The Apuan Alps present an important tectonic "window" in which the most complete structural sequence in the Northern Apennines may be observed. The tectonic-stratigraphic units which are exposed, stacked one over the other by overthrusts, are:

1. (Lowest) The metamorphic Apuan sequences, the so-called "Apuan Autochthon," have suffered repeated tectonism and metamorphism. They consist of phyllites and porphyroids (metasedimentary rocks having the appearance of porphyry) predominantly in the lower part followed by carbonate rocks including the Carrara marble.
2. A series of imbricate structures in metamorphic rocks, among which is the Massa unit.
3. The Tuscan Nappe, an unmetamorphosed and only slightly deformed sequence of sedimentary rocks similar to the Apuan Autochthon.
4. The Liguride sequence, a set of sub-units composed mainly of deep-sea pelagic rocks and ophiolites.

The overthrusts and resulting lower-unit metamorphism have commonly been ascribed to counter-clockwise rotation of the Corsica-Sardinia microplate along an area from Italy to France. This resulted in a collision between continental crust blocks in the late Oligocene, and greenschist facies metamorphism of the underthrust units. Temperatures of 350° to 400°C have been estimated on the basis of Mg partitioning between calcite and dolomite (Crisci *et al.*, 1975).

Two phases of tectonism have been recognized in the Carrara area. In the first phase Apuan sequences were deformed into tight, recumbent folds with flat axial planes, giving rise to a prominent S_1 surface now visible as an axial planar schistosity. In the subsequent phase all of the pre-existing structures were refolded in a low-grade metamorphic environment. It was during this latter phase that cavities in the Carrara marble were created. Bracci *et al.* (1978) divided these cavities into three types:

1. Cavities in factured dolomite masses contained within the marble.
2. Cavities in irregular spathic calcite masses.
3. Cavities in snow-white, coarse-grained marble resulting from a planar schistosity. These have a tube-like shape along the tectonic axis and appear to be a boudinage phenomenon.

For further details on the geology of the Apuan Alps the reader is

1988 34th Annual Tucson Gem & Mineral Show

WHOLESALE DEALER SPACE AVAILABLE AT THE 1988 TUCSON SHOW! SPACE FOR BOOKDEALERS TOO!

WHOLESALE SECTION

The Tucson Gem & Mineral Society's Gem & Mineral Show, acclaimed as the world's finest, is expanding. The February 1988 Show will have a greatly enlarged and relocated wholesale sales area. The upper concourse which circles the Arena of the Tucson Community Center has been selected as the new site for the wholesale area of the Show. This move will more than triple the size of last year's wholesale area. In addition, variable-sized booths larger or smaller than the previous standard booths will be available. There is good access for loading and unloading, plenty of lighting outlets, security will be provided, and entrance to the area will be controlled by the Club and T.C.C. Staff.

The T.G.M.S. Show Committee is seeking wholesale dealers in the following areas: minerals, cut & rough gems, fossils, earth science books, mining memorabilia, jewelry and jewelry findings and any other earth science related field. Wholesale only!

Hours will be from 10–5. It is intended that the area will be catered all day and an air freight company will be on hand to aid your customers with their shipments.

BOOKDEALERS' SECTION

The room that previously held the wholesale area of the Show, in the upper entrance area, will now be the BOOKSELLER section. This is an innovation, and the TGMS hopes to bring together retail sellers of earth science books and magazines in one large hall, rather than being spread out as has been the case previously. Hours will be regular show hours.

The Show for 1988 will be held on February 11th, 12th, 13th and 14th with set-up on the 10th. The Tucson Gem & Mineral Show has over 130 Gem, Mineral and fossil dealers and utilizes over 80,000 square feet of the Tucson Community Center for its displays and dealer booths. Most of the world's leading museums attend and bring outstanding displays for the Show. The Show has dealers and buyers from almost every major country in the world including China and Russia in attendance. There are also fine lectures, symposia and a Meet the Authors program. Last year's Show attendance set a record with over 26,000 people!

INTERESTED? Then fill out the application below and mail it in right now. You will be sent a packet of information and a request for references. If your application is accepted you will be sent a contract by mid-September and an invitation to become a part of the Tucson Show. All applications will be responded to.

Big dealers, small dealers, foreign and domestic, are all invited to apply! The TGMS wants this to be your most successful show ever – Join us!

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(5-foot minimum in Wholesale; Booksellers choose 14 or 20 feet)

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Bookseller Chairmen:
George Balfe
Pat McClain

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NEW

PASADENA '87—SATELLITE SHOW

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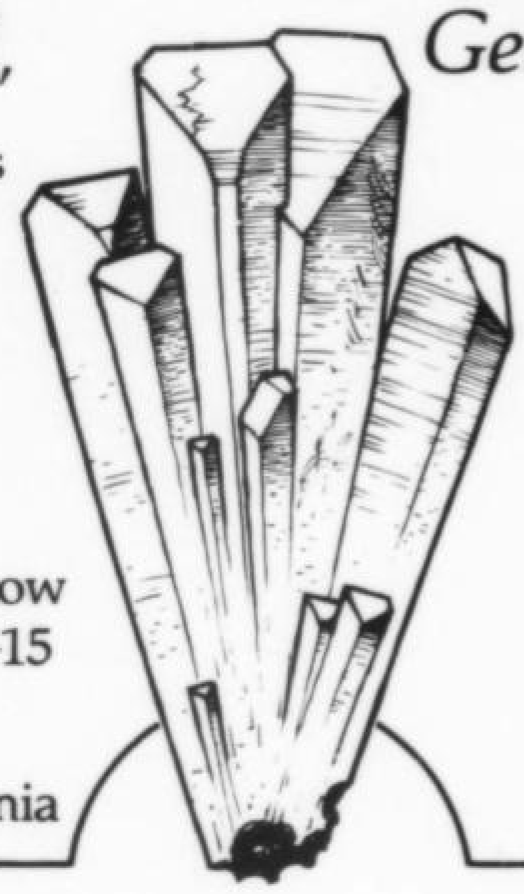

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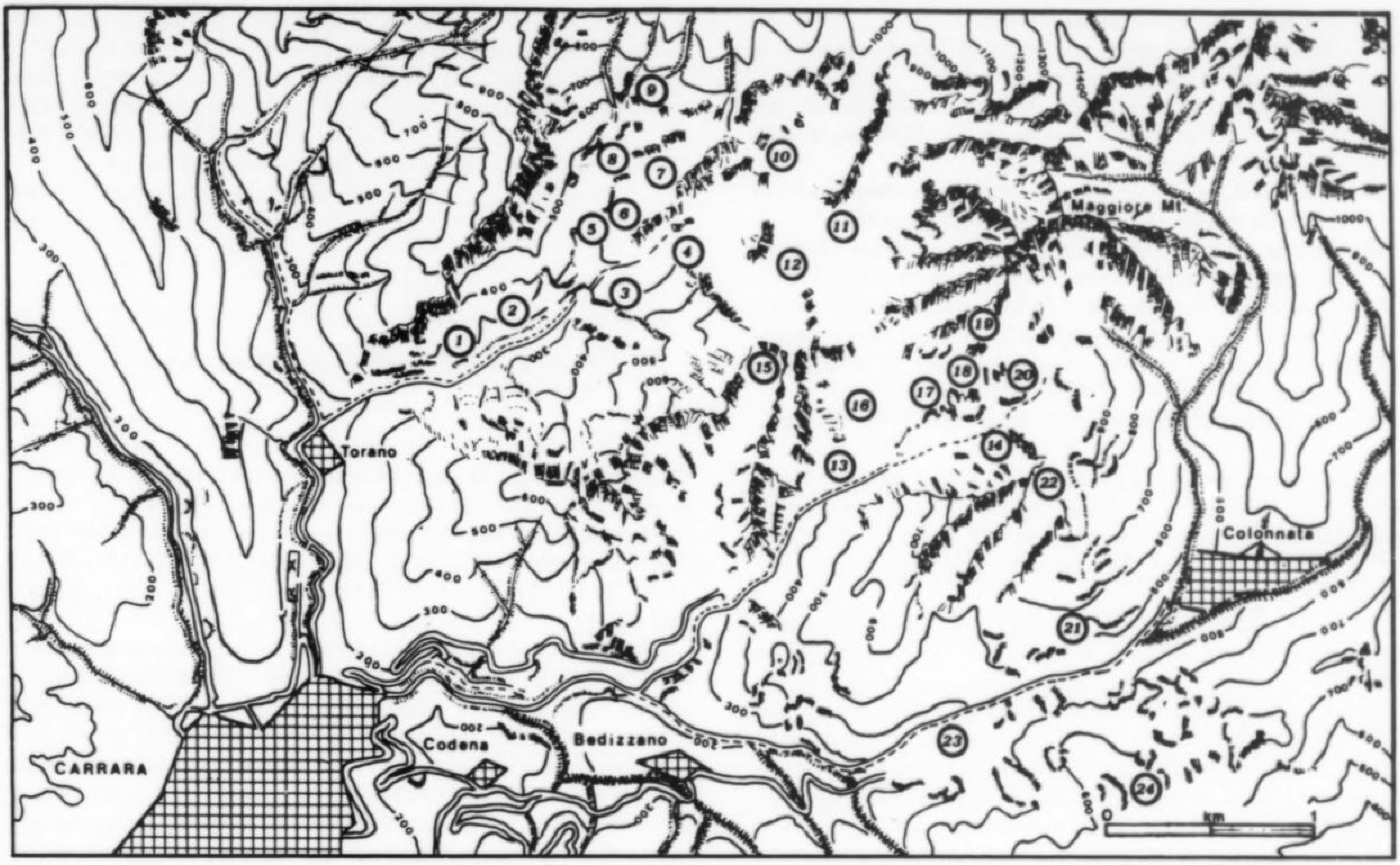

Figure 5. **Map showing the most important quarries: (1) Crestola, (2) Pianello, (3) La Piastra, (4) Battaglino, (5) Bicchieri, (6) La Facciata, (7) Fossa degli Angeli, (8) Lorano, (9) Pradetto, (10) Colle Stretto, (11) Ravaccione, (12) Polvaccio, (13) Galleria di Fantiscritti, (14) Tecchia, (15) Val Bona, (16) Lucchetti, (17) Fabbricotti, (18) La Tagliata, (19) Carbonera, (20) Montecatini, (21) Calagio, (22) Campanili, (23) Artana, and (24) Gioia.**

referred to the specialized literature, particularly Carmignani and Giglia (1975a, 1975b, 1979) and Carmignani, Giglia and Kligfield (1975). For more on petrography and mineralogy see Crisci, Leoni and Sbrana (1975). For more data on chemistry, petrology, mineralogy and economic aspects of the various Apuan marble varieties see *I Marmi Apuani – Schede Merceologiche* (1980), published by Regione Toscana-ERTAG.

THE CAVITIES

Giovanni D'Achiardi, a pioneer researcher in the Carrara area, wrote in 1905:

> The marbles of the Apuan Alps contain many minerals scattered through the calcareous mass and held inside cavities. . . . The study of thin sections under the microscope shows that the abundance of minerals scattered through the marble increases from the statuary [white] varieties to the colored and particularly the multicolored varieties. The abundance of crystalline cavities goes in the opposite direction; they are more abundant in the white varieties.

In that same year Arturo Giampali wrote:

> Cavities, though present in white marbles of the upper lens, reach their greatest development in the white marbles of the lower lens where accessory minerals are more sparsely distributed.

From these words one can deduce the reasons for the particular beauty of Carrara minerals: the snow-white marble matrix and the limited quantities of accessory minerals which therefore occur as exquisitely developed isolated crystals rather than confused aggregates.

The cavities are relatively rare. They are varied and irregular in shape and sometimes rather extensive and channel-like. Lining the inside surfaces are very small, limpid calcite crystals which serve as the esthetic matrix for a wide variety of mineral species.

Clues to the presence of nearby cavities are scarce and subtle. It is only through long experience that collectors and mineralogists learn to read the signs. In any case, cavities are so rare that they are almost never met with on the open mountainside away from quarrying operations. The availability of cavities is therefore dependent in large part on quarrying activities and on the excavation techniques employed. Modern techniques, being very efficient, produce much less waste rock than the ancient methods and leave less for the collector to pick over. This is not really meant as a criticism of modern operations which, like the old, are basically a search for beauty rather than "ore." Still the idea that most cavities are found as by-products of ancient mining lends a certain charm to the specimens.

MINERALOGY

Historical Overview

Numerous mineral species have attracted attention at Carrara over the centuries, particularly quartz and calcite. Specimens, from time to time, would find their way into the hands of mineralogists and published studies would result. A thorough listing may be found in the bibliography to this article, but a few of the more historically important works are as follows:

1597 – Del Riccio mentions quartz crystals.
1820 – Repetti describes seven species (most found imbedded in marble rather than in cavities).
1872 – D'Achiardi describes seven different cavity species and several from a massive marble in his *Mineralogia della Toscana* ("Mineralogy of Tuscany").
1911 – D'Achiardi, in his memoirs, gives exhaustive descriptions of 16 cavity species and others from massive marble.
1920 – Pelloux, in a review of the literature, mentions 17 cavity minerals and several others from massive marble.
1976 – Carobbi and Rodolico, in their important reference work *I Minerali della Toscana,* mention 26 different cavity species.
1982 – Franzini *et al.* describe 48 cavity species (3 of doubtful status).
1986 – The present work, in which 57 cavity species are reported.

Judging from the dates in the above list, and in the full bibliography, it can be seen that the growth of knowledge has progressed somewhat discontinuously (see also Table 1). Peaks of activity occur in the late 19th–early 20th centuries and again in the past decade.

The recent renewal of interest is in part due to improvements in experimental instrumentation now available to mineralogists. But a significant factor must also be the changing attitudes of mineralogists who now feel more inclined toward field work than in the past. Also, there is an increasingly numerous class of sophisticated amateur mineralogists combing the dumps daily for specimens of interest. As a result, laboratory examinations previously requested only rarely are now carried out by the hundreds each year. It seems likely, therefore, that interesting new discoveries will continue to be made.

The Minerals

A total of 57 mineral species have been described from cavities in the Carrara marble (see Table 1). Three of these are considered doubtful because of inadequate original descriptions and because they have not been observed on any of the several hundred specimens examined for this study.

The minerals listed below and on Table 1 are arranged according to Strunz's *Mineralogische Tabellen* (1978); the chemical formulae are from Fleischer (1983).

The dates given on Table 1 for the first reported occurrence of each species are in some cases subject to debate. We have not attempted to identify the first report for the long-known species such as calcite and quartz. Some dates may seem rather recent, but early references commonly do not distinguish between occurrences in massive marble and in open cavities; we have chosen only those which clearly specify cavities as the source.

Following each description of a species in the text we have given a list of numbers keyed to entries in the bibliography. These descriptions, supplemented by the authors' personal knowledge, have been combined to produce the present summary.

As mentioned earlier, this report deals only with cavity minerals. However, for the sake of completeness, the following list of species which have been found in massive marble is presented: sulfur, sphalerite, colusite, pyrite, magnetite, hematite, rutile, quartz, dolomite, gypsum, zircon, epidote, tourmaline, amphiboles (?), muscovite, biotite, chlorite, scapolite (?), orthoclase and albite.

Citations referred to "D'Achiardi" (no first initial) are for Giovanni D'Achiardi; Antonio D'Achiardi, his father, is referred to as "A. D'Achiardi."

Native Elements

Sulfur S

Sulfur occurs generally as small masses lacking a well-defined crystal habit and more rarely as very clear crystals, very small in size (2–3 mm) with typically flat and bright faces. Crystal size is inversely related to richness of forms and perfection of faces.

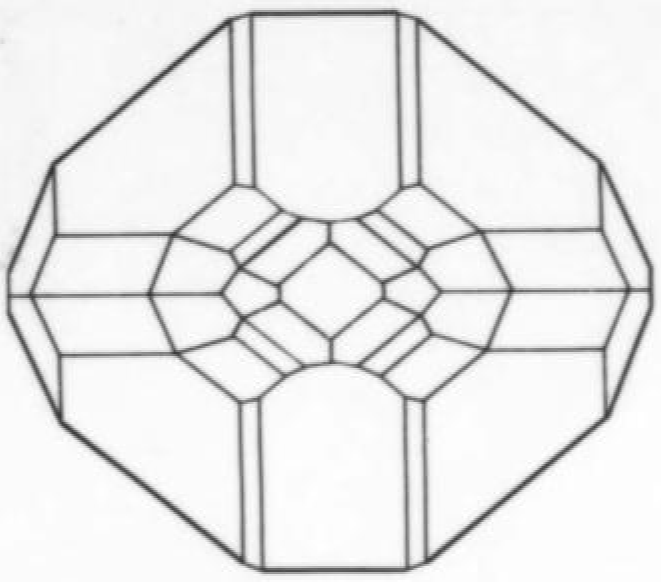

***Figure 6.* Sulfur crystal drawing after D'Achiardi (1905b).**

Manasse (1904) and D'Achiardi (various studies) recognized the following forms: {117}, {115}, {114}, {113}, {112}, {111}, {331}, {313}, {135}, {131}, {110}, {101}, {011}, {013}, {031}, {010} and {001}.

Giampaoli cited examples of sparkling surface features on sulfur crystals and the presence of many small channels and variably shaped holes occurring sometimes so frequently as to make the small masses almost spongy; he also reported a specific gravity of 1.96, lower than that quoted in the literature, and different from the 2.03 reported by A. D'Achiardi. The most frequent associations are quartz, albite, dolomite and gypsum; sulfur has sometimes been observed as inclusions in gypsum. As noted by D'Achiardi, this mineral is most common in the following quarries: Lorano, Fossa degli Angeli, La Piastra, Crestola, Ravaccione, Poggio Silvestro, Belgia and Calagio.

Concerning the origin of sulfur in marbles, D'Achiardi, taking up again a hypothesis of his father, wrote:

> A. D'Achiardi thought sulfur probably originated from the decomposition of organic matter in the original limestones, which later became metamorphosed into marble. Owing to this decomposition, hydrogen sulfide was presumably created first (its presence is confirmed by the bad small often given off by Apuan marbles when broken) especially in the vicinity of cavities; and then, through oxidation, native sulfur formed.

We agree with this hypothesis, which is confirmed by the sulfur isotope studies of Cortecci and Orlandi (1975).
Bibliography: 5, 11, 12, 26, 31, 32, 34, 49, 52.

Sulfides and Sulfosalts

Chalcocite Cu$_2$S

The presence of this mineral in cavities is uncertain; it has never been observed by the authors. Giampaoli described it as follows:

> It occurs very rarely as very thin microcrystalline veins associated with malachite. It has a lead-gray color and a metallic luster; it is readily identifiable because of its softness, being easily cut with a knife, and in the case of small splinters for its fusibility in a candle flame.

These observations do not seem sufficiently unambiguous to guarantee the presence of chalcocite among the cavity minerals.
Bibliography: 32, 34, 52.

Digenite Cu$_9$S$_5$
Bornite Cu$_5$FeS$_4$

We are listing under the same heading these two species because they have always been found closely associated.

We have never observed distinct crystals of either phase, but only small shapeless masses a few millimeters in size, characterized by a vivid metallic luster and bluish violet color. The samples examined lack precise locality data.

It is practically impossible to distinguish these two species without sophisticated analytical techniques.

Bibliography: 47, 52, 53, 56.

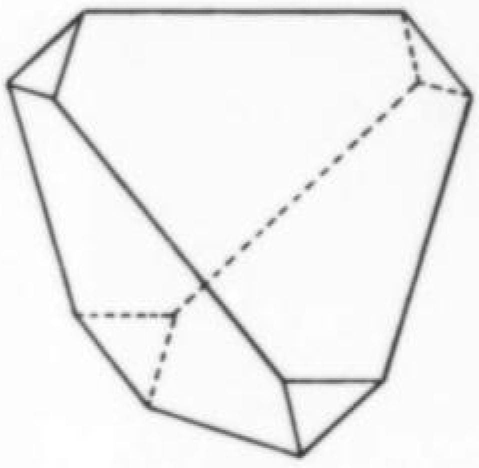

***Figure 7.* Sphalerite crystal drawing showing first-order and second-order tetrahedrons, after D'Achiardi (1905b).**

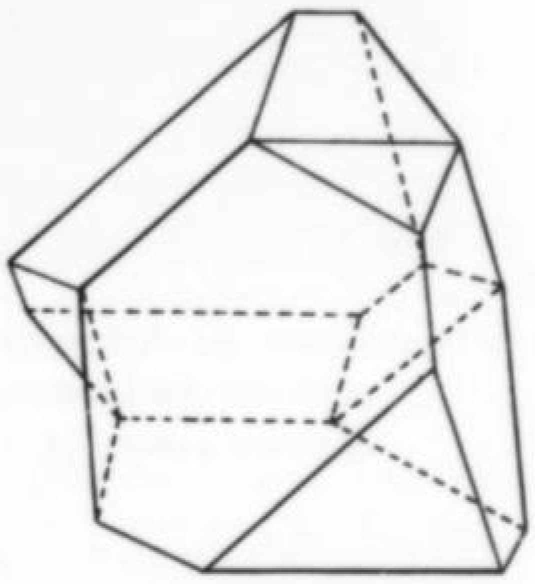

***Figure 8.* Sphalerite crystal drawing showing a twin on (111), after D'Achiardi (1905b).**

Sphalerite ZnS

Jerwis reported sphalerite for the first time in 1874, and it was later described in detail by various authors such as Giampaoli, D'Achiardi and others. Sphalerite is the most interesting and abundant of the cavity sulfides.

It occurs commonly as crystals with tetrahedral habit, often twinned, with colors ranging from light yellow to very dark brown and, on rare occasions, ruby-red. The yellow and red varieties are commonly transparent and brilliant; the very dark crystals are opaque and have a resinous luster.

Although the crystal size rarely exceeds half a centimeter, the perfectly developed tetrahedrons possess a rare and subtle beauty on their snow-white marble matrix.

Sphalerite occurs associated with nearly every mineral found in the marble cavities, but most frequently with quartz, dolomite, gypsum, pyrite and galena; epitaxial overgrowths have been observed with wurtzite and colusite crystals from the Lorano quarries.

Sphalerite is a relatively common mineral, widespread in nearly every quarry; Giampaoli cites the Torrione quarry as particularly rich in this mineral. The present authors have observed that red crystals come mostly from the Fantiscritti basin, while honey-yellow samples, more or less amber-colored with almost always a tetrahedral habit, are typical of the Lorano basin.

Besides tetrahedrons (positive and negative), which are the most common forms and usually the best developed, the dodecahedron, tristetrahedron and cube have also been recognized among the principal forms.

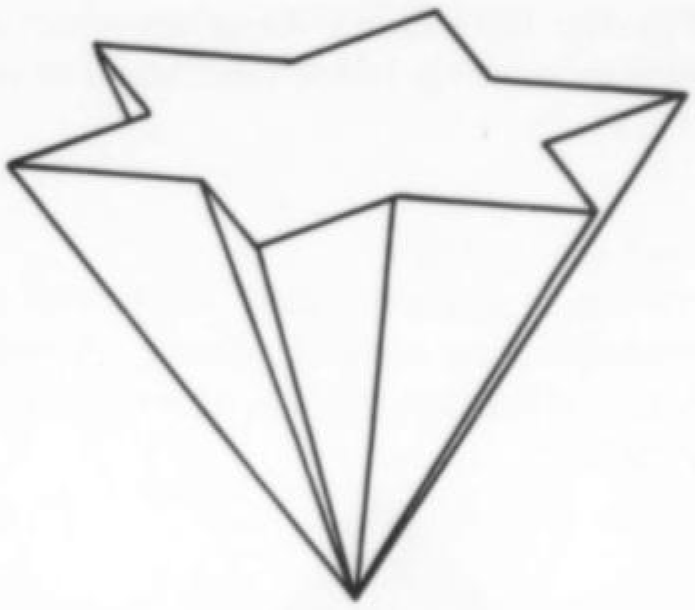

***Figure 9.* Sphalerite crystal drawing showing penetration twin about [111], after Franzini *et al.* (1982).**

The more or less dark color of sphalerites is commonly ascribed to their iron content and the temperature of formation. Since at the Carrara occurrence there is some doubt as to the validity of the relationship between color, iron content and temperature of formation, to explain the apparent contradiction of very dark sphalerites occurring in genetic environments at low temperatures, Leoni and Orlandi have carried out a chemical study on samples of variously colored sphalerites. The above mentioned authors did not find any direct relationship between color and iron content and other minor elements (Mn, Cd, As, Cu). Scott and Barnes (1972) have pointed out the same fact, and also that color is indicative of non-stoichiometry of sphalerites and therefore of f_{S_2} (sulfur fugacity) at which they were formed, i.e., the larger the f_{S_2}, the darker the color. Together with temperature. f_{S_2} is also a decisive factor in the sphalerite-wurtzite transition. In fact, both minerals are characterized by different molar ratios S:(Zn + . . .), greater than one in sphalerites and less than one in wurtzites (Nickel, 1965).

On the basis of these data, Bracci *et al.* have supplied a genetic interpretation of an association between a sphalerite crystal and a wurtzite crystal found in a cavity. The authors have pointed out how crystallization of wurtzite following that of sphalerite is due to a decrease of f_{S_2} where temperature and pH are constant.

Bibliography: 12, 26, 28, 32, 34, 46, 49, 50, 52, 53, 54, 56, 58.

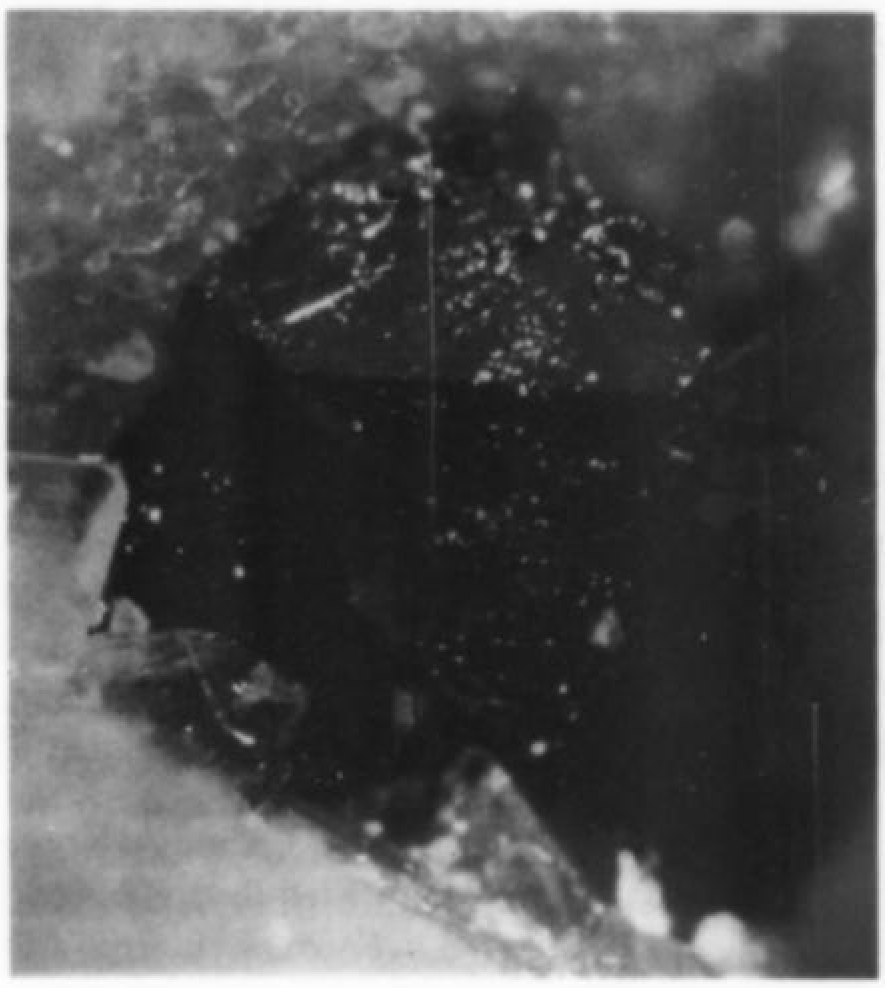

***Figure 10.* Famatinite, dark bronze colored crystal with enargite, 2 mm, Calagio quarry. Lari collection, Bracci photo.**

Famatinite Cu_3SbS_4
Luzonite Cu_3AsS_4

Famatinite has been found so far only in the Calagio quarries, often associated with acicular crystals of zinkenite. It occurs as crystals with bisphenoidal habit and as small masses, dark brown in color.

The cell data obtained from Weissenberg X-ray diffraction patterns are $a = 5.38$ Å, $c = 19.69$ Å.

Chemical analyses carried out by electron microprobe have also revealed the presence of arsenic in variable amounts from 1.72 up to 2.69%.

Some recent qualitative chemical analyses carried out on EDS at the SEM of the Institute of Mineralogy and Geochemistry at the

University of Florence have shown As values which can be interpreted as antimonian luzonites rather than arsenical famatinites.
Bibliography: 51, 53, 56.

Colusite $Cu_3(As,Sn,V,Fe)S_4$

Nearly all crystals of predominantly tetrahedral habit so far described as tetrahedrite are actually colusite. A study based on chemical and X-ray diffraction analyses of single crystals has confirmed the identification.

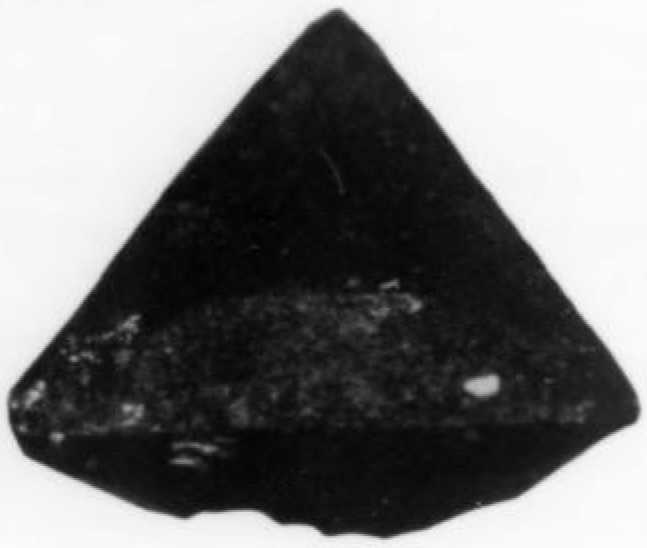

***Figure 11.* Colusite crystal, 3.5 mm, showing tetrahedron modified by tristetrahedron, Lorano quarry. Orlandi collection, Gini-Orlandi photo.**

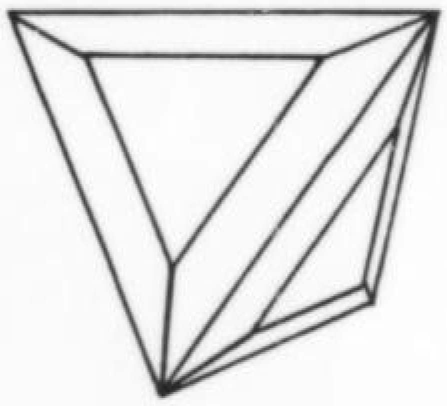

***Figure 12.* Colusite crystal drawing showing typical tetrahedron-tristetrahedron habit, after Franzini *et al.* (1982).**

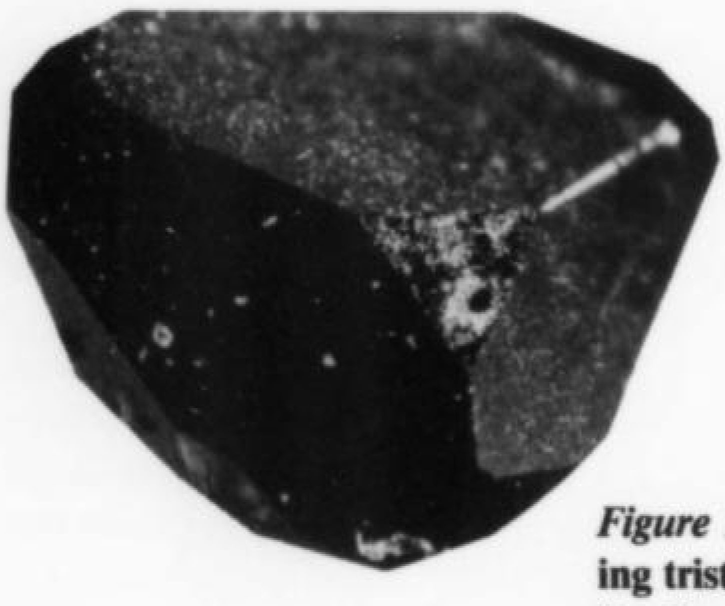

***Figure 13.* Colusite crystal showing tristetrahedral habit, 1.5 mm, La Facciata quarry. Giovannini collection, Gini photo.**

In the light of these studies both minerals can now be distinguished macroscopically, though not always easily, by the black color of tetrahedrite and the very dark bronze color of colusite. Moreover, while colusite always shows a tetrahedral habit, tetrahedrite occurs in much more complex habits.

The specimens examined came from the quarries of the Lorano basin (La Facciata, Fossa degli Angeli, Lorano and Pradetto) and from the Fantiscritti quarry. The crystal sizes rarely exceed 2 mm. It is commonly found with sphalerite and wurtzite, also in typical epitaxial relationships.
Bibliography: 53, 56, 57.

Sulvanite Cu_3VS_4

Among the minerals found at Carrara, sulvanite is considered among the rarest. Thus far only three specimens have been seen by the authors.

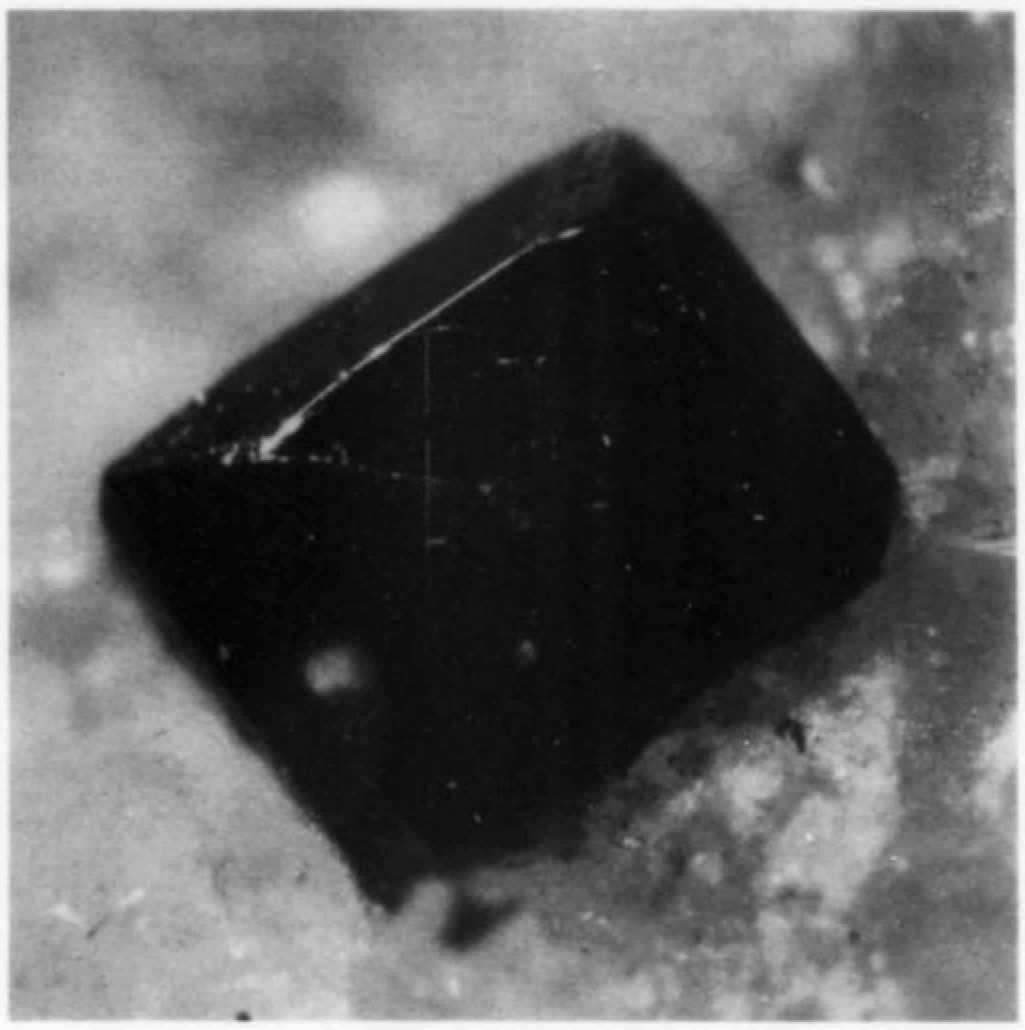

***Figure 14.* Sulvanite crystal, 2 mm, showing cube-tetrahexahedron habit, quarry unknown. Bigarani collection, Gini-Orlandi photo.**

The first identification of sulvanite at Carrara is very recent, though the specimen studied and identified by Orlandi is probably the same one that more than 60 years ago D'Achiardi described as an unknown.

In fact, the specimen examined by Orlandi comes from the collection of the Museum of Mineralogy at the University of Pisa; it was in a drawer, labeled with the following notice: "new mineral of copper?" In a second note D'Achiardi dealt with this specimen and showed that it contained copper and sulfur and not lead, arsenic or antimony:

> Consequently it cannot be a galena [as he had assumed in his first work using simple macroscopic observations]. Neither can I compare this mineral, for its habit and for other traits already described, with any sulfur-type copper mineral, nor can I support that it is a sulfosalt, since, perhaps because of the scarcity of minerals, I could not verify any of the metalloids that characterize the principal minerals of this group.

In D'Achiardi's time, this was only the second known occurrence for the species. The first description of sulvanite was by Goyder in 1900.

The most beautiful of the three sulvanite specimens seen is certainly the above-mentioned one, now exhibited in the Museum of Mineralogy at Pisa, in the glass case of Apuan minerals: it shows the cubic form only, measures 3 mm on edge, is black, opaque and has a vivid metallic luster. In one of the other two specimens observed, the dodecahedron faces modifying the cube were identified.

To identify this rare mineralogical species, X-ray powder diffraction patterns and single-crystal X-ray diffraction patterns have been obtained, indicating a cell of $a = 5.392 \pm 0.002$ Å. A recent chemical analysis carried out on the electron microprobe at the Institute of Mineralogy of Modena has confirmed the identification which had been struggled with for so long.

Both specimens found recently came from the Fantiscritti and Canal Piccinino quarries.
Bibliography: 39, 40, 47, 52, 53, 56.

Tetrahedrite $(Cu,Fe)_{12}Sb_4S_{13}$

Tetrahedrite in cavities is much less common than previously thought. In fact, following a systematic study of possible tetra-

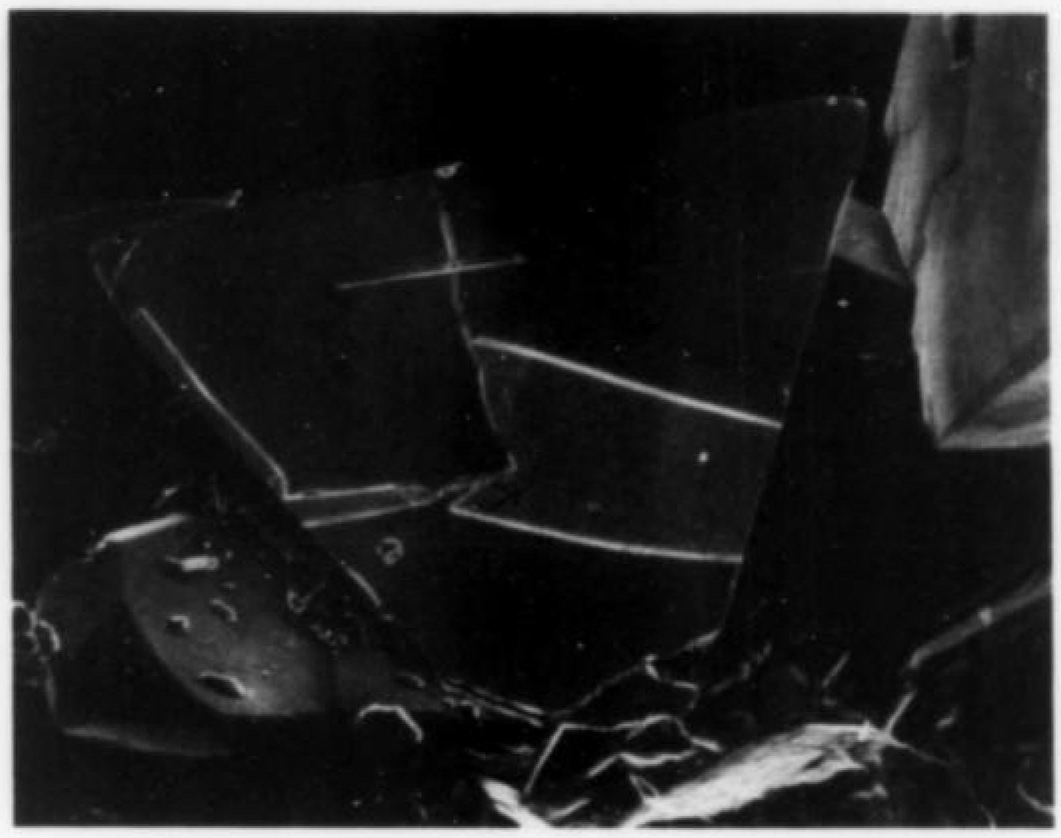

Figure 15. **Tetrahedrite crystal, 0.7 mm, Calagio quarry. Lari collection, Orlandi SEM photo.**

hedrite crystals (opaque, metallic, predominantly tetrahedral habit), it turned out that the overwhelming majority of these was really colusite. D'Achiardi wrote inconclusively:

> A tiny tetrahedral crystal with remarkable gray metallic luster, totally opaque, both at the edges and in the fine powder was examined through the microscope. I thought it was not sphalerite in this instance, but presumably tetrahedrite. Both crystal habit and face peculiarities agree with this determination; however, I could not effect chemical tests, lest I should destroy the only specimen I had.

Following the discovery of two small crystals completely identical to those described by D'Achiardi, Orlandi was able to carry out X-ray diffraction analyses using a Gandolfi camera, thus confirming the presence of tetrahedrite within cavities. The cell parameter obtained is $a = 10.22$ Å, in agreement with values reported in the literature for tetrahedrite; this value is distinctive from the 10.6 Å characteristic of colusite.

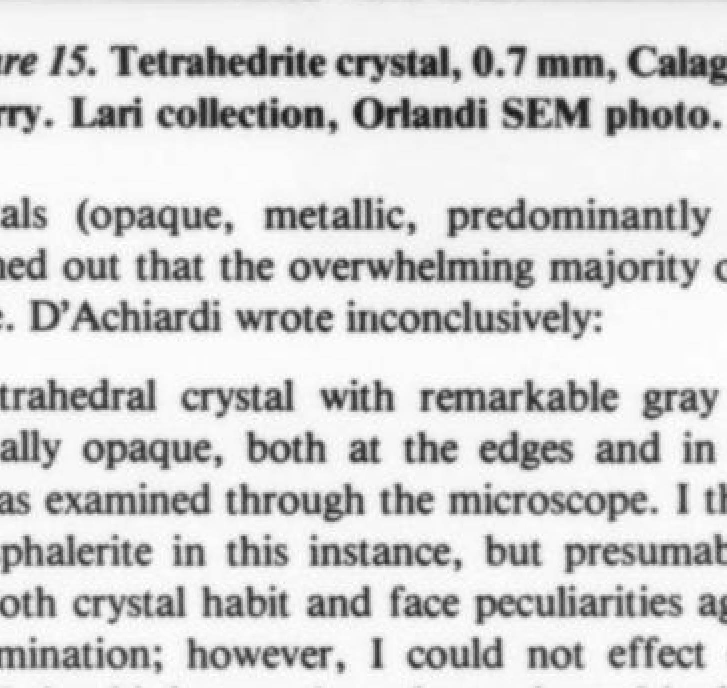

Figure 16. **Tetrahedrite crystal drawing showing a crystal from the Gioia quarry, from Bracci *et al.* (1980).**

In addition to simple tetrahedral habit, tetrahedrite occurs more frequently in much more complex habits, with a large number of faces, similar to the well-known "binnite" crystals of the Lengenbach quarry in Switzerland.

Tetrahedrite crystals rarely exceed 2–3 mm; it has been found at the Fossa degli Angeli, La Facciata and Calagio quarries.

Bibliography: 34, 47, 52, 53, 56.

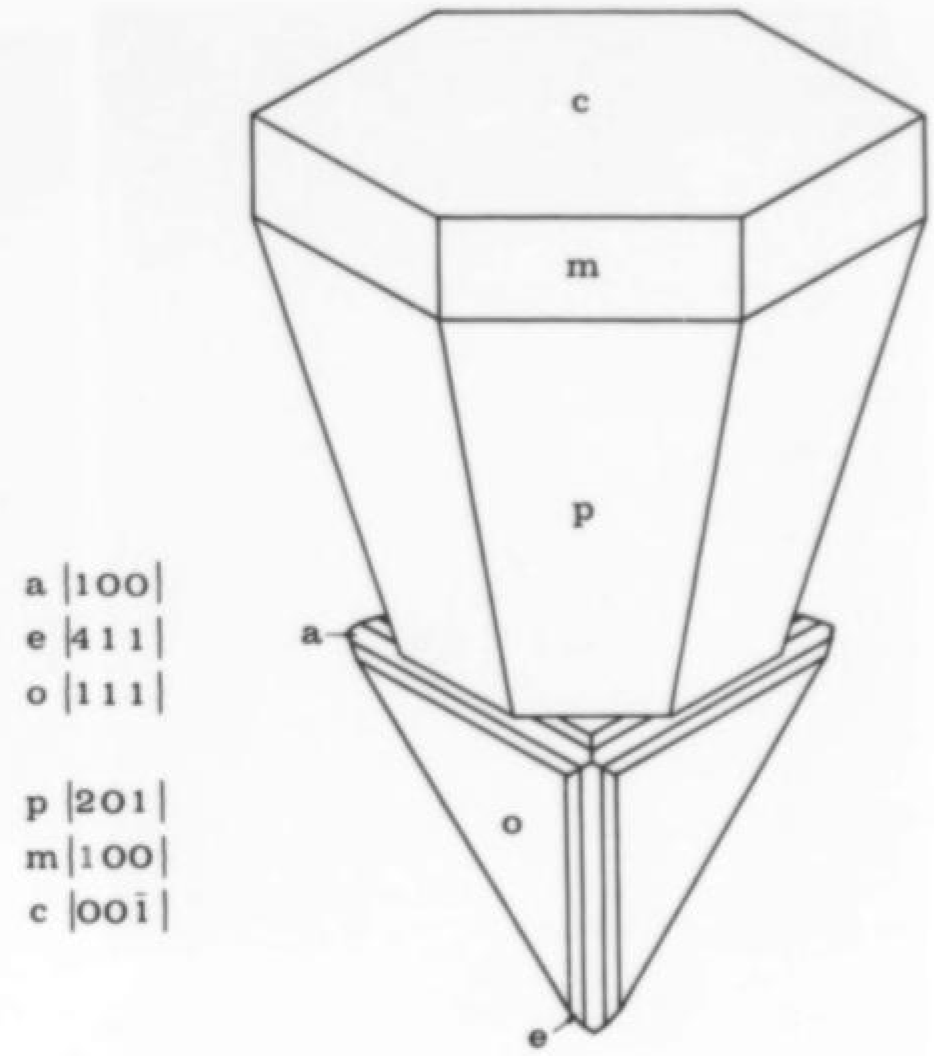

Figure 17. **Crystal drawing showing wurtzite crystal (top) in epitaxial overgrowth on sphalerite crystal (bottom), from Bracci *et al.* (1978).**

Wurtzite (Zn,Fe)S

Wurtzite has been reported very recently, and is very rare in cavities. The identical colors of sphalerite and wurtzite, plus the peculiar habits of twinned sphalerite which can have a pseudohexagonal appearance, have long prevented recognition of wurtzite at Carrara.

It occurs commonly as hexagonal pyramidal crystals; the color ranges from honey-yellow to red-brown. Crystals rarely exceed 2 mm.

X-ray diffraction data are in accordance with the 2H polytype of wurtzite.

So far it has been found only in the quarries of the Lorano basin, commonly associated with sphalerite and colusite, with which it often shares an epitaxial relationship.

The epitaxial orientation of these minerals to each other involves the three planes of symmetry of sphalerite and colusite and the three P^1 of wurtzite; furthermore the parallelism between the three-fold axis of sphalerite and colusite and the two-fold axis of wurtzite is particularly important. This kind of epitaxy matches the structural similarity of the wurtzite (001) plane with the sphalerite and colusite (111) planes.

Chemically wurtzites are richer in minor elements than sphalerites of the same occurrence.

Bibliography: 53, 54, 56.

Enargite Cu_3AsS_4

Enargite is the most common mineral among the sulfosalts at Carrara. The most important occurrences are at the Calagio quarries in the Colonnata Valley.

Among the sulfosalts, it can be easily identified by the trained eye because of its typical prismatic habit, its pitch-black color, metallic luster and easy cleavage. Crystal sizes can exceed 1 cm.

The forms which have been observed by the authors in the different crystals are: {100}, {010}, {001}, {101}, {201}, {112} and {111} of which {110} is the most frequent and best developed, commonly associated with {100}, {010} and {001} in the most typical crystals.

Bibliography: 47, 52, 53, 56.

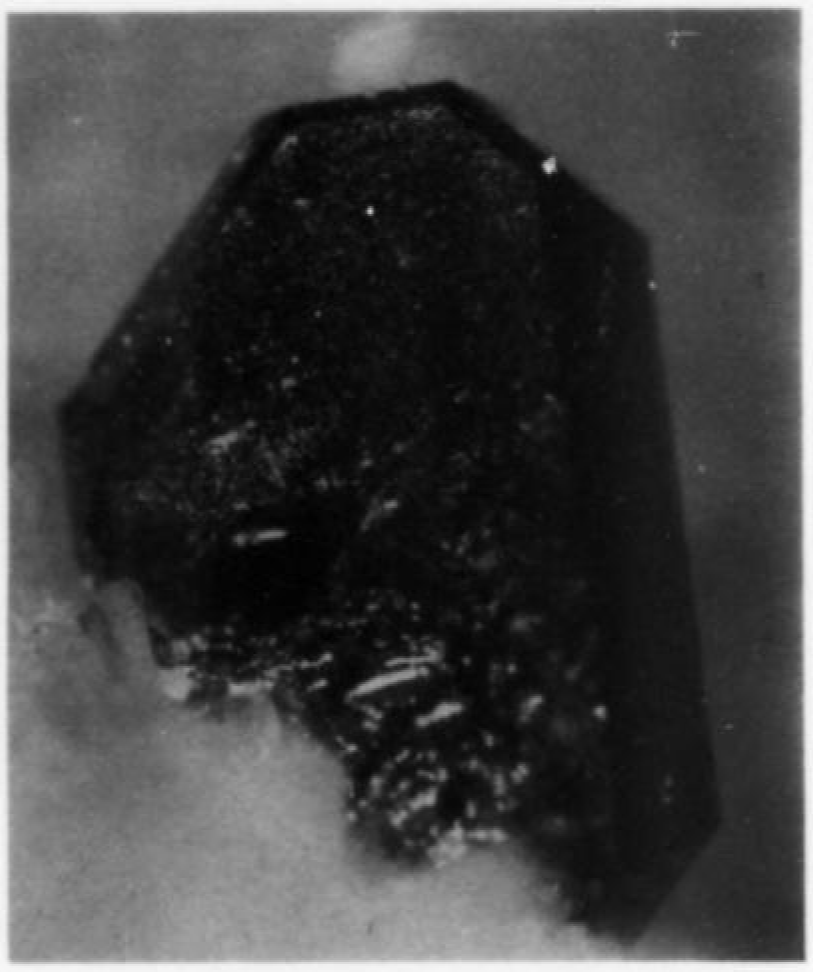

Figure 18. **Enargite, tabular crystal 4 mm long, Calagio quarry. Conforti collection, Gini-Orlandi photo.**

Galena PbS

Galena is a relatively abundant mineral among the sulfides. It is commonly associated with sphalerite and pyrite and it occurs in almost all quarries in the Carrara area, but most frequently in the Fantiscritti and Calagio quarries.

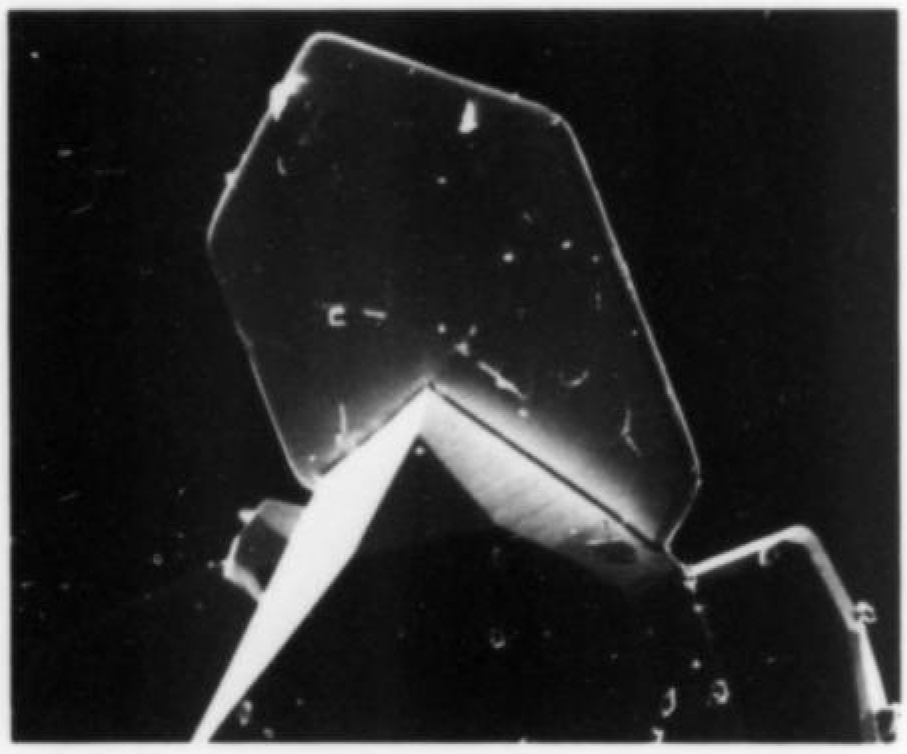

Figure 19. **Tabular galena crystal, 0.3 mm, on pyrite, Calagio quarry. Del Chiaro collection, Orlandi SEM photo.**

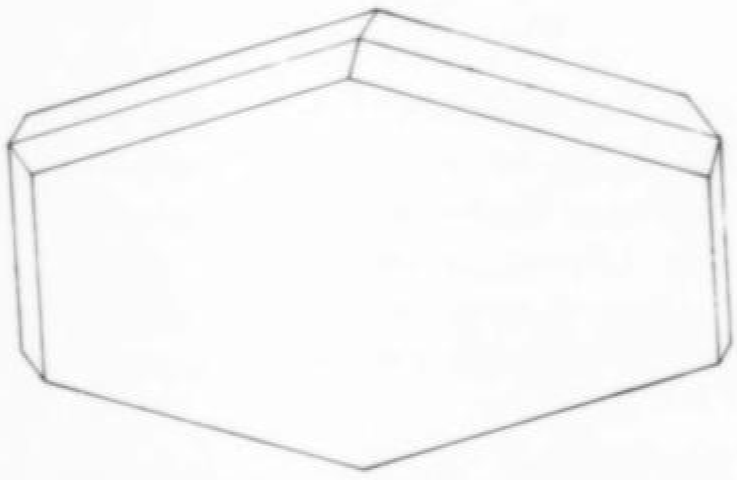

Figure 21. **Galena crystal drawing showing distorted "hexagonal tabular" habit, after Dalena (1978).**

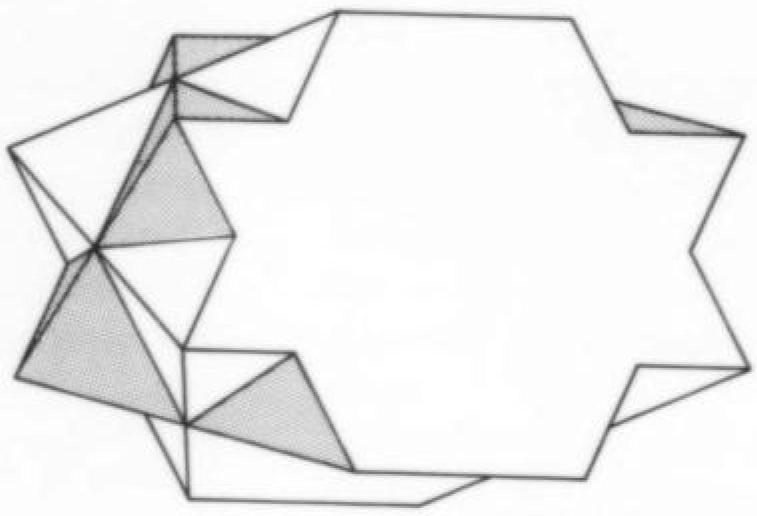

Figure 20. **Galena crystal drawing showing distorted octahedral penetration twin, after Dalena (1978).**

The morphology of this mineral is very interesting; it forms as small shapeless masses, cubes, cuboctahedrons and as more or less regular octahedrons, which are isolated or grouped together. But it also often occurs as tabular, hexagonal-shaped crystals. This habit can be thought of as an octahedron flattened on the three-fold axis.

Octahedral crystals twinned by penetration through (111) are rare.

Bibliography: 32, 34, 49, 52, 53, 56.

Covellite CuS

Covellite at Carrara is as beautiful as it is rare. Very few specimens have been observed by the authors. One of these specimens is composed of a very large crystal (over 1 cm) with the typical, very flattened, hexagonal prismatic habit.

Covellite can be easily identified because of its habit and its bright brown-purple color.

Bibliography: 47.

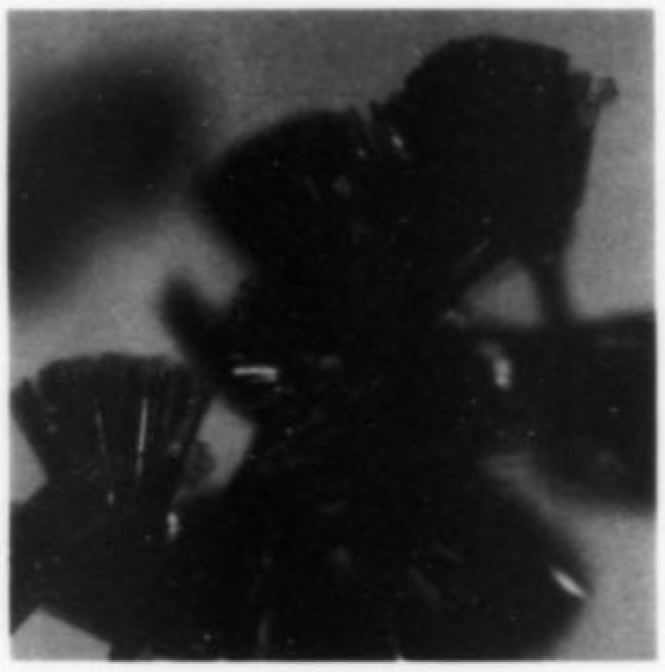

Figure 23. **Stibnite crystals in sheaf-like groups to ‹1 mm, Calagio quarry. Conforti specimen, Gini-Orlandi photo.**

Stibnite Sb_2S_3

Stibnite has been observed as very rare and minute sheaf-like groups of very thin acicular crystals with a typical lead-gray color and a vivid metallic luster. It occurs associated with other sulfides and sulfosalts in the Calagio quarries.

Bibliography: 51, 53.

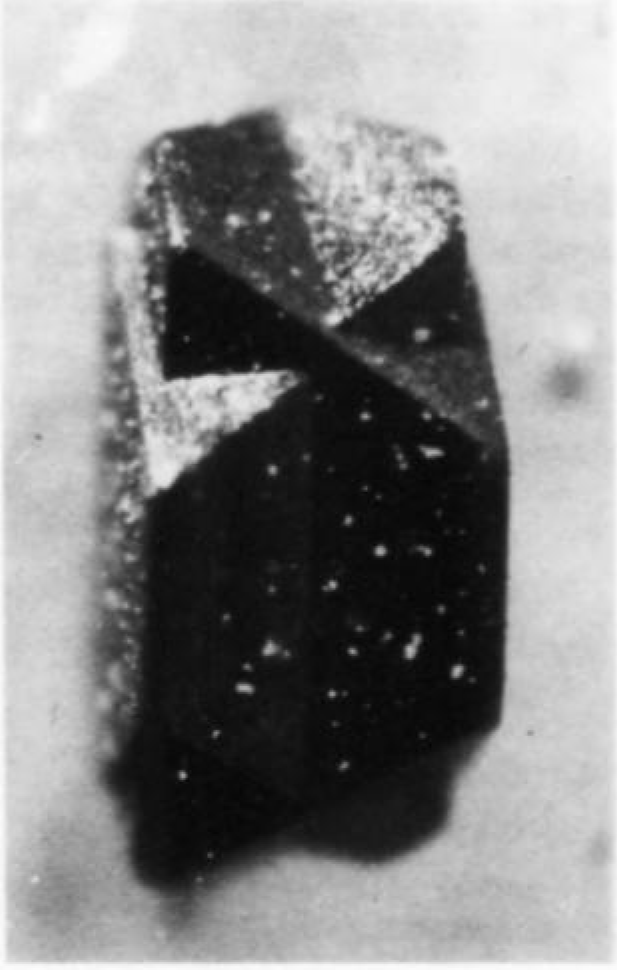

Figure 22. **Galena penetration twin composed of two octahedral crystals, 1 mm, Lorano quarry. Bianchi collection, Gini-Orlandi photo.**

Pyrite FeS_2

Pyrite is among the first reported minerals from the Carrara marble. As early as 1784 and 1820 (respectively) Spallanzani and Repetti described it. However, these authors and others described pyrite as widespread in massive marble; this is, in fact, the most common mode of occurrence, although pyrite is also the most common sulfide in cavities.

It occurs frequently in the quarries of the Fantiscritti basin as pyritohedral crystals associated with red sphalerite and galena. The

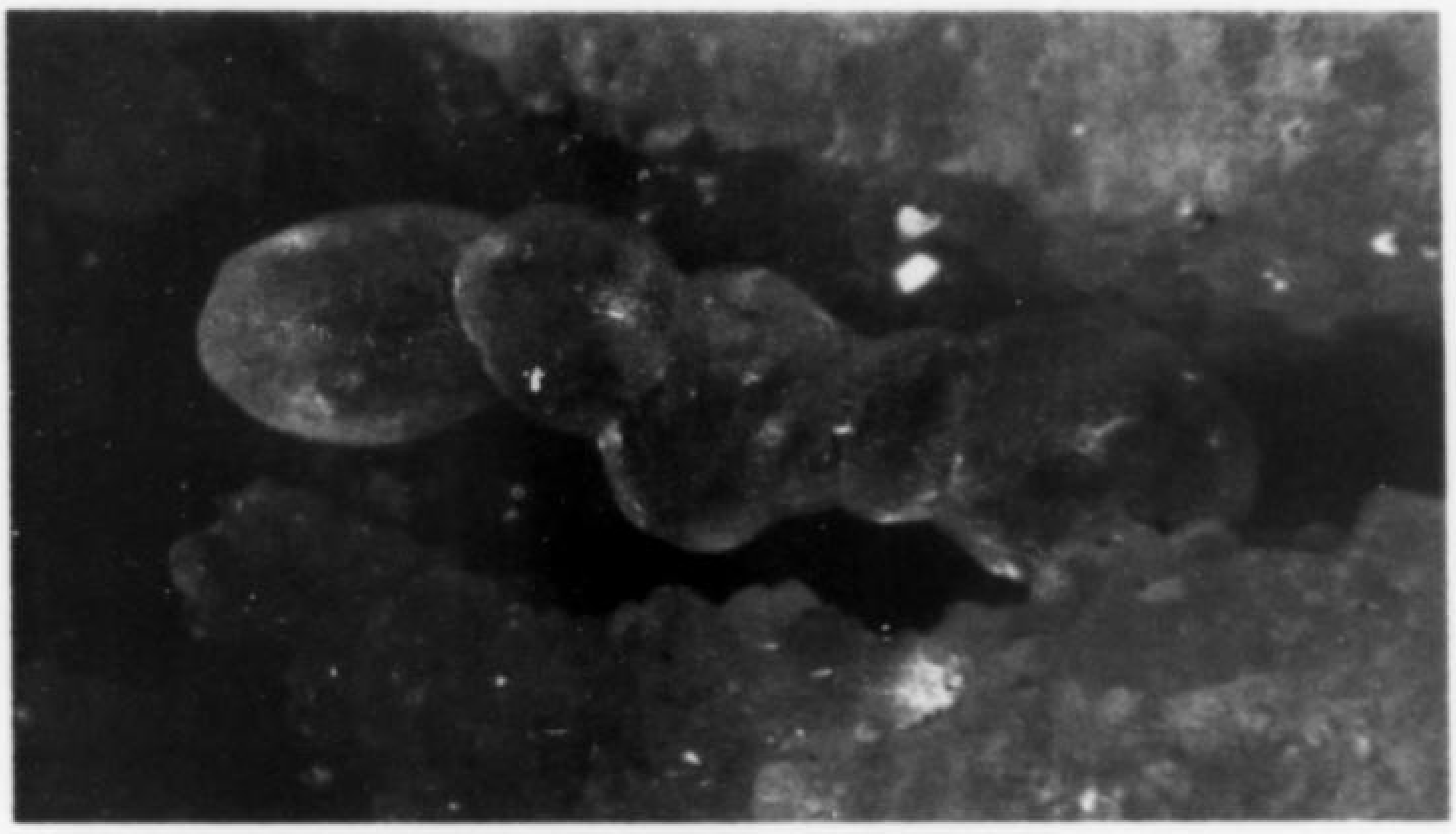

Figure 24. **Sulfur, crystal aggregate, 2 mm, La Facciata quarry. Brizzi collection and photo.**

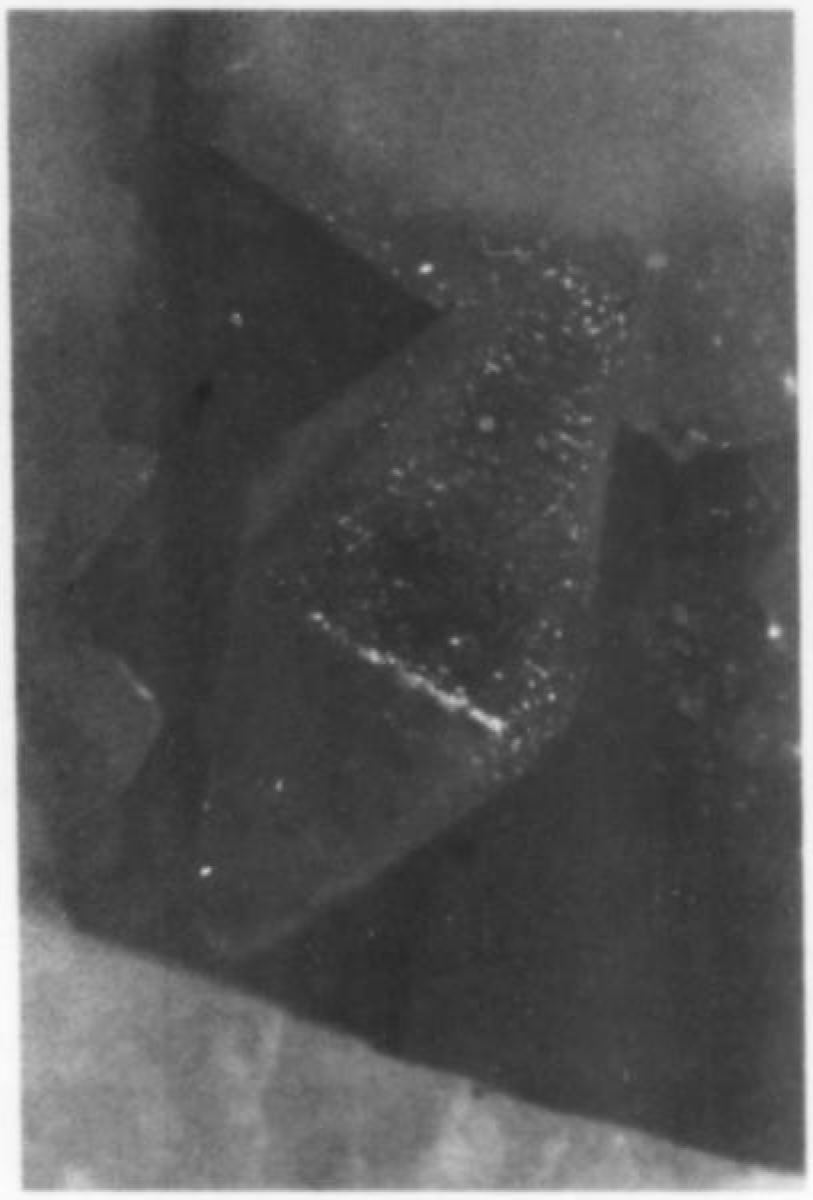

Figure 25. **Sulfur crystal, 1 mm, La Facciata quarry. Bianchi collection, Gini-Orlandi photo.**

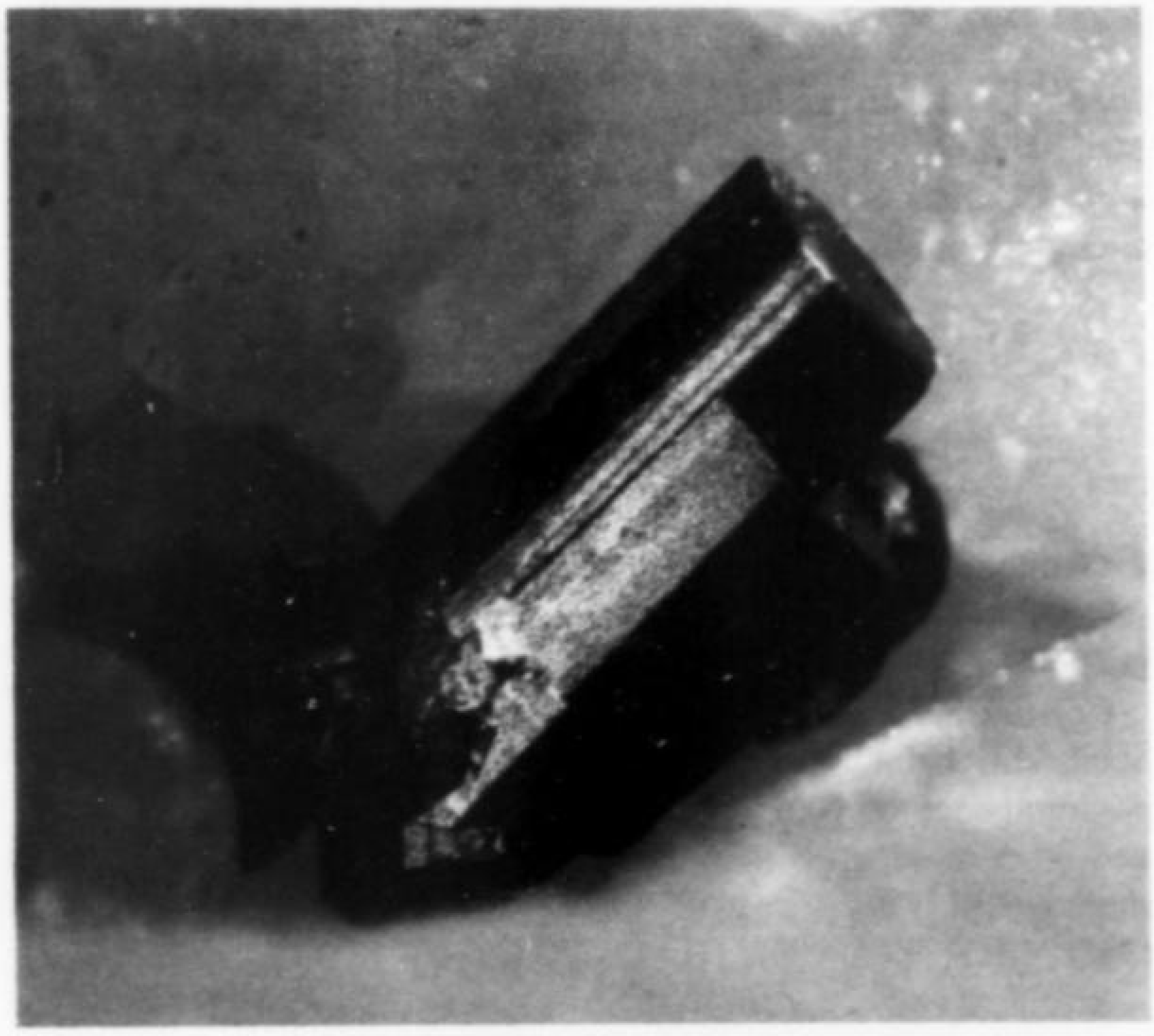

Figure 26. **Enargite crystal, 2 mm, with gold-colored alteration patina, Artana quarry. Del Chiaro collection, Gratziu photo.**

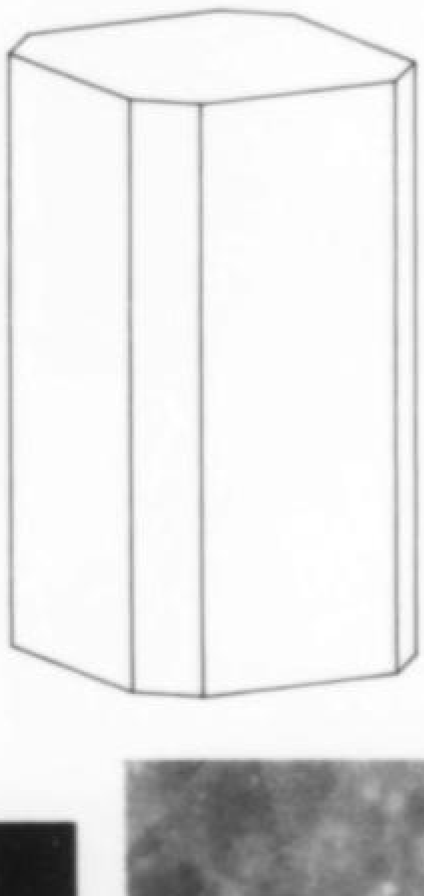

Figure 27. **Enargite crystal drawing.**

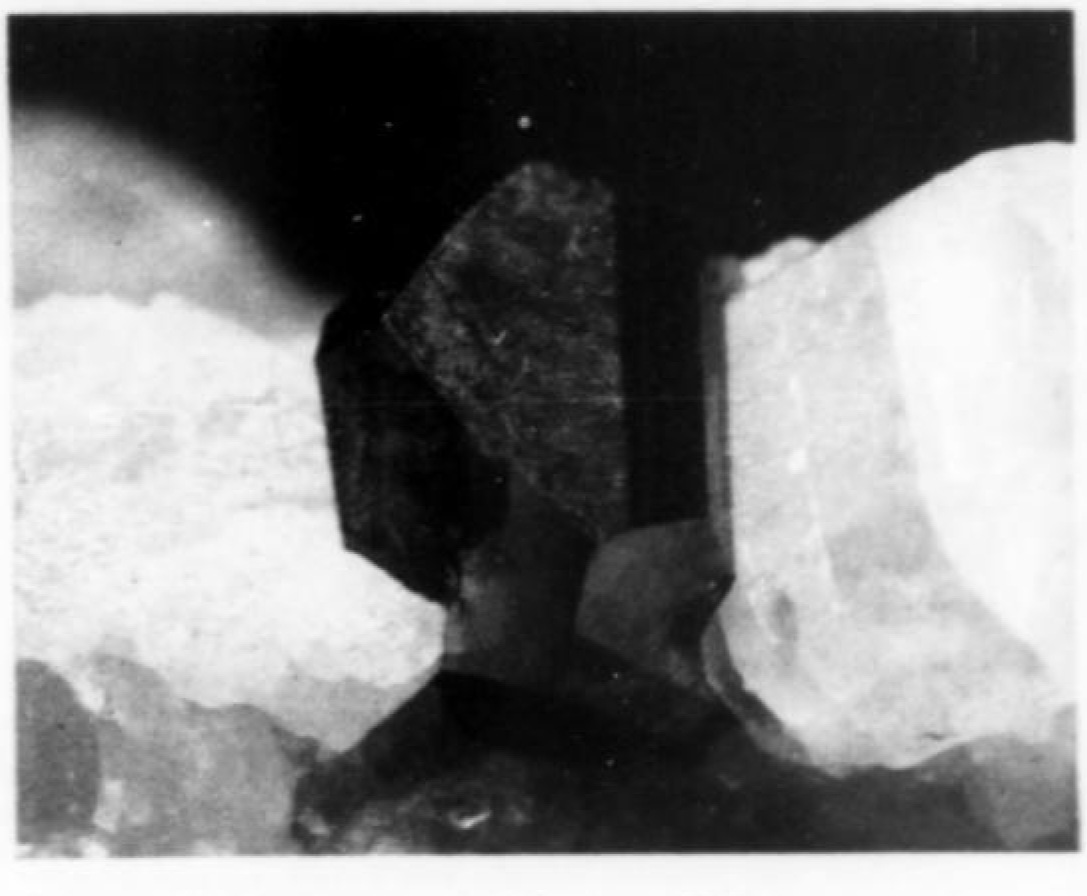

Figure 28. **Pyrite crystal, 18 mm, Colonnata quarry. Conforti collection, Nova photo.**

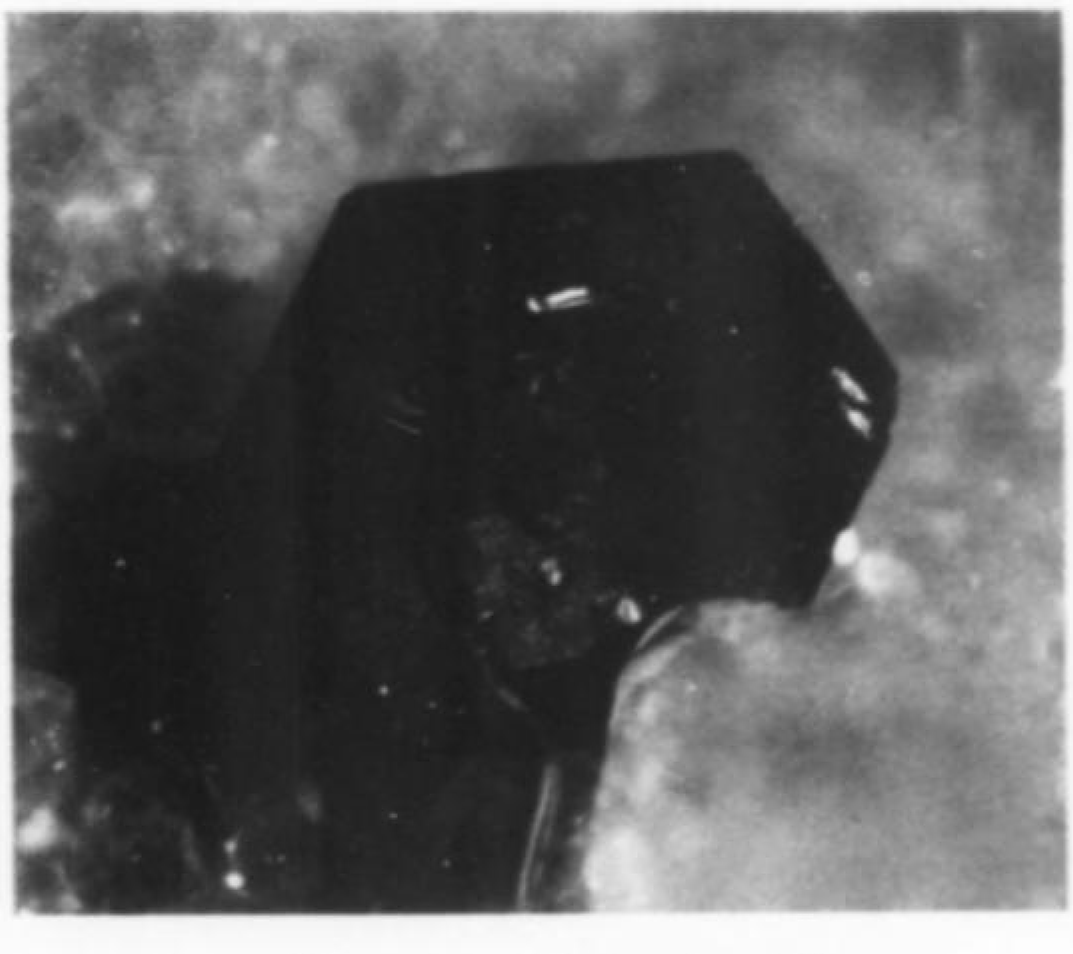

Figure 29. **Covellite rosette of flattened crystals, 2 mm, Artana quarry. Masetti collection, Gini-Orlandi photo.**

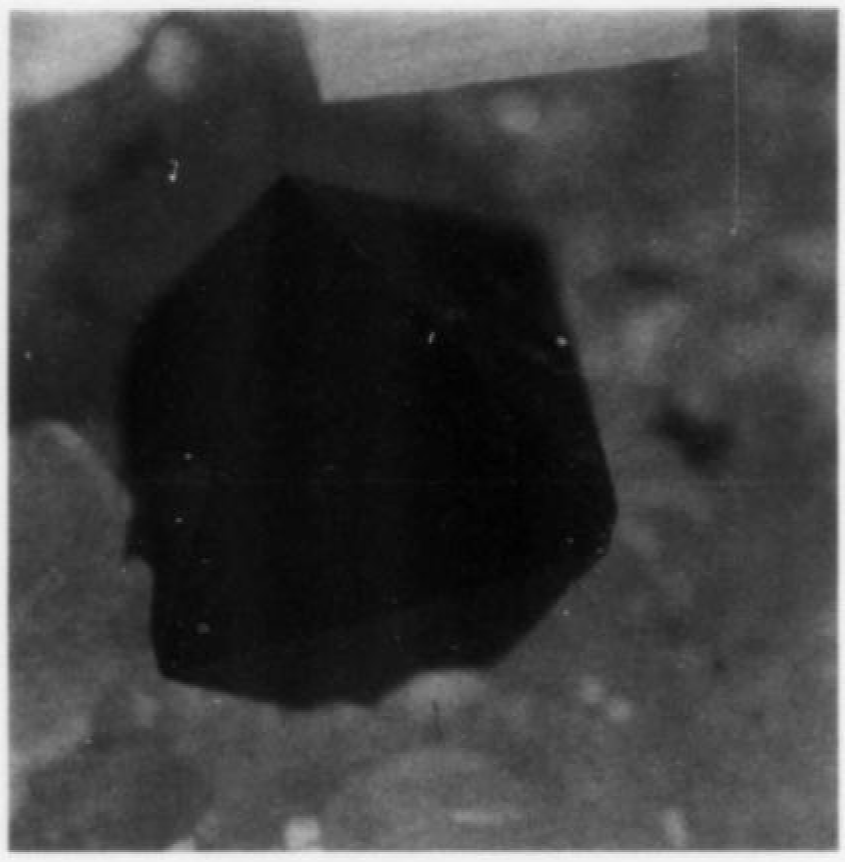

Figure 30. **Pyrite, altered reddish octahedral crystal 3 mm in size, Calagio quarry. Lunardi specimen, Orlandi photo.**

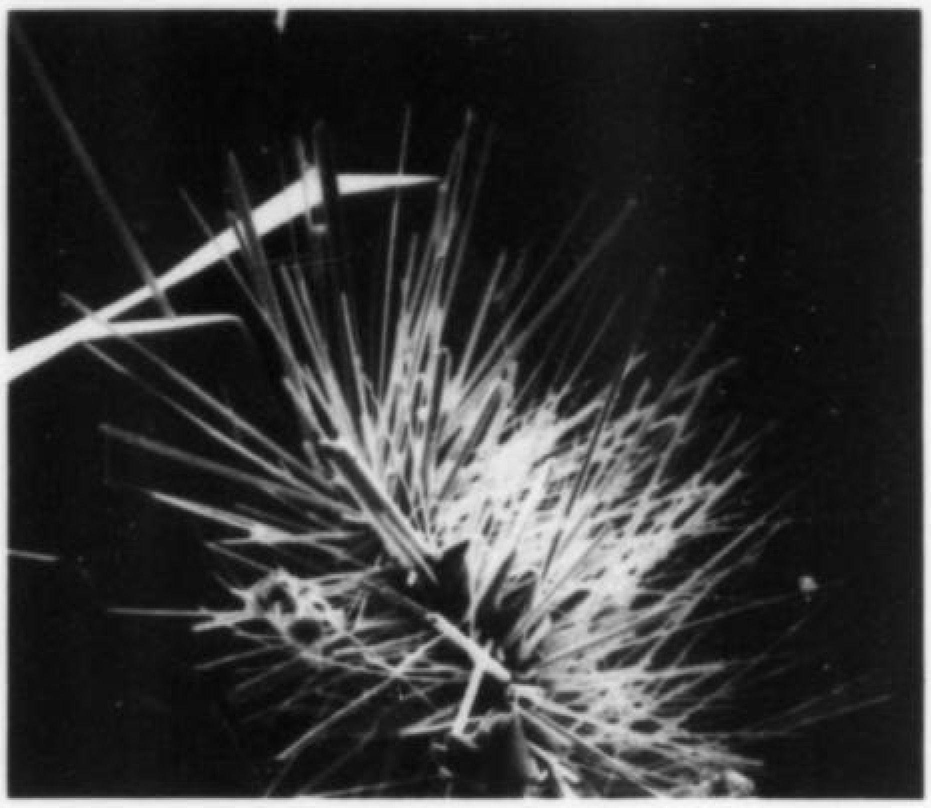

Figure 31. **Pyrite, acicular crystal group, 0.25 mm across, Calagio quarry. Del Chiaro collection, Orlandi SEM photo.**

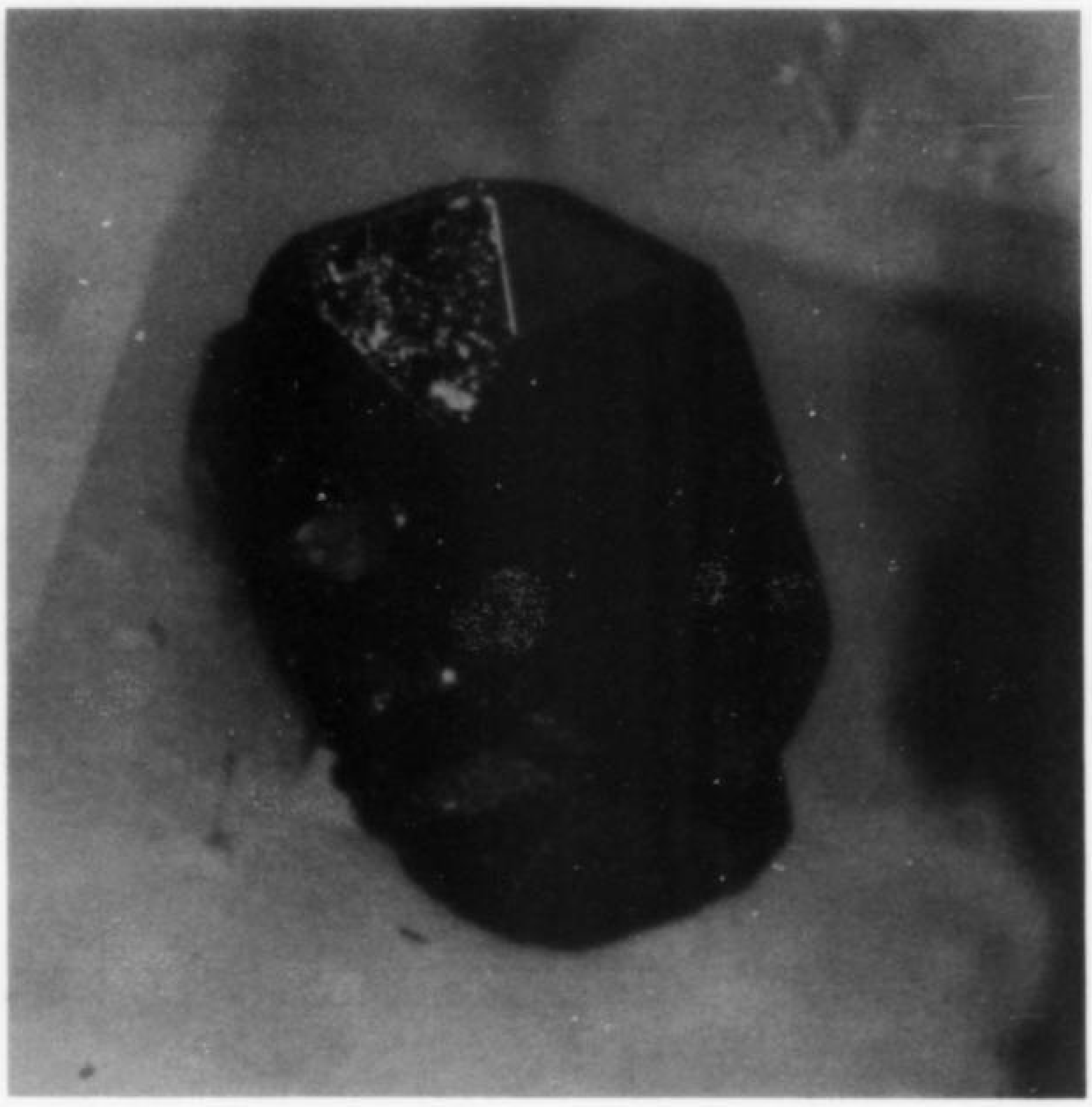

Figure 32. **Bournonite crystal, 2 mm, Fantiscritti quarry. Bigarani collection, Gini-Orlandi photo.**

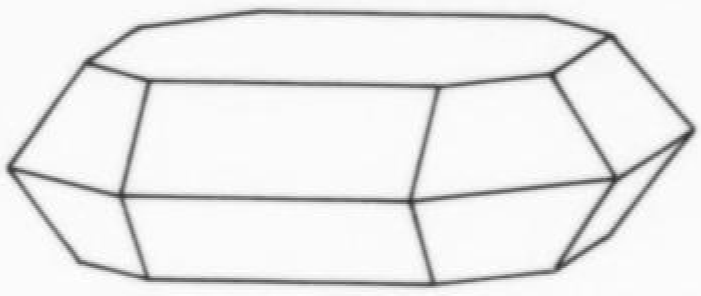

Figure 33. **Bournonite-seligmannite crystal drawing, after Franzini *et al.* (1982).**

latter occurs as very small, tabular crystals with a hexagonal outline directly implanted on the faces of the pyrite crystals.

In addition to pyritohedrons with cubic modifications, rare crystals of octahedral habit have been found; crystals twinned in (110) commonly known as "iron crosses" are rare.

Groups of acicular pyrite microcrystals are particularly rare.
Bibliography: 4, 5, 6, 11, 12, 26, 27, 32, 34, 42, 52, 53.

Arsenopyrite FeAsS

D'Achiardi classified as arsenopyrite a "very small metallic mass, with no apparent crystalline structure, gray in color, with a light grey-greenish luster, opaque also in powder," associated with a sphalerite crystal from the Piastra quarry.

No analytic data exists in support of this identification, and the presence of this mineral in the cavities is therefore doubtful.
Bibliography: 34, 52.

Seligmannite $PbCuAsS_3$
Bournonite $PbCuSbS_3$

Seligmannite-bournonite crystals are always very small (1 to 3 mm) and are lead-gray in color with a vivid metallic luster. They occur in practically every quarry of the Carrara basin, but most frequently in the Calagio quarries.

Gandolfi powder patterns indicate that these crystals are in the seligmannite-bournonite series; however, on this basis, it is not possible to determine which end-member is present.

Crystals are almost always twinned and show a rather variable habit; this habit is often tabular and it is characterized by the predominance of {001}. But crystals with prismatic dipyramidal and other more squat habits display a great number of forms, including {100}, {010}, {001}, {110}, {130}, {310}, {101}, {203}, {302}, {011}, {023}, {112}, {223} and {12.3.2}.

A typical twinned crystal of this mineral is illustrated in Figure 34a. It is an association of four individuals twinned on [110]. The pseudotetragonal prism appears to consist of four thin, small faces, forming between them four angles of about 90°, belonging to four crystalline individuals that can be listed in the angular position as {010}, {100}, {010} and {100}.

The interpretation of this twin is rather complex since in the minerals of the seligmannite-bournonite series the inner angle between the planes (110) and ($\bar{1}$10) is about 86°. Therefore a penetration twin according to [110] of four individuals, whose perpendicular section to [001] is represented in Figure 34b, should collectively fail to close by about 16°.

On the basis of single-crystal X-ray diffraction patterns and morphological measurements from which the presence of a pseudotetragonal prism is evident, we suggest an interpenetration of four twinned individuals. All of them cooperate in generating the faces of the prism: the situation sketched in Figure 34c is thus realized.

An accurate measurement of cell parameters for these twinned crystals has yielded values which are almost exactly intermediate between the end-members of the series.

Microprobe analyses of samples from Fantiscritti have revealed Sb contents ranging from a maximum of 23.51% to a minimum of

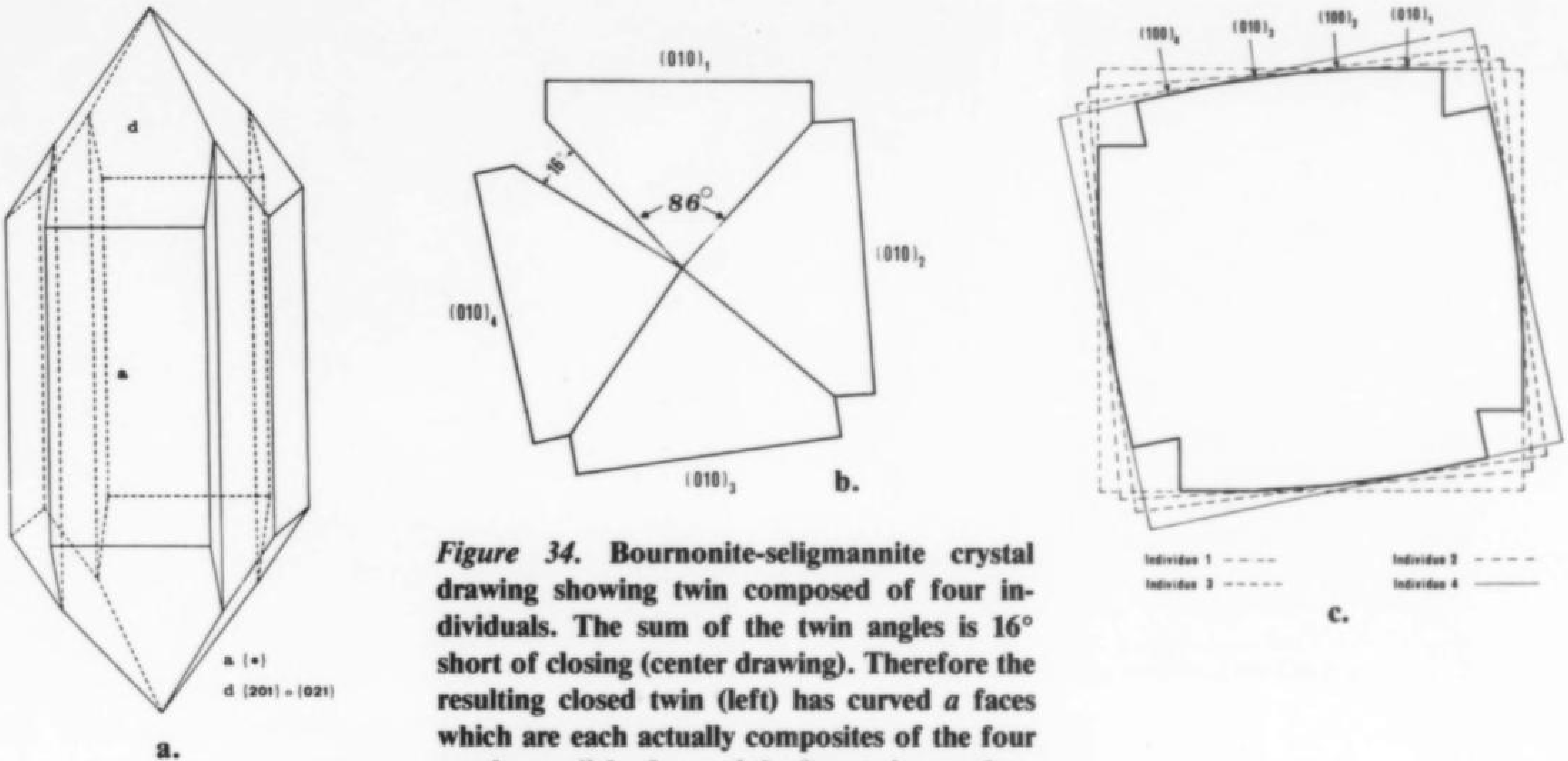

Figure 34. **Bournonite-seligmannite crystal drawing showing twin composed of four individuals. The sum of the twin angles is 16° short of closing (center drawing). Therefore the resulting closed twin (left) has curved *a* faces which are each actually composites of the four nearly parallel *a* faces of the four twin members (right).**

8.70%. We can therefore conclude that, in the cavities of Carrara marble, bournonite (Sb end-member content 24.94%) is present, as well as a series of intermediate compositions leading to seligmannite.

Bibliography: 47, 51, 53, 56.

Jordanite $Pb_{14}(As,Sb)_6S_{23}$
Geocronite $Pb_{14}(Sb,As)_6S_{23}$

These two minerals are described here together since they represent a single series.

Jordanite and geocronite have similar macroscopic characteristics and are therefore only distinguishable (with difficulty) by X-ray diffraction. On the basis of physical properties it is possible to specify only the series jordanite-geocronite; chemical data are generally required for further identification.

Dell'Anna and Quagliarella reported from the Torano quarries, "a small crystalline mass lacking a well defined morphology," associated with pyrite, sphalerite and fluorite and which, on the basis of chemical and crystallographic data, they identified as jordanite. In 1974 Orlandi reported again the presence of jordanite; in 1976 Orlandi and Bianchi also reported the presence of geocronite. In 1980 Bracci *et al.* reported two analyses, one of jordanite and one of geocronite.

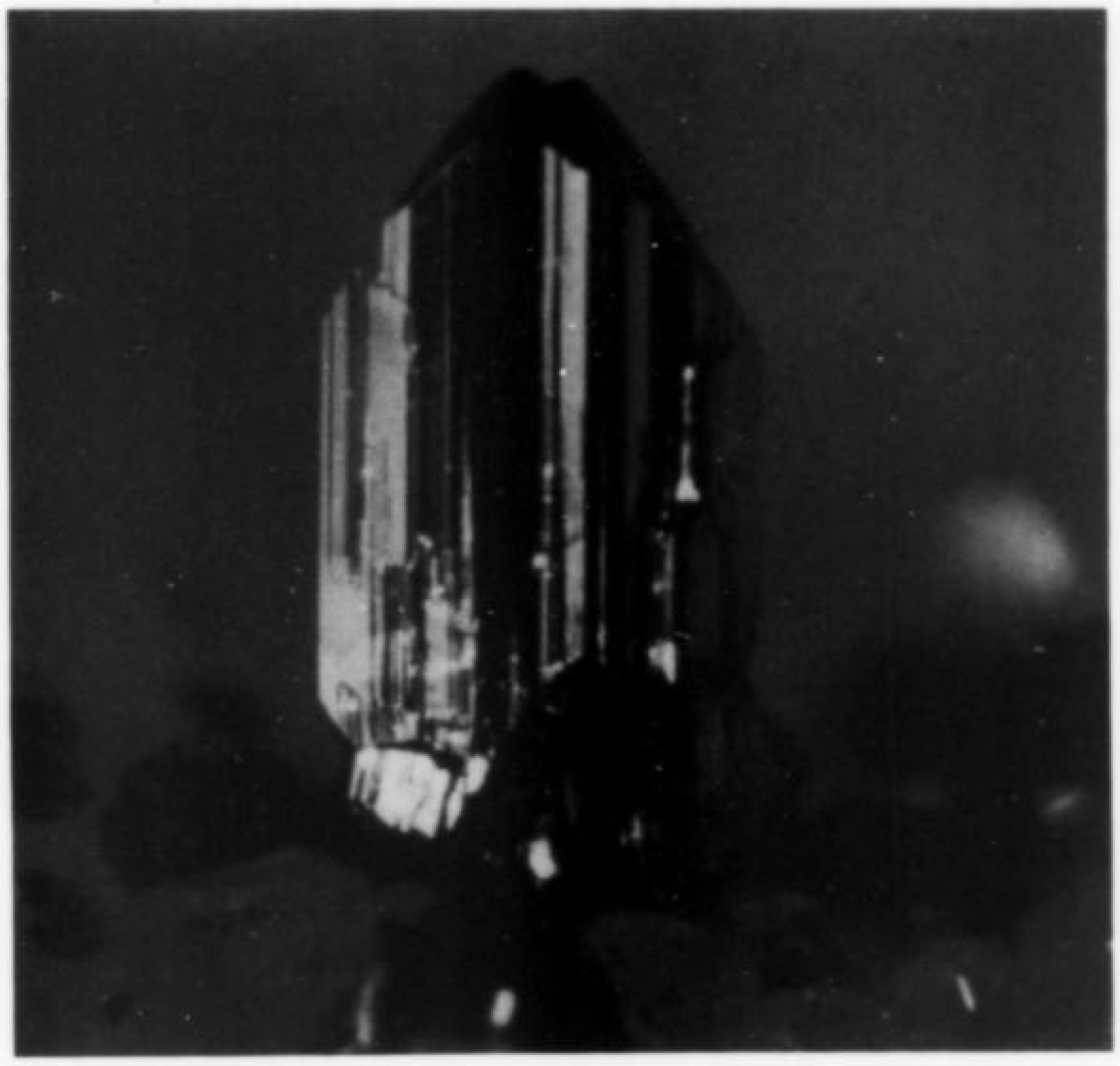

Figure 35. **Jordanite crystal, 1 mm, with pyrite, Fantiscritti dumps. Del Chiaro collection, Orlandi photo.**

Figure 36. **Jordanite crystal, 0.2 mm, Fantiscritti quarry. Lari collection, Orlandi SEM photo.**

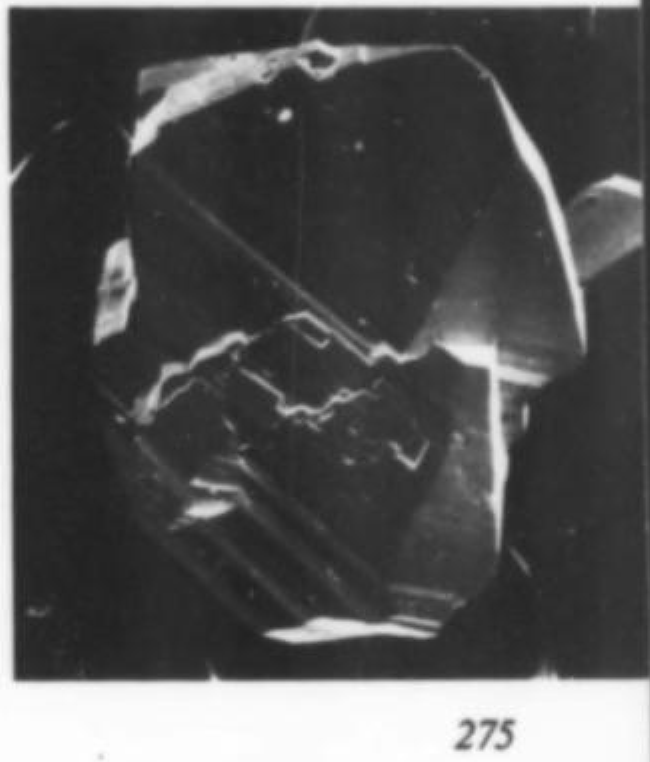

Figure 37. **Geocronite crystal, 0.3 mm, showing typical stepped growth, Calagio quarry. Del Chiaro collection, Orlandi SEM photo.**

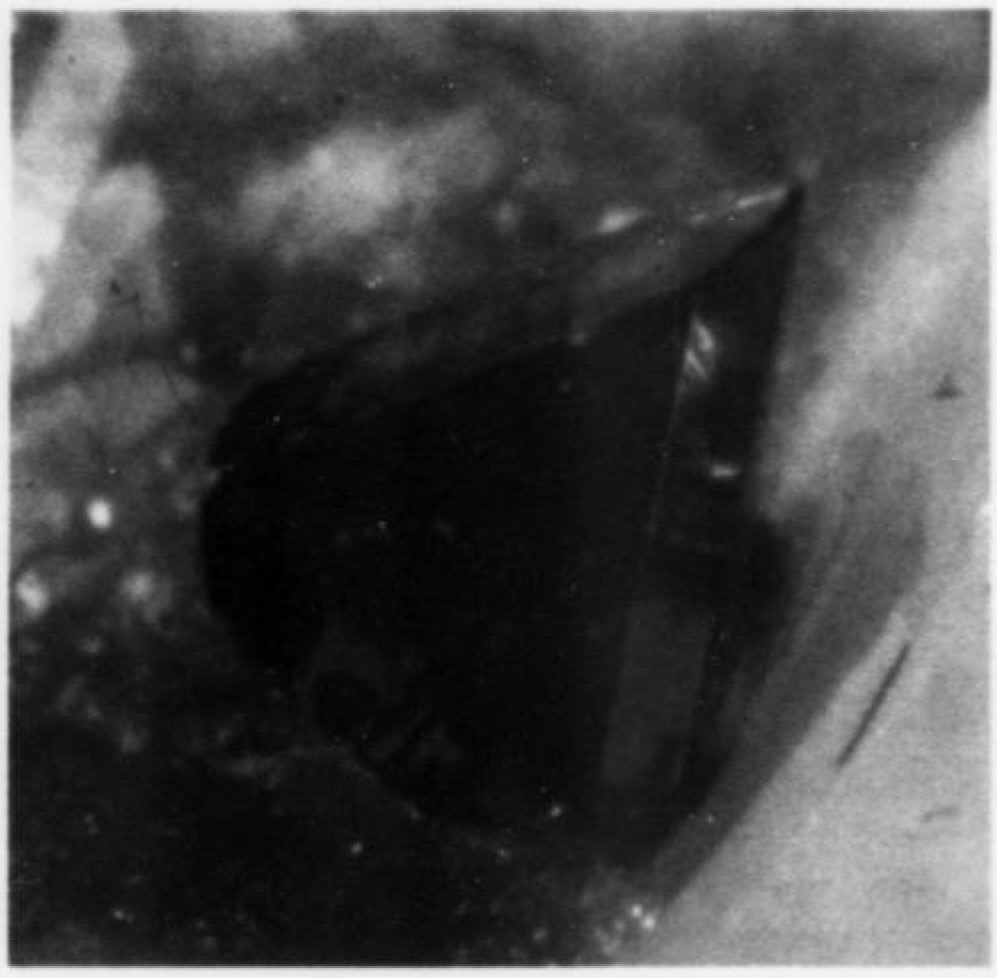

Figure 38. **Sphalerite crystal, 8 mm, Lorano quarry. Brizzi collection and photo.**

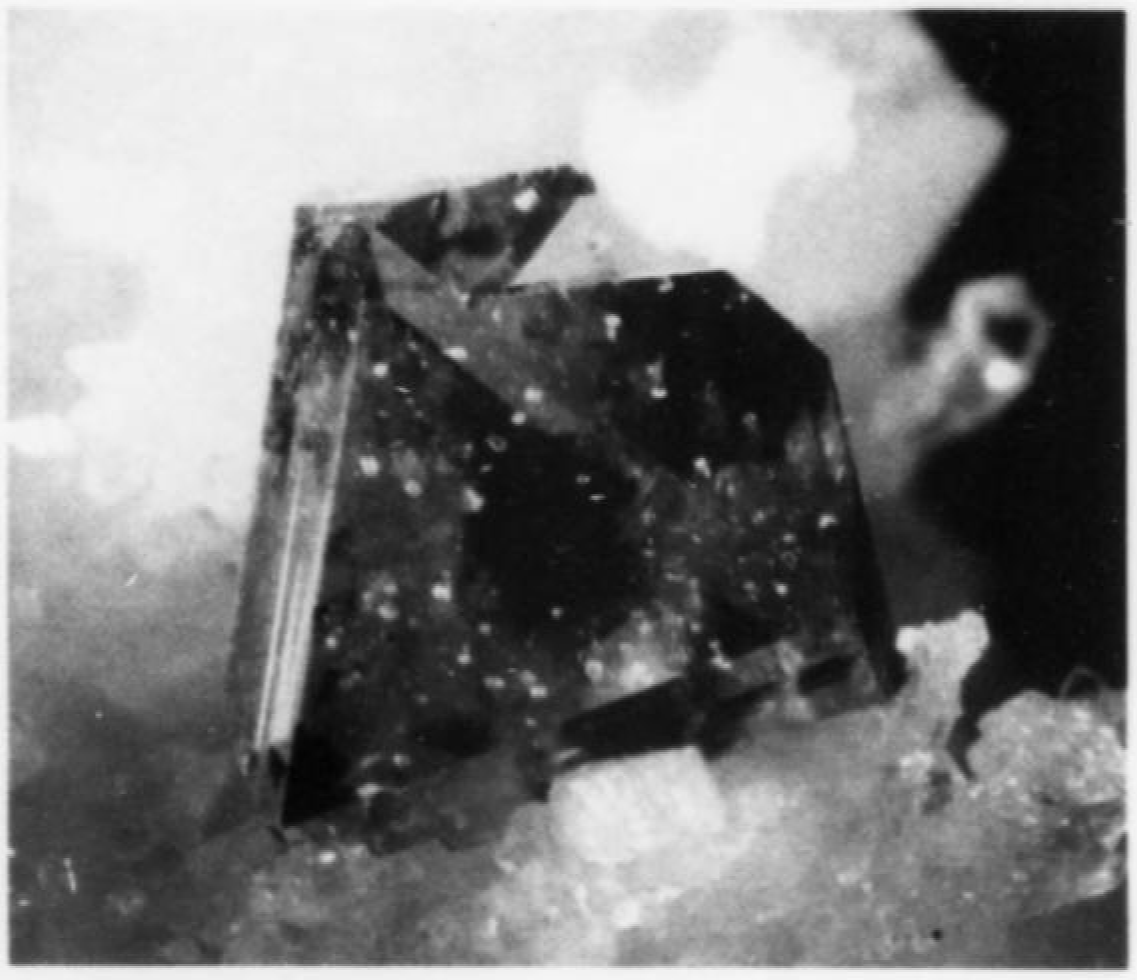

Figure 40. **Sphalerite crystal, 4 mm, Lorano quarry. University of Pisa collection, Gini-Orlandi photo.**

Figure 39. **Sphalerite, amber colored crystal, 5 mm, with black colusite, Lorano quarry. Bigarani collection, Gini-Orlandi photo.**

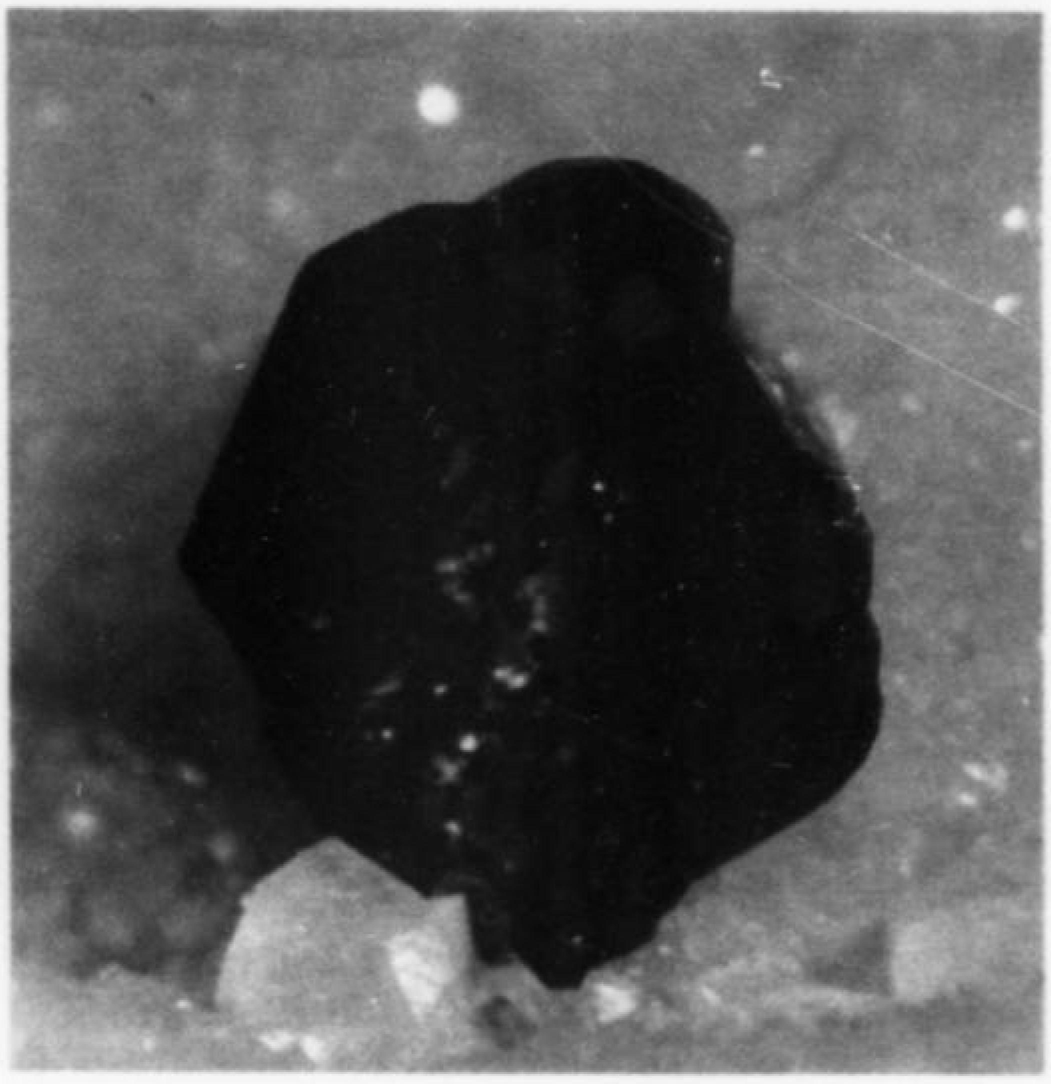

Figure 41. **Tetrahedrite crystals on sphalerite crystal, 5 mm, Fossa degli Angeli quarry. Granai collection, Gini-Orlandi photo.**

Figure 42. **Sphalerite crystals to 1.5 mm, Montecatini quarry. L. Del Chiaro collection, Orlandi photo.**

Figure 43. Sphalerite crystal, 2 mm, Fantiscritti quarry. Orlandi collection, Gratziu photo.

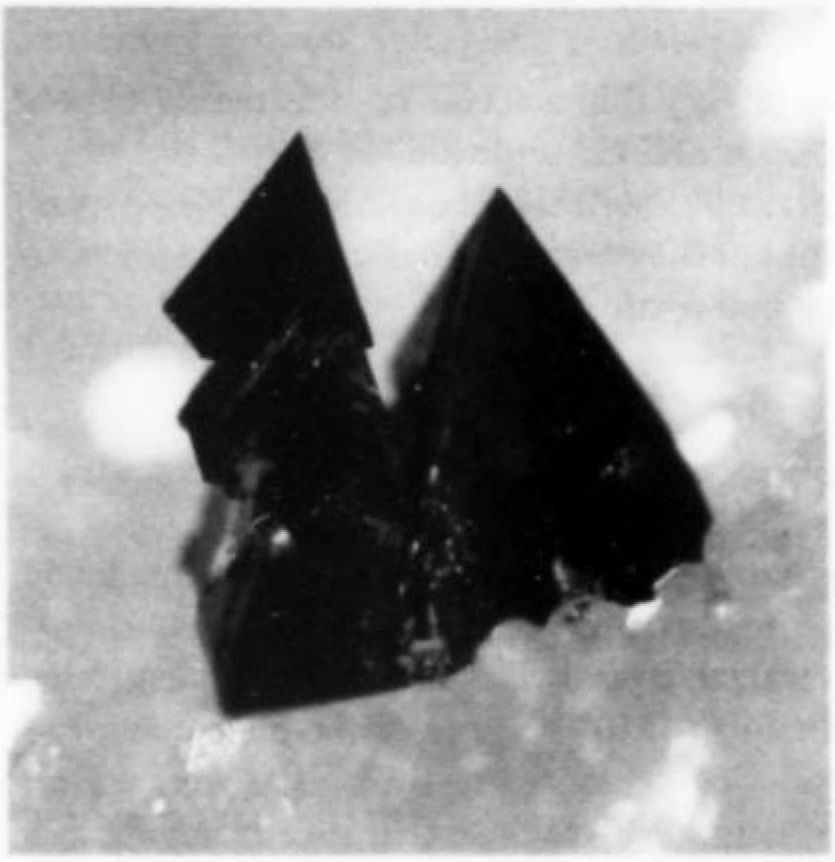

Figure 44. Colusite and sphalerite crystal group, 2.5 mm, La Facciata quarry. Del Chiaro collection, Orlandi photo.

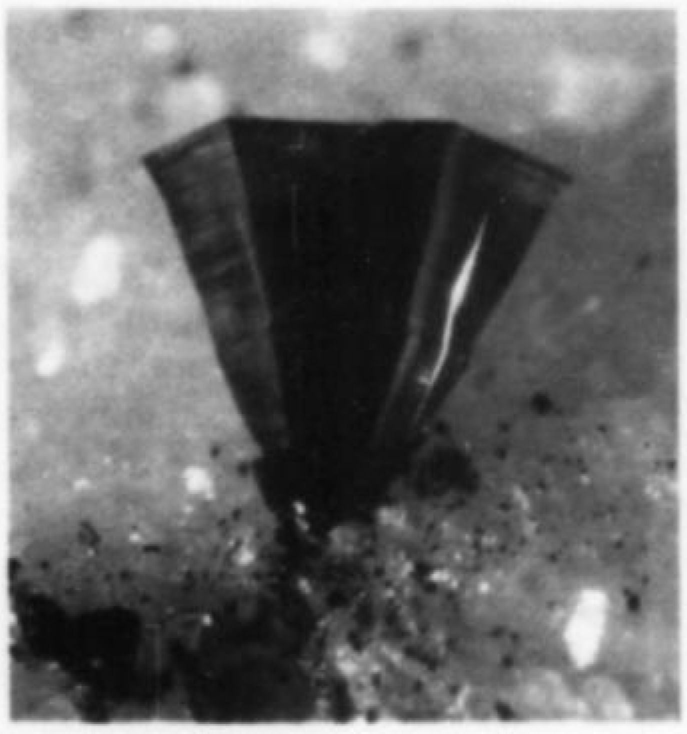

Figure 45. Pyramidal wurtzite crystal, 1.5 mm, Val Pulita quarry. Del Chiaro collection, Orlandi photo.

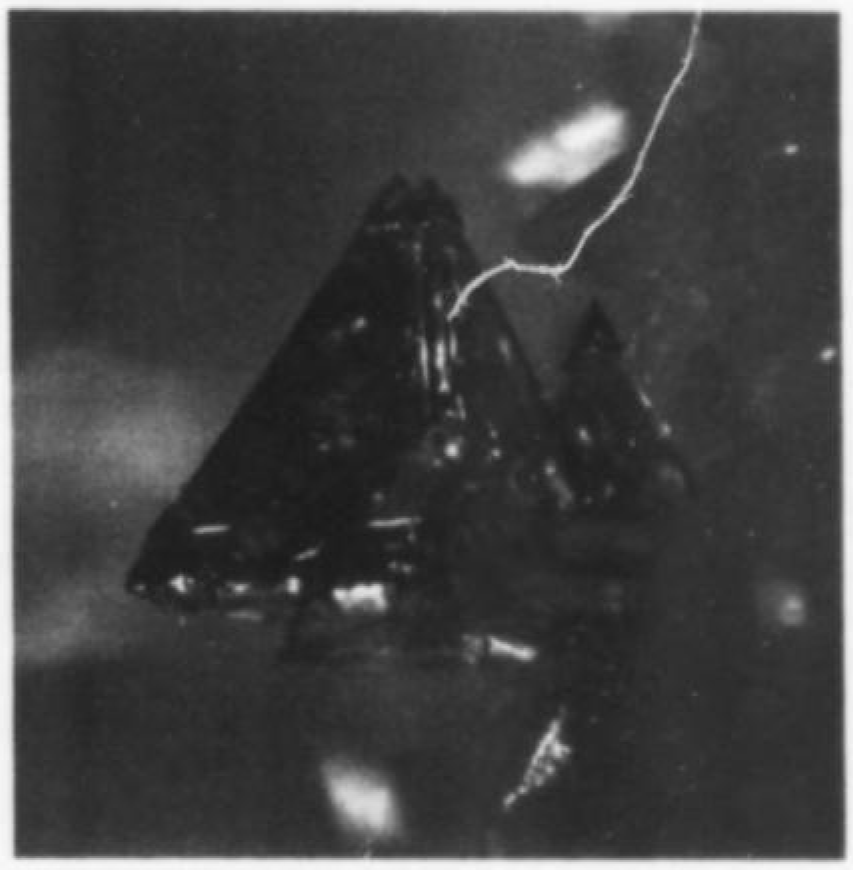

Figure 46. Red wurtzite in epitaxial overgrowth on yellow sphalerite crystal, 0.3 mm, Fossa degli Angeli quarry. Bianchi collection, Gini-Orlandi photo.

Figure 47. Wurtzite crystal, 3 mm, with colusite, La Facciata quarry. Granai collection, Gratziu photo.

Figure 48. Wurtzite parallel growth, 12 mm, Val Pulita quarry. Brizzi collection and photo.

Figure 49. **Geocronite crystal, 1 cm, one of the largest collected thus far, Calagio quarry. Granai collection, Bracci photo.**

Dell'Anna and Quagliarella obtained an Sb value of 0.2%; Bracci *et al.* obtained values of 0.11% and 5.8%. Therefore the presence either of geocronite or jordanite in the cavities of the Carrara marble is confirmed.

These two minerals are rather rare and are found predominantly in the Calagio quarries and in the Fantiscritti basin. They occur as very small crystals, though one crystal of geocronite measuring 4.5 mm has been found.

These minerals are almost always twinned, are lead-gray in color with a metallic luster and a well-defined crystal habit. Bracci *et al.* (1980) distinguished two characteristic habits:

1. A habit simulating a hexagonal dipyramid truncated by well developed {010} faces.

2. Pseudohexagonal-dipyramidal habit with characteristic striations on the faces and growth steps.

Moreover the authors advance a hypothesis that the crystals with type 1 habit are jordanite ($Sb = 0.11\%$), while those with type 2 habit are probably geocronite ($Sb = 5.8\%$).
Bibliography: 45, 47, 51, 52, 53, 56.

Zinkenite $Pb_6Sb_{14}S_{27}$

This rare sulfosalt of Pb and Sb has been found only in the Calagio quarries, associated with famatinite.

The crystals are acicular with striated faces parallel to the elongation, lead-gray color and often covered with an opaque alteration coating.

Cell parameters obtained from Weissenberg X-ray diffraction studies are: $a = 44.5$ Å, $c = 8.65$ Å. An electron microprobe analysis has also revealed the presence of Cu and As in more than negligible quantities (respectively 4.08 and 0.94%) and has yielded the formula $Pb_6Cu_{2.31}Sb_{10.81}As_{0.45}S_{27.44}$ which is in good agreement with the ideal formula $Pb_6Sb_{14}S_{27}$.
Bibliography: 53, 56.

Semseyite $Pb_9Sb_8S_{21}$

Semseyite is a very rare mineral, occurring as minute, dark gray crystals with metallic luster, associated with famatinite. It comes from the Calagio quarries. The crystals have rounded edges and are helicoid-shaped.

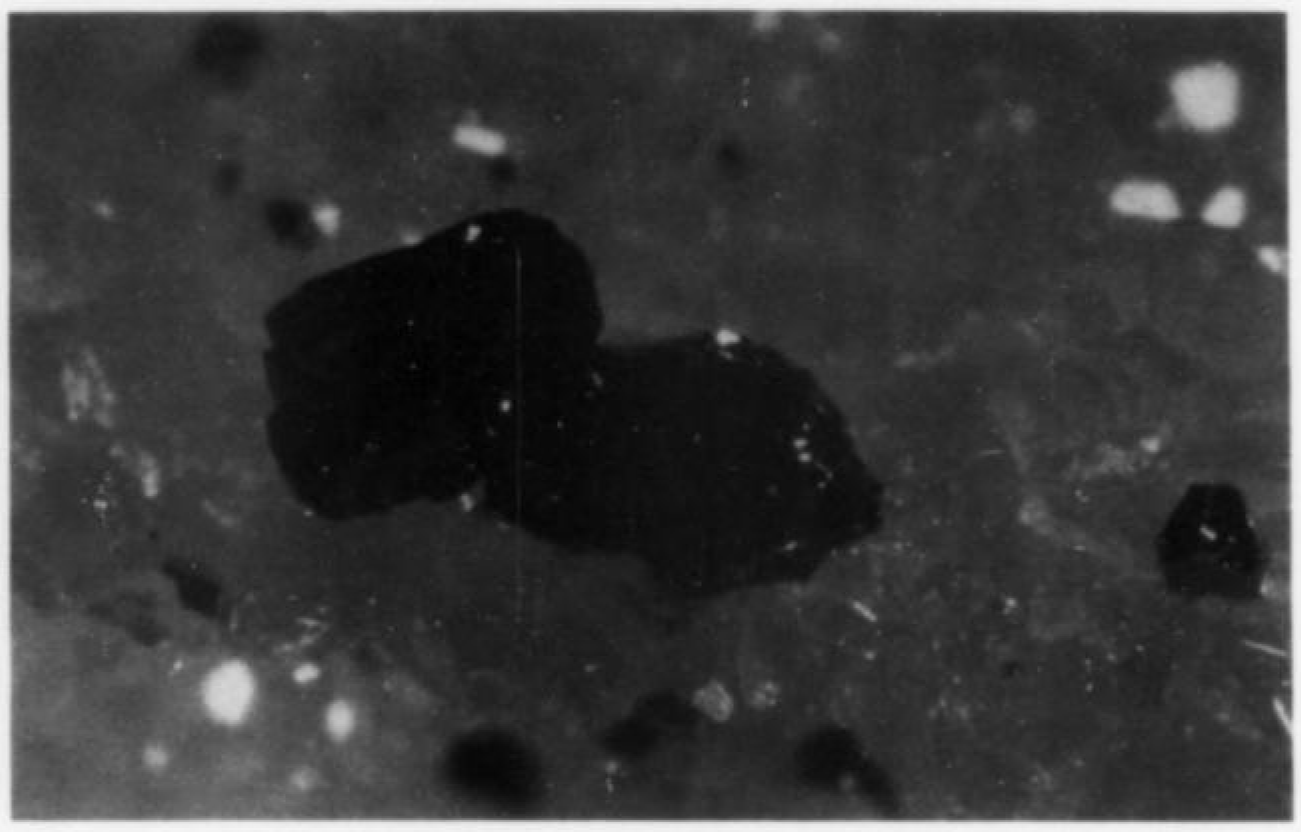

Figure 50. **Semseyite crystals, 2 mm, with pyrite, Calagio quarry. Lari collection, Bracci photo.**

Boulangerite $Pb_5Sb_4S_{11}$

Orlandi and Bianchi reported this sulfosalt from the Carrara cavities for the first time in 1976; it was identified by single crystal X-ray diffraction studies, and its crystallographic constants specified.

The mineral occurs as very thin acicular crystals tightly twisted together; it is gray in color and has a metallic luster.

Up to now boulangerite has been found only in the Calagio quarries and in some quarries of the Fantiscritti basin, usually associated with sphalerite, galena and pyrite.
Bibliography: 51.

Realgar AsS
Orpiment As_2S_3

These two minerals have been mentioned both by Giampaoli and D'Achiardi, who tried to carry out, among other things, a morphological study on realgar crystals; he succeeded in identifying with certainty only the form {110} because of the poor quality of the images from curved faces measured on the optical goniometer.

These two authors mention realgar as a very rare mineral and say that the two minerals come from the Ravaccione and Lorano Basso quarries.

Apart from a sample of uncertain locality that has been found very recently, the authors have seen only the old specimens kept at the Museum of Mineralogy of Pisa.

Orpiment has been observed occurring as very thin, golden splinters, as an alteration product of realgar crystals.
Bibliography: 28, 32, 34, 52.

Halides

Sellaite MgF_2

The first and only report of this rare mineralogical species in the cavities of the Carrara marble dates back to Pelloux (1919). The author described a crystal without matrix, which he had received from some "amateurs of the mineral sciences" who had purchased it at the Piastra quarry.

The crystal is prismatic in habit and measures about 3 x 5 mm.

The prism is composed of nine faces, a very thin one of the form {120} and the others of the forms {100} and {110} having approximately the same degree of development.

At one end the crystal is broken while at the other it is "drusely" terminated by faces of the form {011} belonging to parallel individuals, and by three faces belonging to the dipyramids {112}, {551} and {4.11.1}.

Moreover, Pelloux noticed that the crystal contained minute in-

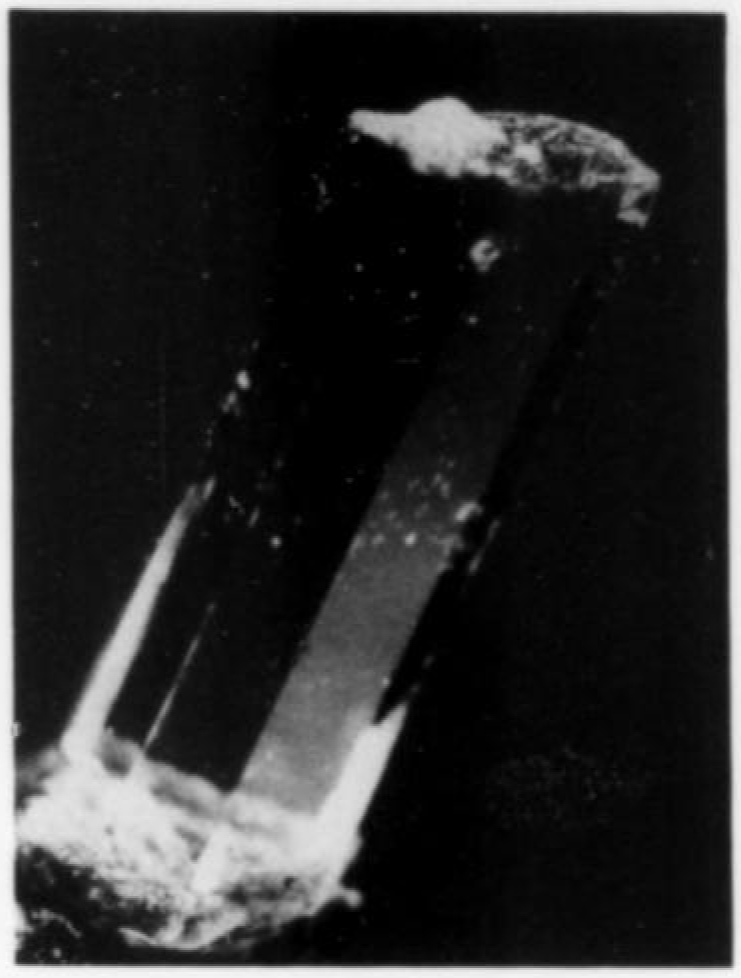

Figure 51. **Sellaite crystal, 5 mm, the only one collected thus far, La Piastra quarry. University of Bari collection, Gini-Orlandi photo.**

clusions of gypsum, sulfur and probably anhydrite as in the sellaite of Gebroulaz.

The fact that only a single sellaite specimen has been found serves to underline its rarity. The unlimited availability of Ca^{++} ions if compared to those of Mg^{++} has certainly influenced the sellaite-fluorite equilibrium in favor of the latter.
Bibliography: 41, 52, 56.

Fluorite CaF_2

Fluorite crystals are normally colorless with somewhat greasy luster and an almost universal cubic habit. The cube faces commonly have approximately equal development, but sometimes two opposing faces prevail on the others and the crystal takes on a tabular appearance.

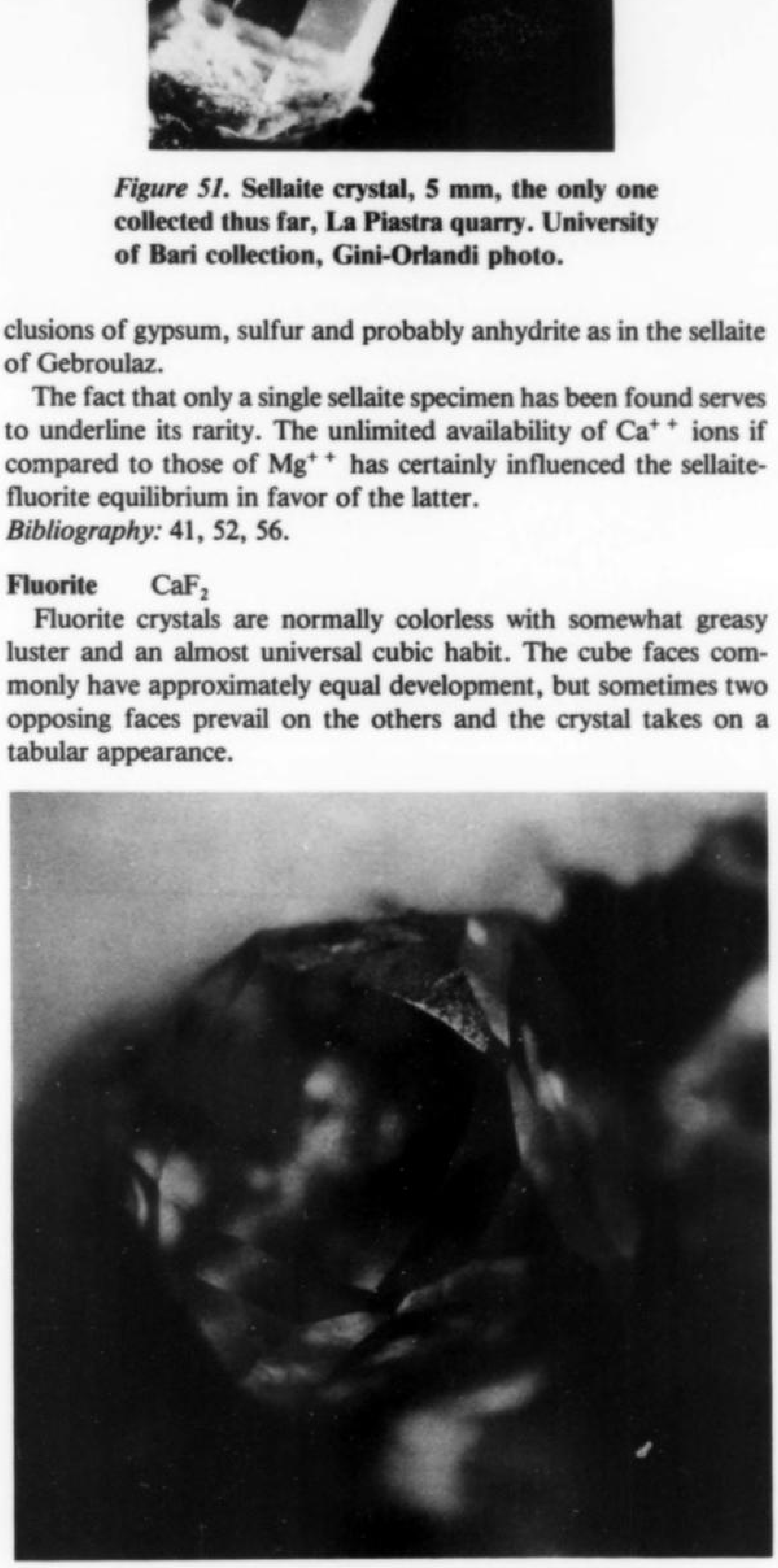

Figure 52. **Fluorite crystal, 3 mm in size and colorless, showing the forms {111}, {110} and {221}; Gioia quarry. Lunardi collection, Bracci photo.**

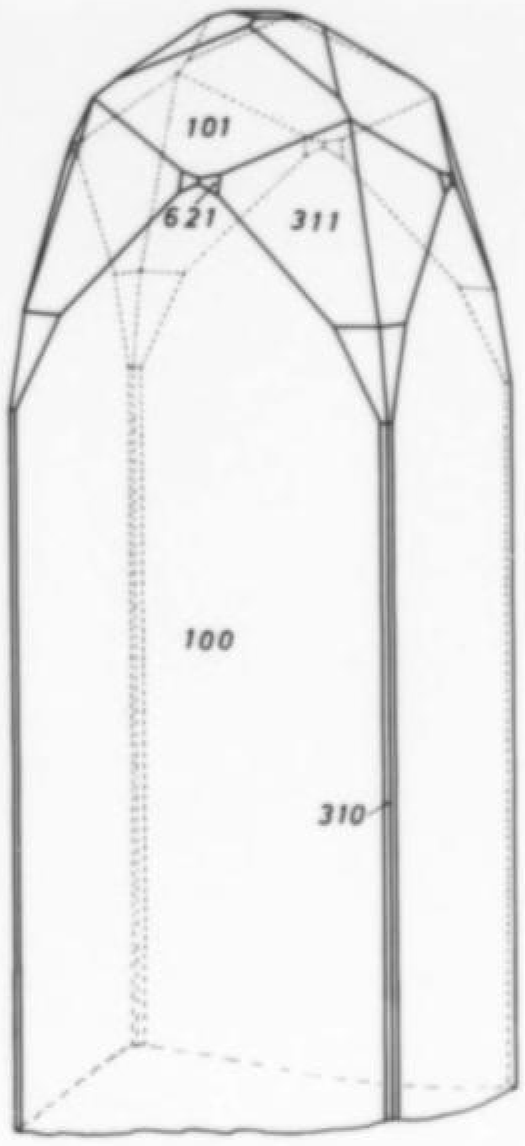

Figure 53. **Fluorite crystal drawing showing elongated habit, after Dalena (1978).**

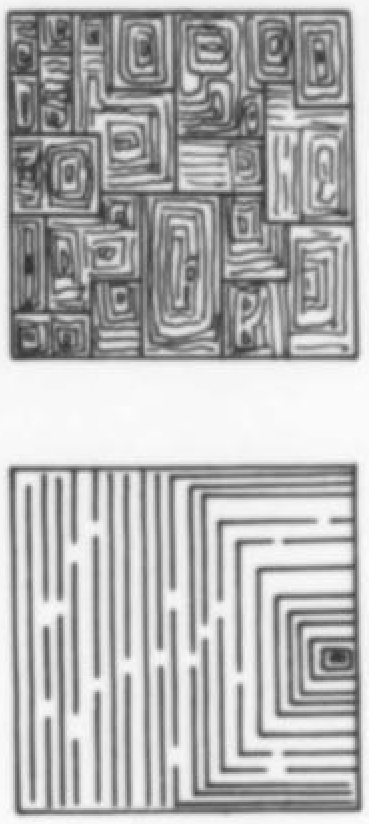

Figure 54. **Fluorite drawing showing growth hillocks on cube faces, after D'Achiardi (1905b).**

Crystals with a prismatic habit (distorted along the 4-fold axis) have also been observed; a crystal with this type of habit whose terminated extremity has developed numerous small faces is quite exceptional (Fig. 53). Penetration twins about [111] are very rare; parallel association by which a smaller cube appears to be implanted on the face of a larger one is also rare.

The cube faces are never perfectly flat, but show typical accretion figures appearing as numerous, small, step-like reliefs with lines parallel to the edges of the cube and making the surfaces of these faces rough.

Fluid inclusions within polyhedral cavities were observed in 1893 by Silvestri.

Fluorite is one of the most common minerals in the cavities, found in every quarry of the Carrara basin; it is particularly abundant in the Piastra quarry. The minerals that most frequently accompany fluorite are quartz, gypsum, dolomite and albite.

Fluorite with a typical violet color and always associated with adularia (orthoclase) crystals is typical of the Crestola Bassa, Gioia, Campanili and Calagio quarries, where cavities are in dolomite masses included in the marble.
Bibliography: 16, 24, 26, 28, 32, 34, 39, 52, 53, 56.

Oxides and Hydroxides

Hematite Fe_2O_3

Hematite is a relatively common mineral in the massive marble and in veins, associated with magnetite in the marble varieties known as *paonazzo* and *paonazzetto*. It is extremely rare in cavities.

The only two specimens known were collected on the dumps of the Gioia quarries; hematite, occurring as bright lamellar crystals, was found associated with violet fluorite and adularia (orthoclase).
Bibliography: 32, 34, 52, 56.

Quartz SiO_2

Of the many cavity minerals from the Carrara marble, quartz is preeminent in a number of ways. It is among the most wide-spread minerals; it has been known and described for the longest time; and

Figure 55. **Fluorite crystal, 2 mm, Gioia quarry. Del Chiaro collection, Guelphi photo.**

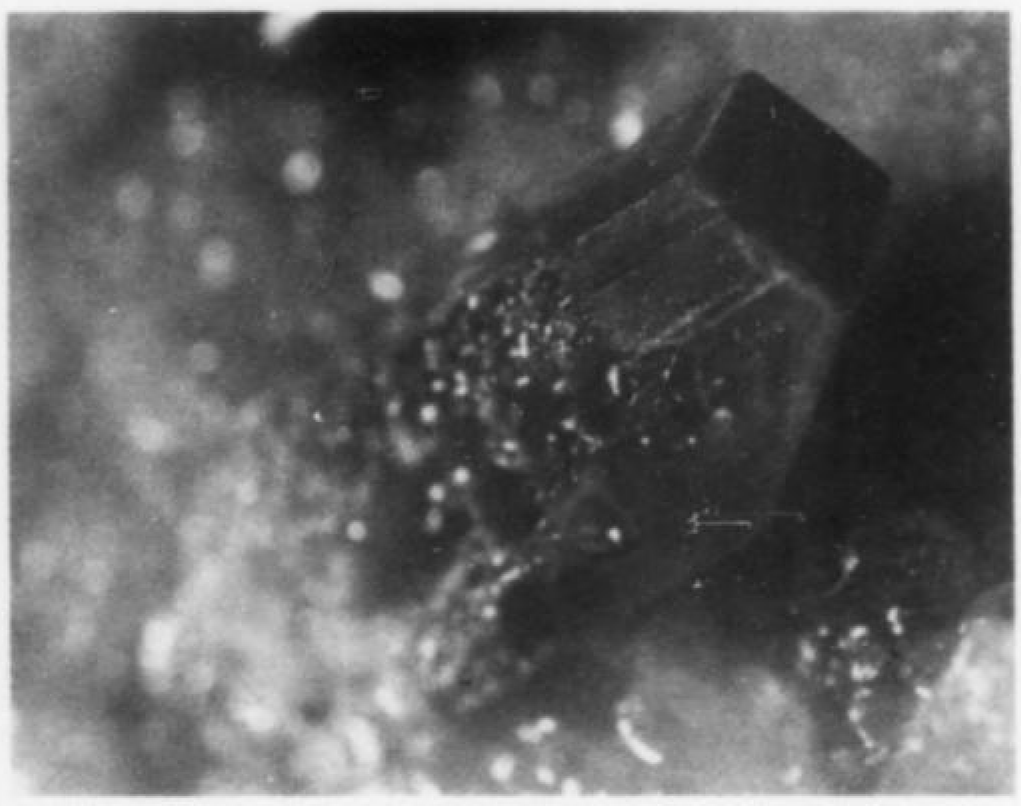

Figure 56. **Realgar crystal, 4 mm, quarry unknown. University of Pisa collection, Orlandi photo.**

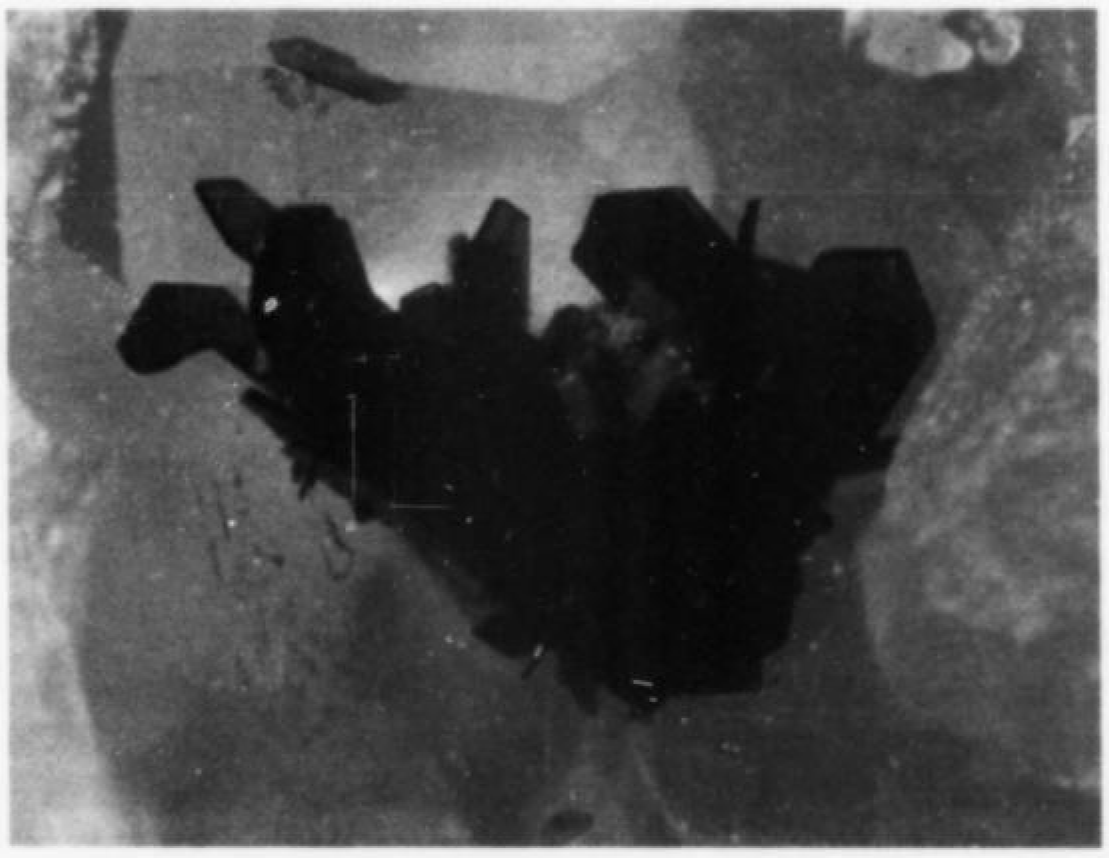

Figure 57. **Azurite crystals to less than 1 mm, Calagio quarry. Bianchi collection, Orlandi photo.**

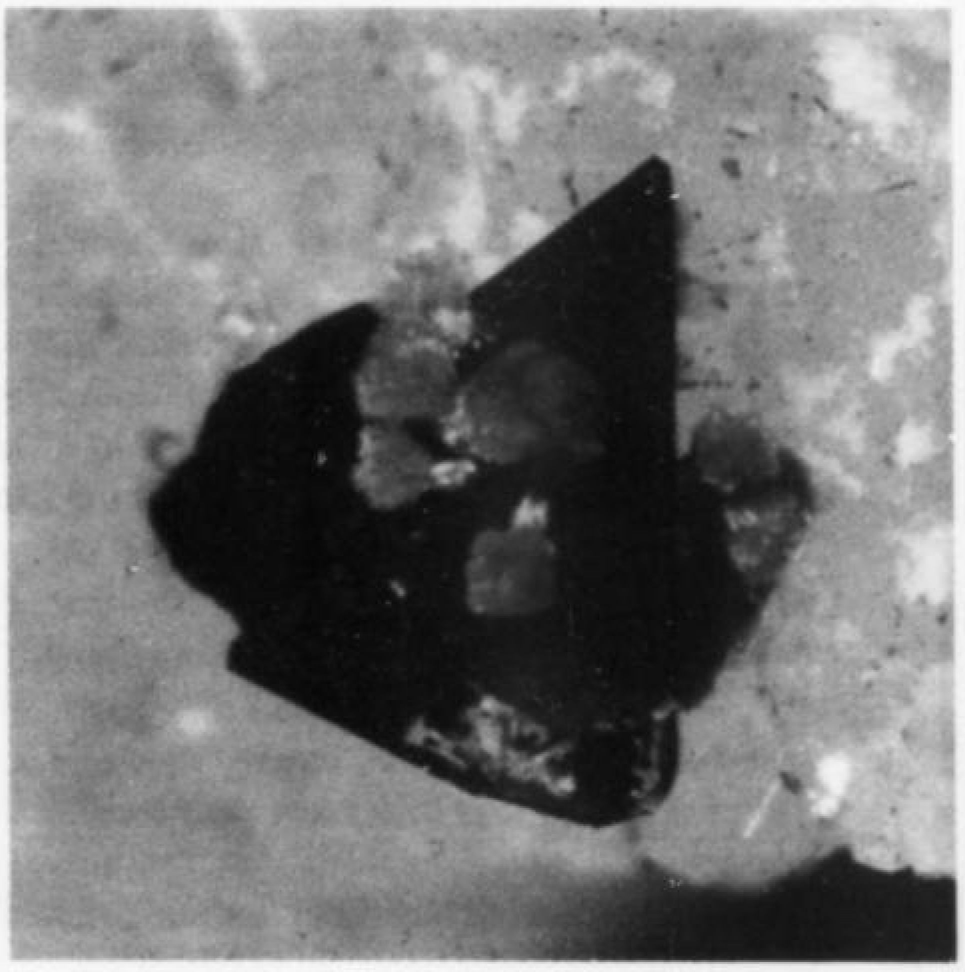

Figure 58. **Malachite on altered tetrahedrite (?), 1 mm, Calagio quarry. Lari collection, Bracci photo.**

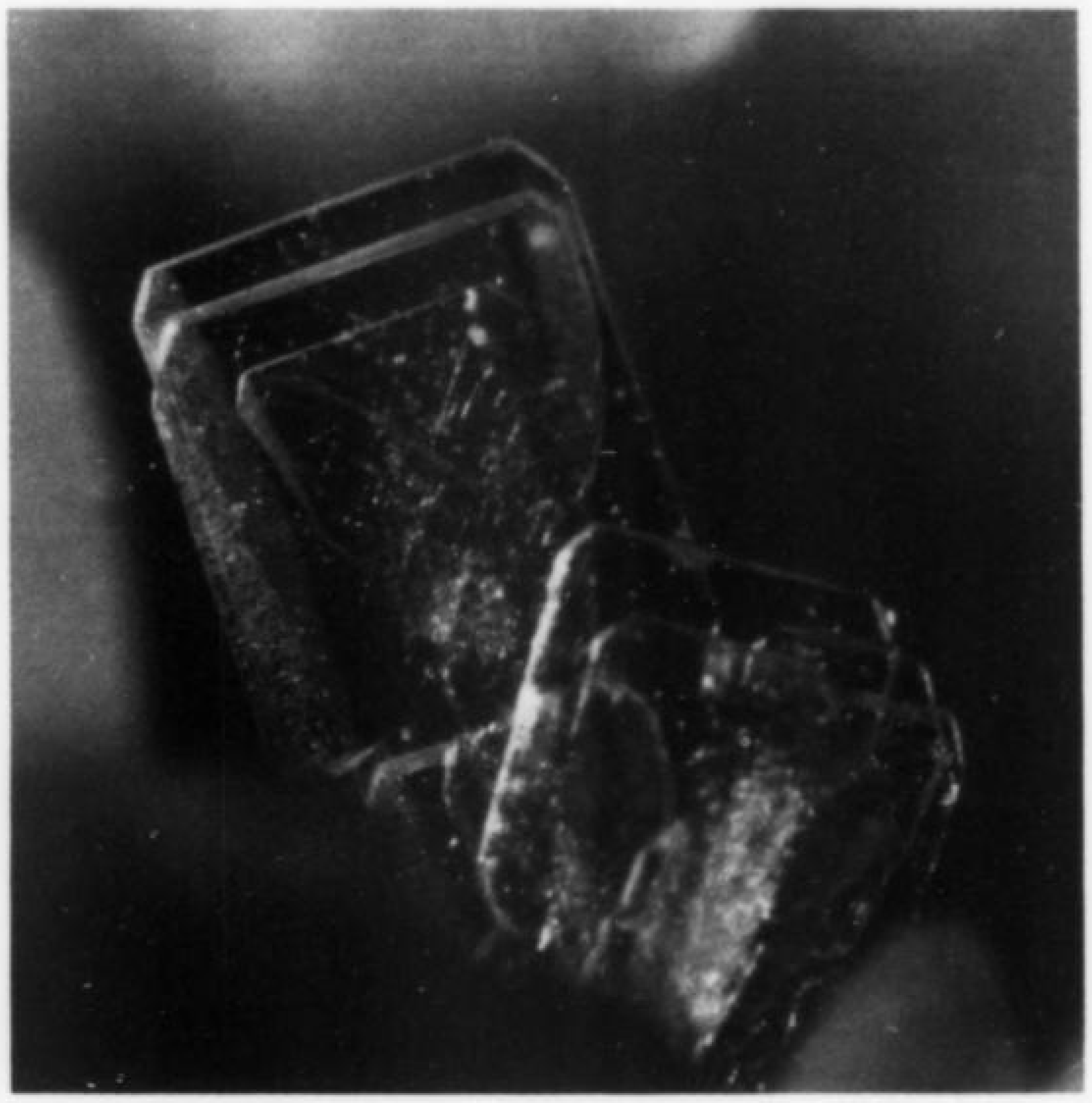

Figure 59. **Celestite crystals, 2 mm, Lucchetti quarry. Marini collection, Gratziu photo.**

it forms, like gypsum, the largest crystals. Other, more subjective, distinctions apply as well: it is among the most beautiful minerals of the cavities; it is the easiest to identify even by the layman; and it has been the most heavily traded specimen species.

There are numerous reports in the literature concerning quartz, but they tend to be somewhat disappointing. Quartz from the Apuan marble, because of the perfection of its crystalline habits, has attracted more interest among researchers for its general properties than for the peculiarities of its different occurrences. Apuan marbles have been adopted as a training ground for specialized

Figure 60. **Quartz crystal (left handed), 2 cm, La Facciata quarry. University of Pisa collection, Gini-Orlandi photo.**

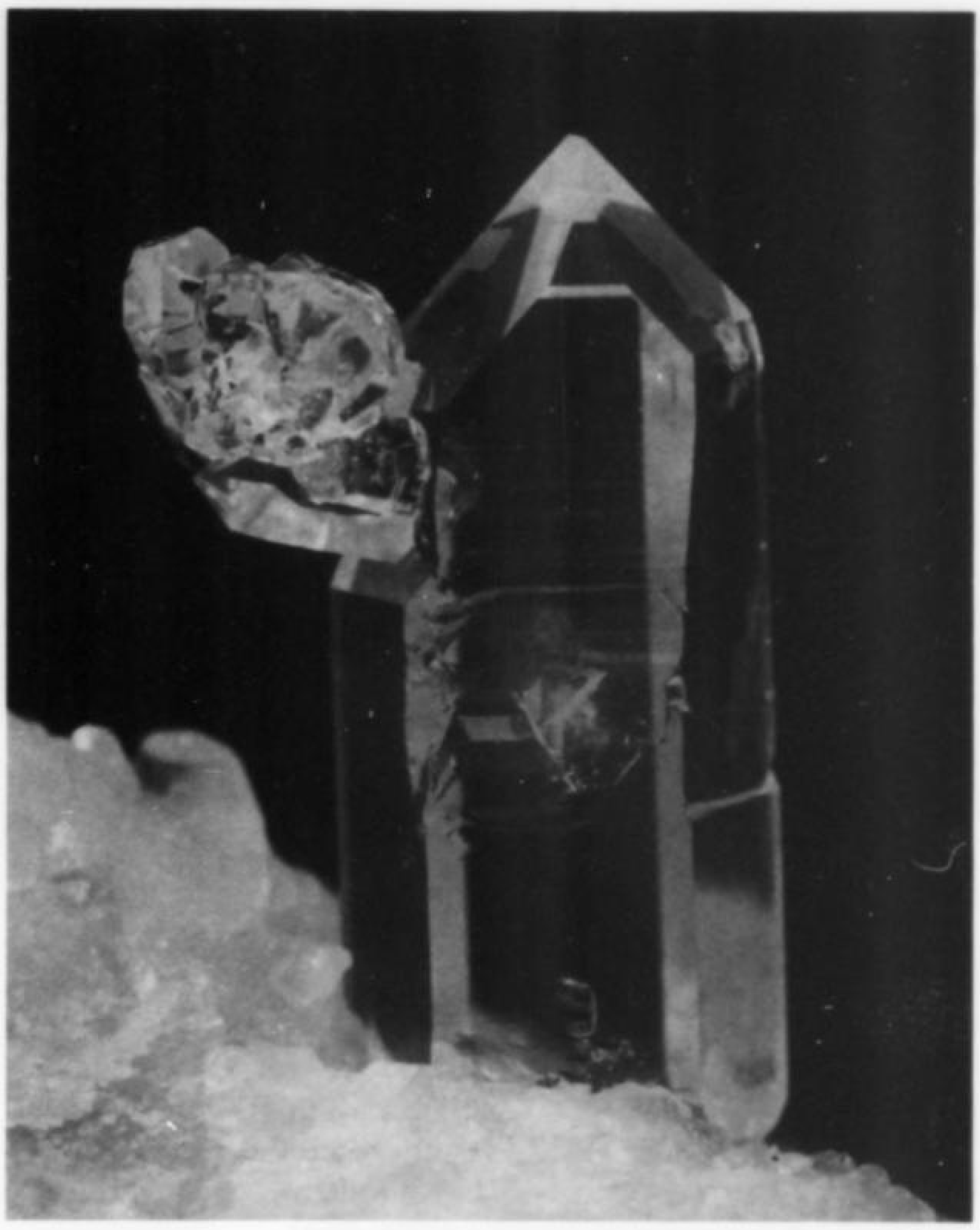

Figure 61. **Quartz crystal, 1.5 cm, Fantiscritti quarry. Bianchi collection, Guelfi photo.**

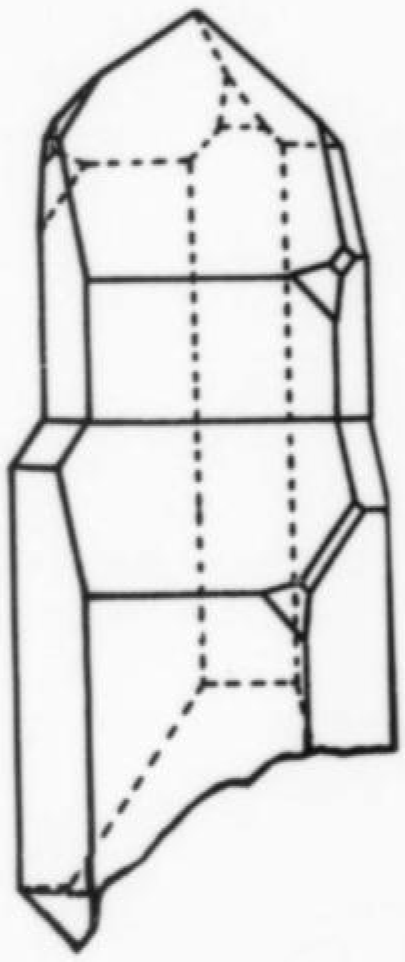

Figure 62. **Quartz crystal drawing from Aloisi (1909).**

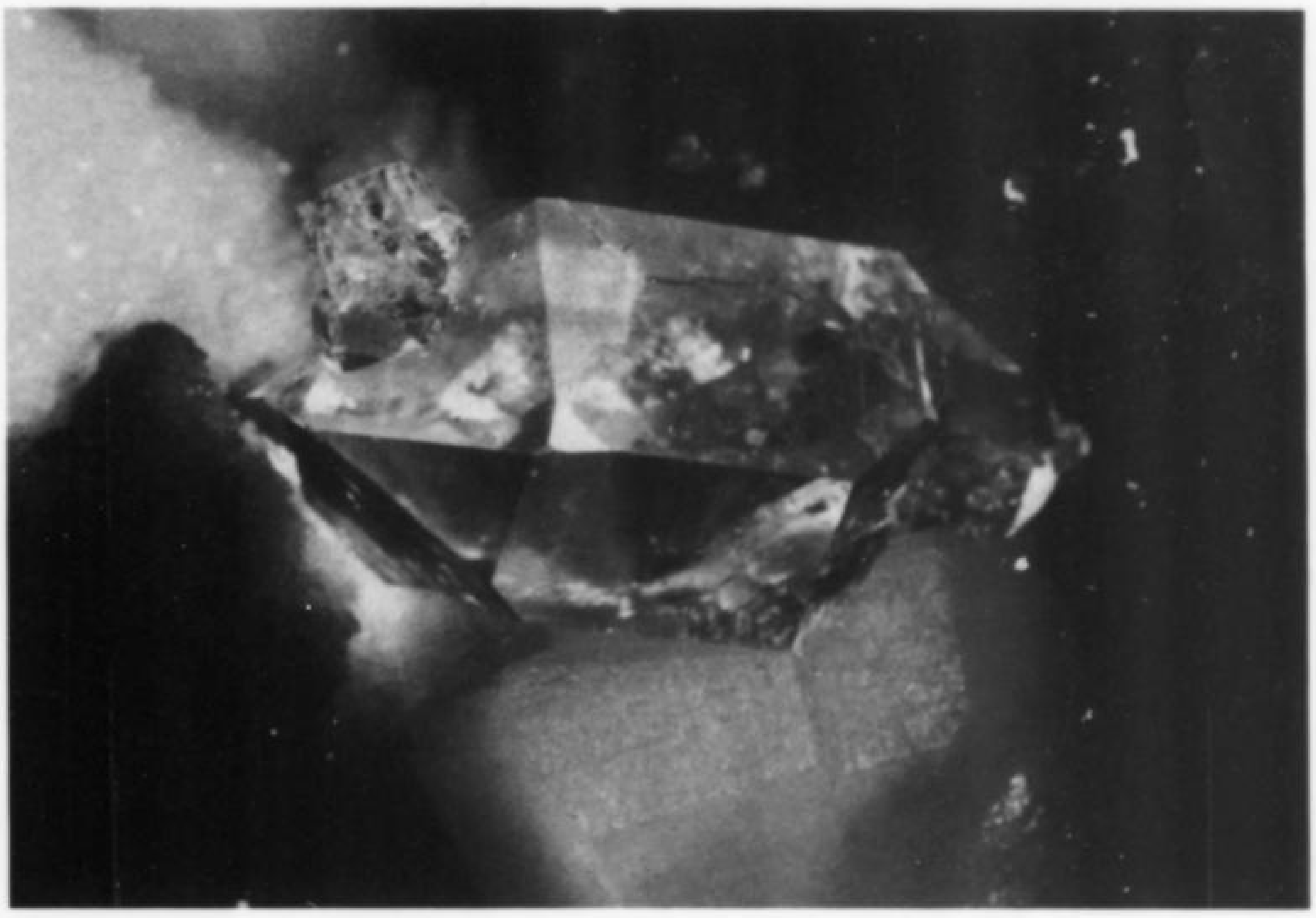

Figure 63. **Quartz crystal, 1.5 cm, La Facciata quarry. University of Pisa collection, Orlandi photo.**

research (such as that of Tonani on morphology) in numerous subfields of classic and modern mineralogy.

To explain the remarkable perfection of cavity quartz crystals from Carrara is it useful to remember the conditions of genesis. As early as the late 1700's, Spallanzani considered the crystals noteworthy, observing that almost all quartz crystals at other localities are implanted on a siliceous matrix, whereas those of the Carrara marble always have calcareous matrix. Mineral collectors know that this is not so rare. However, it is true that quantitatively, quartz crystals on limestone (or on marble) are rare, since the percentage of SiO_2 of these rocks is usually low. (The common white marbles of Carrara have SiO_2 contents lower than 0.1%.)

From these data it follows that quartz crystallization in marble cavities is a slow-moving phenomenon that can produce crystals of particular perfection. And how perfect they are! As Spallanzani said:

> Of the huge quantity of rock crystals preserved in the museum of Pavia, those from Germany, Hungary, Switzerland and other areas are valuable in themselves, some of them being choice crystals; nevertheless there is none that could be compared to the Carrara crystals.

A description of quartz was given by Aloisi, who lists, among other things, a bibliography requiring only the addition of the already quoted 1955 work by Tonani to be brought up to date.

The quartz crystals from Carrara cavities are very limpid and colorless; sizes range from a few millimeters to about 10 cm. At the Museum of Mineralogy at Pisa University a crystal from the Zaccagna collection is preserved; it was collected in the Scaloni quarries (bardiglio marble varieties) in 1889 and was described by Aloisi. It measures 9 cm in the direction of the 3-fold axis, and has a maximum width of 8 cm.

The habit is defined by the constant association of the prism, normally not much developed, with both rhombohedrons $\{10\bar{1}1\}$ and $\{01\bar{1}1\}$. Perfect, doubly terminated crystals are not rare, which is rather surprising.

Other habits are less common, differing from the one described above either because the crystals are flattened on two opposite faces, because they occur in a triangular shape due to the development of three alternate faces of the prism, or because they show faces with shapes different from the ones mentioned above.

Carrara quartz therefore shows a very simple habit; however in the literature, based on the study of a great number of crystals, 84 different forms have been identified. Following a careful critical review and consideration of new, personally collected data, Aloisi considered as certain only 36 forms, which are classified as follows:

1 hexagonal prism
10 positive rhombohedrons
17 negative rhombohedrons
2 trigonal dipyramids
6 trigonal trapezohedrons

Much has been said of the peculiarities of crystal faces which show striations, opacities, and other surface features mostly related to crystal growth, or more rarely due to corrosion. The particularly interesting demonstration given by Tonani using delicate interferometric methods, showed the presence of a double saddle-like bending developed mainly from the rhombohedron faces.

Even these observations are not particularly unusual for the species; in fact, at least at the macroscopic level, all these phenomena are not very strikingly developed in Carrara quartz. The crystals mostly show perfectly flat and shiny faces, even on the prism which is typically striated at other localities. This accounts for the uncommon brilliance of Carrara quartz crystals, which give light from numerous internal reflections made possible by the perfection of the faces.

Parallel growths are not especially common, at least for the most classic, perfectly clear and colorless crystals, which occur almost always isolated like the crystals of all the species described. However, Aloisi described parallel growth of crystals having the "helicoidal" or gwindel habit, and also overlapping crystals along the axis of greater symmetry regularly decreasing in size.

Twins according to the Dauphine law are common and macroscopically recognizable when the trapezohedron has developed; the faces of this form are found on two adjoining vertices.

Much rarer are twins on the Brazil law, with complete penetration of the two twins to generate an apparently single crystal in which, however, faces of right and left forms are found simultaneously. This determination is not always easy or certain; it would therefore be suitable, from a purely diagnostic point of view, to have it confirmed by optical observations which, unfortunately, require the destruction of the crystal. It is therefore better to remain in doubt and keep the specimen intact.

Crystals twinned on the Japan law have been described by several authors, but Aloisi considers them as doubtful. In fact, this twin can be feigned by chance unions of crystals and a reliable identification can be obtained only by means of rather exact goniometric measurements.

Bibliography: 1, 2, 3, 4, 5, 7, 8, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 25, 26, 30, 32, 35, 38, 43, 44, 52.

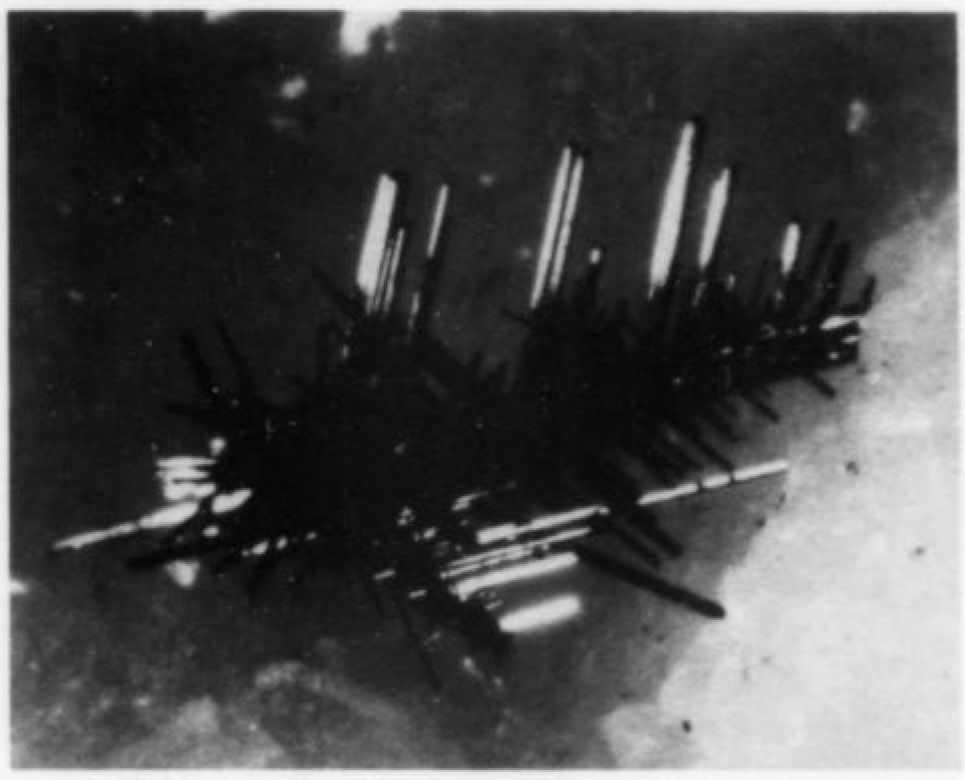

***Figure 64.* Rutile crystal intergrowth, 5 mm, Crestola quarry. Salini collection, Gini-Orlandi photo.**

***Figure 65.* Rutile crystals, 4-5 mm, Crestola Bassa quarry. Orlandi specimen, Gratziu photo.**

Rutile TiO_2

Rutile is rather common in the Crestola Bassa and Gioia quarries and is one of the few cavity minerals found at two quarries only. Rutile occurs generally as acicular crystals up to several centimeters long, striated parallel to the elongation, red-brown in color and with a submetallic luster. Reticulated acicular intergrowths similar to what is called "sagenite" rutile have been observed; knee-like twins are rarer.

Quartz, dolomite and orthoclase are the minerals most frequently associated with rutile.

Cavities in which rutile has been found are in dolomite masses at both of the above-mentioned localities. Concerning the quarries of Crestola Bassa, the data of Bracci *et al.* (1978) show relatively high TiO_2 contents (500 ppm) in dolomites containing cavities. In this particular case the presence of rutile, like that of anatase and brookite in cavities of the same quarry would seem directly due to

Figure 66. **Rutile, twinned crystal, 1 cm, Gioia quarry. Salini collection, Gini-Orlandi photo.**

the particular composition of host rock surrounding the cavities. The same mechanism is likely to have operated at the Gioia quarries, though data is not currently available.
Bibliography: 28, 34, 52, 55, 56.

Anatase TiO_2

Thus far anatase has been found only at the Crestola Bassa quarries.

The crystals show typical dipyramidal habit, which is sometimes truncated by the remarkable development of the pinacoid {001}. The smaller individuals are transparent and reddish brown in color. They are found in marble cavities near masses of pink or grayish dolomite, associated with milk-white crystals of adularia and dolomite.
Bibliography: 53, 56.

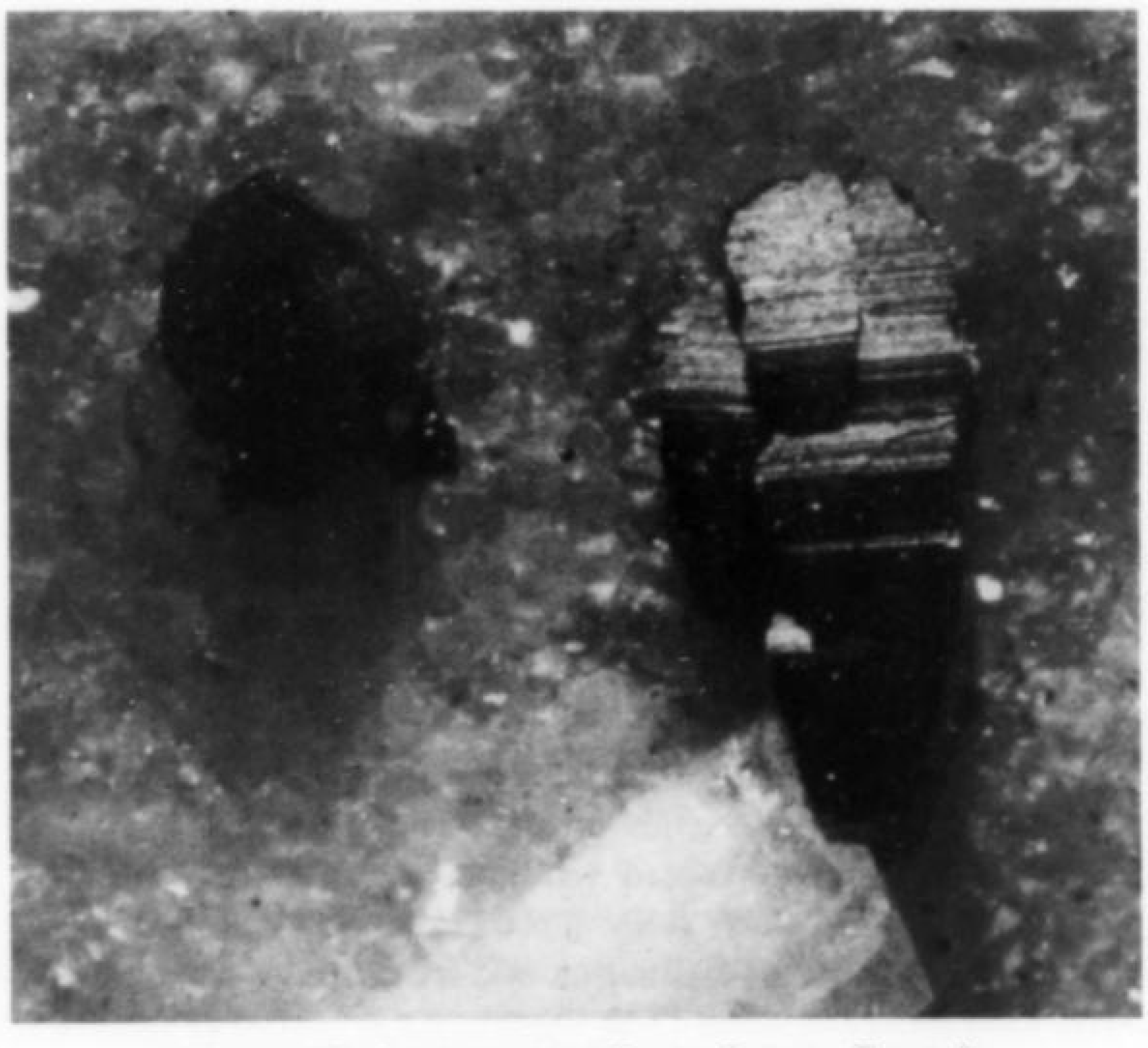

Figure 67. **Anatase crystals, to 3 mm, Crestola quarry. Orlandi collection, Bracci photo.**

Brookite TiO_2

Also in the Crestola Bassa quarries, where rutile and anatase have been found, brookite, the third of the TiO_2 polymorphs, has recently been found and reliably identified.

It occurs as very pale brown crystals with typical longitudinal striations on the faces. The crystal size varies from a few millimeters to about 1 centimeter in length.
Bibliography: 58.

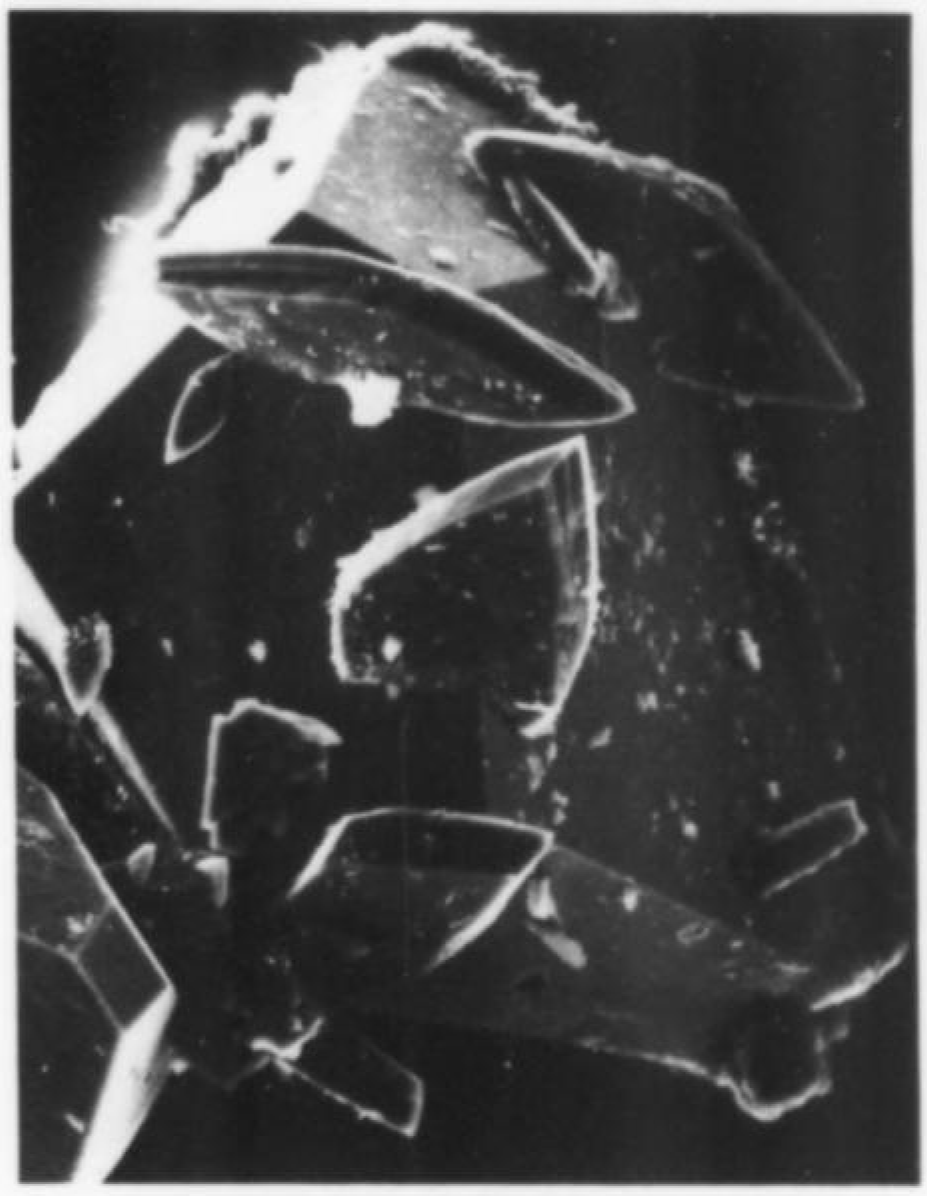

Figure 68. **Gibbsite, in platy crystals to 140 microns, on pyrite, Fantiscritti quarry. Del Chiaro collection, Orlandi SEM photo.**

Gibbsite $Al(OH)_3$

Gibbsite usually occurs as white, opaque spherules made up of bacillary individuals lacking in a crystalline habit, but rather similar to small stalactitic protuberances.

It is difficult to identify this species without specialized techniques because of the presence of two other similar minerals in marble cavities: hydrozincite and strontianite.

So far only one specimen of gibbsite in crystals with well-defined habit has been found; they are lance-shaped microscopic crystals on pyrite.
Bibliography: 51.

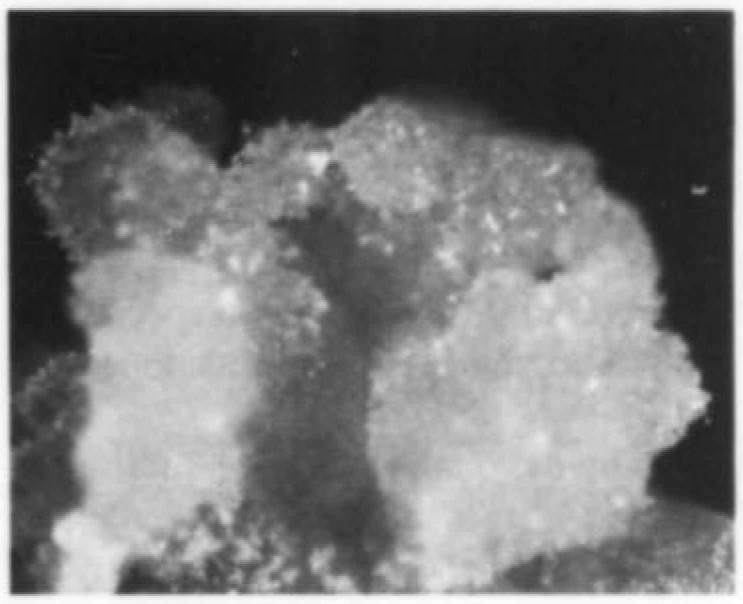

Figure 69. **Nordstrandite crystal aggregate, 1.5 mm, Calagio quarry. Lari collection and photo.**

Nordstrandite $Al(OH)_3$

Nordstrandite is the most recently identified mineral from the marble cavities. It has been found in a sample from the Fantiscritti quarry. It occurs as a minute (1 mm) microcrystalline aggregate of microscopic, pale apple-green crystals.

Figure 70. **Lithiophorite, in brown earthy spherules, 3 mm, Lorano quarry. Bianchi specimen, Dalena-Bracci photo.**

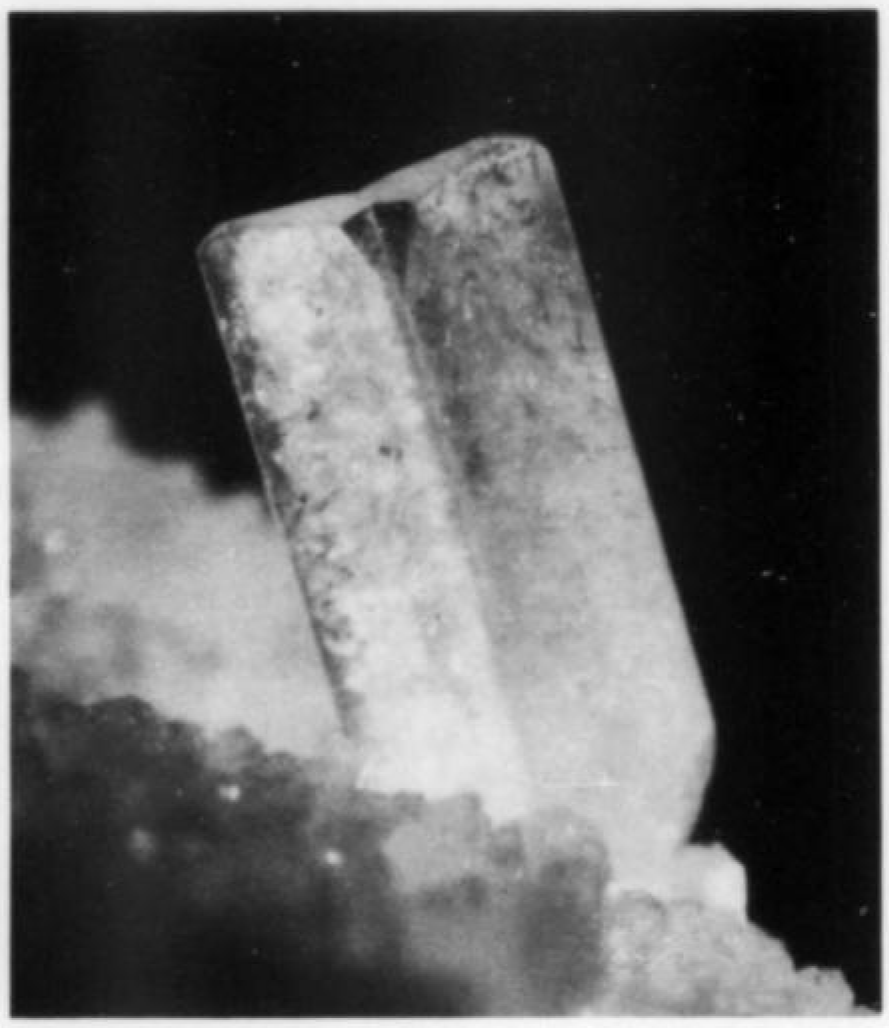

Figure 71. **Calcite, twinned crystal 9 mm long, Calagio quarry. Dalia collection, Orlandi photo.**

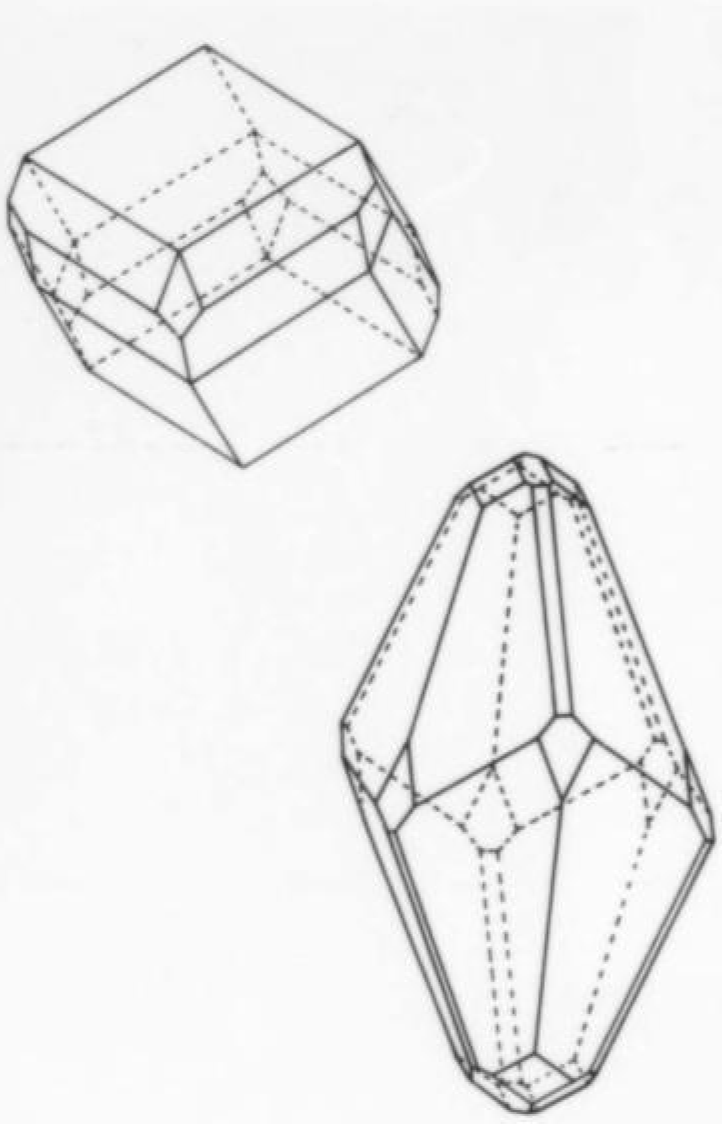

Figure 72. **Calcite crystal drawings after D'Achiardi (1905a).**

Lithiophorite $(Al,Li)Mn^{+4}O_2(OH)_2$

Lithiophorite has been found in the Lorano quarries where it occurs as earthy aggregates of deep brown spherules. Chemical qualitative analysis by X-ray fluorescence has shown, besides the presence of manganese, traces of Zn, Ni, Cu and Co.

Carbonates

Calcite $CaCO_3$

Calcite is always present in marble cavities, occurring as minute, transparent crystals of the same sizes as the grains in the marble mass. It forms either beautiful crystallizations made up of scalenohedral and rhombohedral individuals, or spathic masses sometimes reaching remarkable sizes.

The largest crystals are 4–5 cm long; they are generally opaque and milk-white in color. The most common habits result from the prevailing development of the principal rhombohedron $\{100\}$ and the scalenohedron $\{20\bar{1}\}$.

A morphological study carried out on more than 100 crystals by D'Achiardi showed that only a very small proportion of crystals is suited to such analysis, and that "crystals yielding satisfactory results for all forms are the exception."

D'Achiardi noted that associations of the forms $\{100\}$, $\{3\bar{1}\bar{1}\}$ and $\{20\bar{1}\}$ are the most common in crystals with a rhombohedral habit, while in crystals with scalenohedral habit he recognizes two common and different form associations: $\{100\}$, $\{3\bar{1}\bar{1}\}$, $\{110\}$, and $\{20\bar{1}\}$; and $\{100\}$, $\{311\}$, $\{110\}$, $\{11\bar{1}\}$ and $\{20\bar{1}\}$. Moreover he notes that the rhombohedron faces $\{100\}$ are present in practically every crystal and constantly show a "reeding" generated by two systems of numerous and thin striations "giving them a special appearance and luster." The rhombohedron $\{3\bar{1}\bar{1}\}$ and scalenohedron $\{20\bar{1}\}$ are always present.

Spathic calcite (called *luccica* by the quarrymen) is in indication of the nearby presence of cavities; in fact this type of calcite contains those particular types of cavities that we have called "cavities in spathic calcite" and, more rarely, partially fills the cavities contained in the *macchia bianca.*

Chemical analyses carried out on samples of spathic calcite have revealed the presence of appreciable amounts of Mg (MgO = 1% on the average). X-ray diffraction analyses have shown that Mg is present both in the calcite lattice itself (substituting for Ca^{++}) and in thin dolomite domains irregularly scattered through the calcite.

Isotope analyses have been carried out on associations of gypsum, calcite and dolomite crystals as well as on the calcite of the marble matrix, in order to determine their O^{18} and C^{13} content. These have been done in order to verify the existence of an isotopic equilibrium between gypsum, calcite and dolomite and between these minerals and the marble matrix; such an equilibrium, if found, could be used to estimate the temperature of formation. Unfortunately, calcite and associated dolomite proved not to be in isotopic equilibrium and were probably deposited by solutions of varying physiochemical parameters.

Bibliography: 5, 11, 26, 32, 33, 36, 48, 52.

Dolomite $CaMg(CO_3)_2$

Dolomite is very common in the cavities. It is particularly distinctive due to the constant bend of the faces of the rhombohedron and the resulting typically saddle-shaped crystals.

Isolated crystals, generally infrequent, are opaque and milky white in color. Aggregates of numerous saddle-shaped rhombohedral crystals with a pearly luster are most common.

The pale green color that some saddle-shaped groups show is due to traces of iron and manganese as shown by X-ray fluorescence analysis and not to "minutely scattered chlorite" as asserted by Giampaoli.

Chemical and mineralogical analyses have shown that dolomite crystals are actually composed of two distinct phases: dolomite and calcite, the latter in microscopic domains amounting to between 4–10% of the crystals (Bracci *et al.,* 1978).

Bibliography: 11, 12, 26, 32, 33, 48, 52.

Aragonite $CaCO_3$

Only one sample of aragonite has been found. It occurs as colorless and transparent crystals up to 3 mm in length, having a prismatic habit and a pointed termination. The calcite crystals lining the cavity in which aragonite crystals are implanted show considerable evidence of dissolution and are coated with an apple-green, unidentified mineral. The specimen was found at the Fantiscritti quarry.

Bibliography: 59.

Figure 73. **Dolomite in typically saddle-shaped crystals, 3 cm, Colonnata quarry dumps. Baldi collection, Gini-Orlandi photo.**

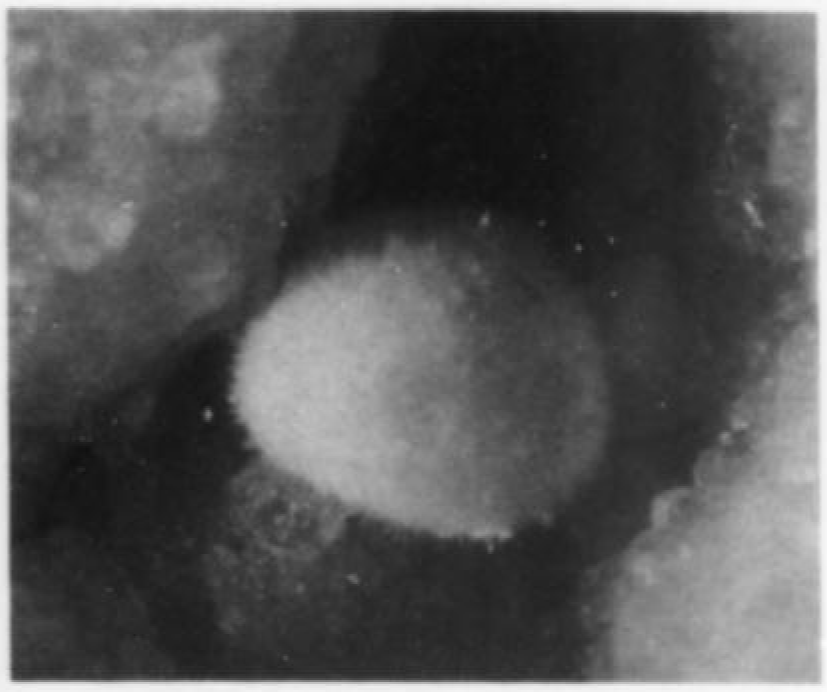

Figure 74. **Dawsonite, spherical aggregate, 1 mm, Fossa degli Angeli quarry. Lunardi collection, Guelfi photo.**

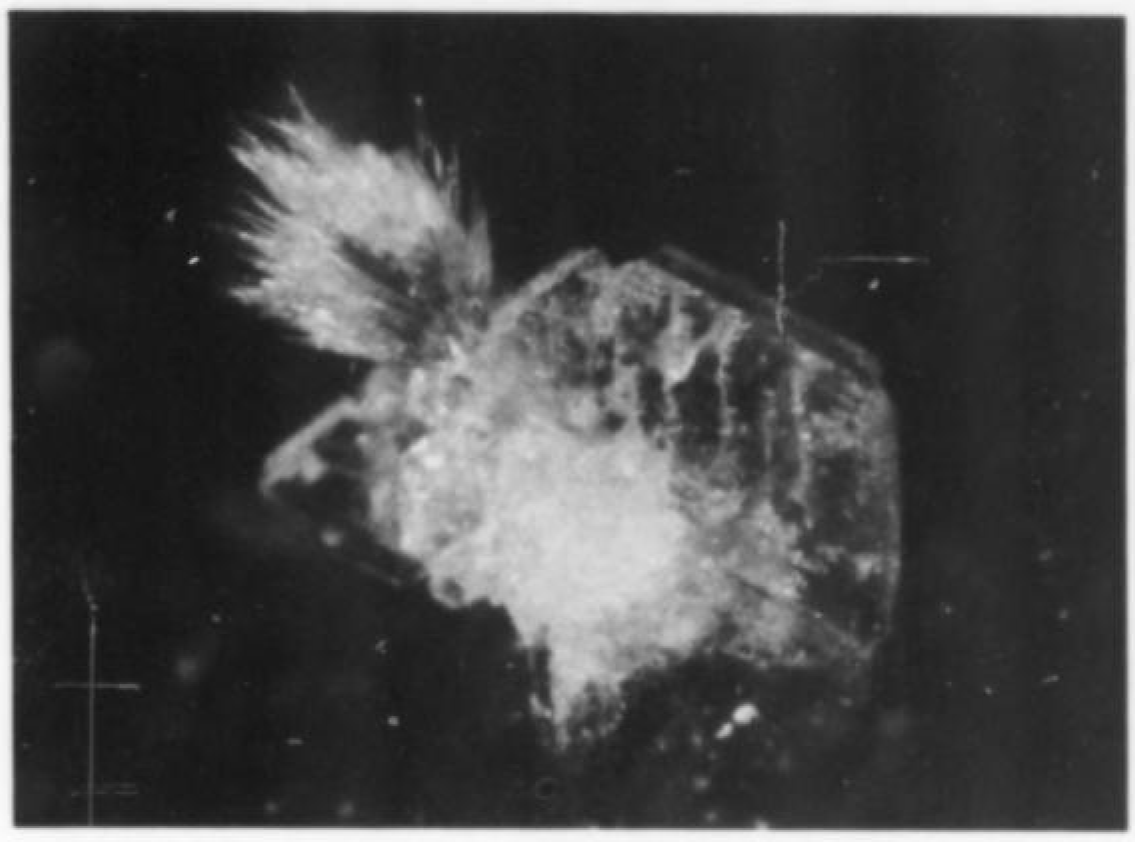

Figure 75. **Strontianite crystals, 2 mm, La Facciata quarry. Lunardi collection, Orlandi photo.**

Dawsonite $NaAl(CO_3)(OH)_2$

Dawsonite has been recently found as white spherical tufts and aggregates less than 1 mm in diameter at the Fossa degli Angeli quarry.

Strontianite $SrCO_3$

Strontianite occurs as thin, white, translucent, acicular crystals always in tufts and globules. It has been found in the Lorano and Fantiscritti areas and is commonly associated with dolomite, albite and quartz.
Bibliography: 51.

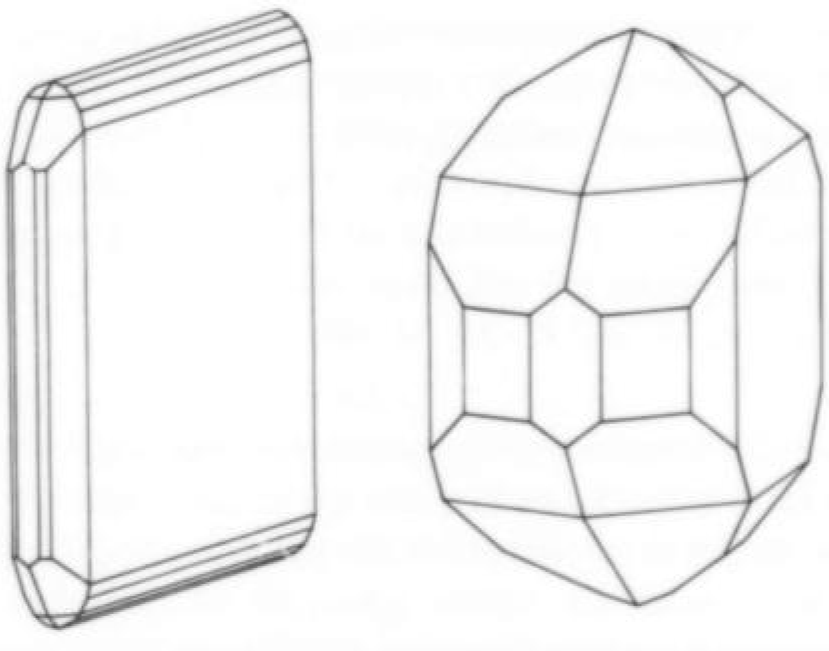

Figure 76. **Cerussite crystal drawings, from Orlandi (1974).**

Cerussite $PbCO_3$

Cerussite has been found as an alteration product of small galena masses in marble from the Fantiscritti quarries; associations include sphalerite and hydrozincite. Specimens from the Calagio quarry are associated with volborthite and mimetite.

The crystals, very minute in size, have proved highly suitable for morphological studies because of the perfection and luster of the faces.

The habit is variable, ranging from individuals characterized by an extreme development of the form {010} to other individuals of more dipyramidal form. The forms recognized in the various crystals are: {100}, {010}, {110}, {130}, {111}, {112}, {021}, {011}, {012} and {013}.
Bibliography: 46, 52.

Azurite $Cu_3(CO_3)_2(OH)_2$
Malachite $Cu_2(CO_3)(OH)_2$

These two mineral species, both being alteration products of primary copper minerals, are almost always associated and therefore they are described here together. Malachite occurs as crusts, spherules and sprays of acicular crystals with typical green color; azurite can also produce beautiful, minute crystals which are eagerly sought by collectors.
Bibliography: 26, 32, 33, 52.

Rosasite $(Cu,Zn)_2(CO_3)(OH)_2$

Only one specimen of rosasite has been found, a small nodule with fibrous-radiating structure measuring about 2 mm, deep apple-green in color and associated with aurichalcite. It was found at the Fantiscritti quarry.
Bibliography: 59.

Hydrozincite $Zn_5(CO_3)_2(OH)_6$

Hydrozincite occurs as snow-white globular aggregates up to 4 mm in size and composed of very thin bacillary crystals.

Only one specimen (from the Fantiscritti quarry), associated with sphalerite of which it is an alteration product, has been recognized.

In the same cavity alteration has affected some small galena masses that appear to be partially transformed into cerussite.
Bibliography: 46, 52.

Aurichalcite $(Zn,Cu)_5(CO_3)_2(OH)_6$

Aurichalcite occurs as silky blue plates grouped together on a single specimen, forming two rosettes with a size of about 2 mm. It is associated with rosasite, and was found at the Fantiscritti quarry.
Bibliography: 59.

Sulfates

Anhydrite $CaSO_4$

Anhydrite was doubtfully reported by Pelloux as an inclusion in the sellaite crystal; requires confirmation.
Bibliography: 41.

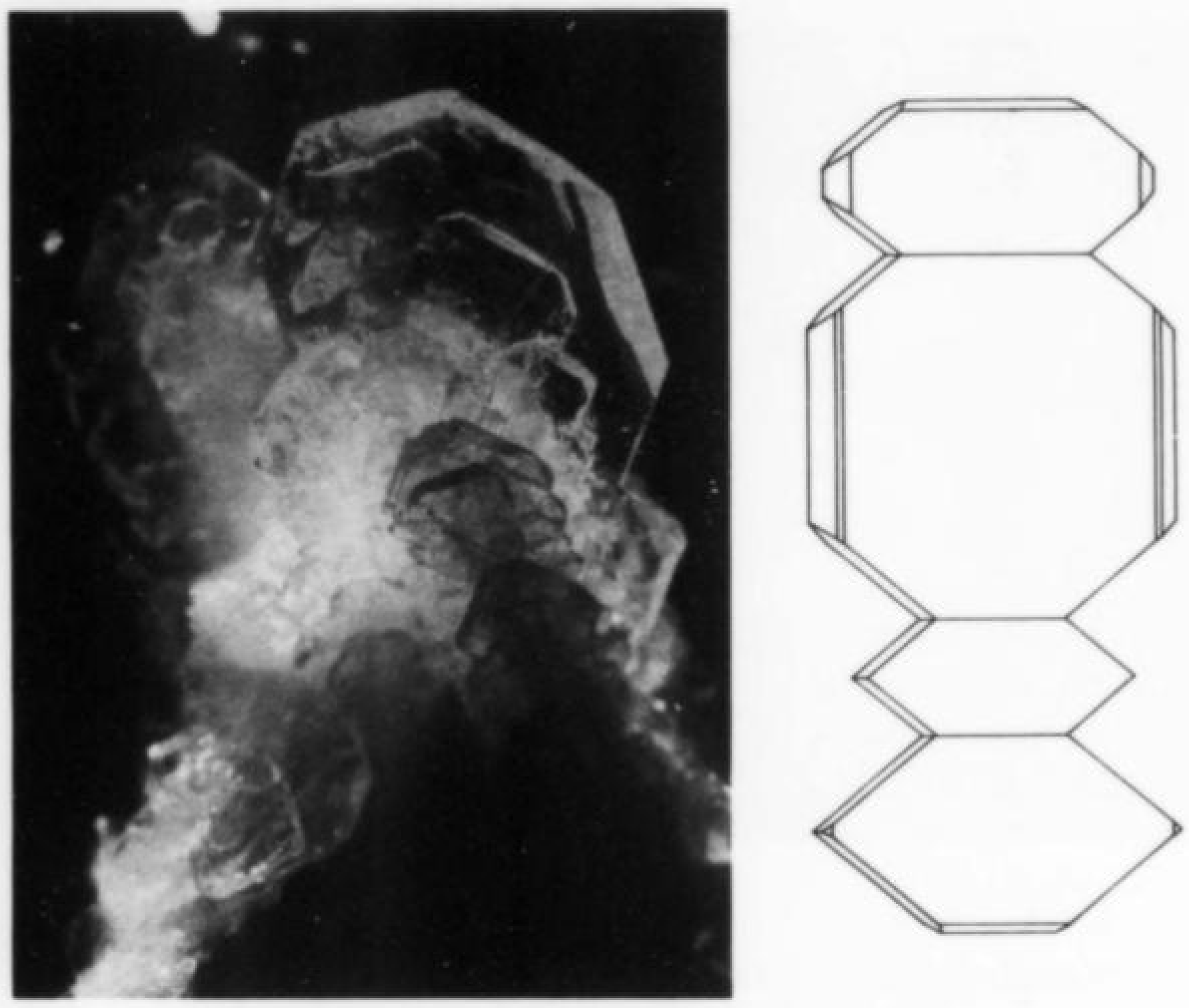

Figure 77. **Celestite crystals in parallel growth, 4 mm, La Facciata quarry. Giovannini collection, Orlandi photo. Right: Celestite crystal drawing showing parallel growth, from Orlandi (1974).**

Celestite $SrSO_4$

Celestite always occurs as well-formed tabular crystals, often grouped in parallel association to form bacillary individuals several centimeters long.

The crystals have a bright vitreous luster; they are usually colorless or whitish in color, rarely more or less vivid yellow-amber.

Crystallographic forms include {001} which is the most developed one and {102}, {104}, {110} and {011}.

The Lorano and Frantiscritti quarries are where celestite has most often been found, usually associated with quartz, dolomite, albite and gypsum.
Bibliography: 46, 49, 52.

Barite $BaSO_4$

Barite is among the least interesting cavity minerals for collectors because of its generally unaesthetic appearance.

Though not a very common mineral, barite is widespread in almost every quarry of the Carrara basin. D'Achiardi reported it in 1906, having identified it in some specimens from the Zaccagna collection which came from the Fossa degli Angeli and Poggio Domizio quarries.
Bibliography: 36, 39, 52.

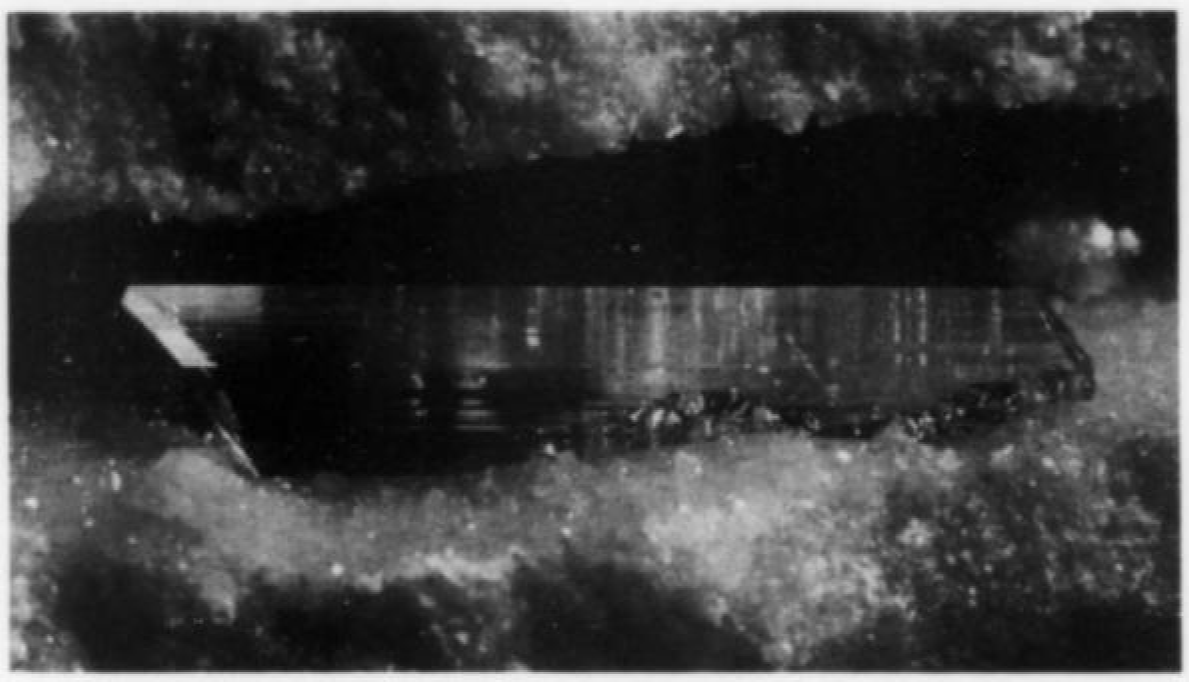

Figure 78. **Gypsum crystal, 2 cm, Fantiscritti quarry. Bargagna collection, Orlandi photo.**

Gypsum $CaSO_4 \cdot 2H_2O$

> After quartz, calcite and dolomite, gypsum can be considered the most common mineral found in cavities. Among others who described this mineral, my father, Jervis, quotes it among the minerals of Poggio Silvestro, while Giampaoli describes groups of large, parallel-growth crystals with faces which are brilliant, but sometimes striated or wavy, and notes their occurrence in the quarries of Fossa dell'Angelo, Lorano, Calagio, Belgia, etc.

Thus D'Achiardi begins his description of this mineral in one of his several papers on Carrara minerals.

Gypsum is not only one of the most common minerals, but also the one which produces, together with quartz, the largest crystals (to more than 10 cm).

The crystals are usually colorless and very clear, rarely isolated, more frequently in association with various individuals. It is associated with all cavity minerals, but especially with quartz and saddle-shaped dolomite. D'Achiardi notes again that gypsum is among the minerals which have crystallized last in cavities.

Isotope studies carried out on gypsum and celestite have revealed that the isotopic composition of the two minerals both for oxygen and sulfur is remarkably homogeneous, with enrichment in O^{18} and S^{34} in comparison with present marine sulfate of about 18‰ and 8‰ respectively. According to Cortecci and Orlandi the most probable interpretation for the data concerning the isotopic composition of oxygen is represented by an isotopic rebalancing of sulfate with groundwater. Data concerning sulfur would indicate, furthermore, a partial bacterial reduction of sulfate. However, analyses of the isotopic composition of sulfur in galena, sphalerite and native sulfur have precluded a derivation of gypsum, celestite and barite sulfate from the oxidation of sulfur.
Bibliography: 11, 12, 26, 32, 34, 48, 49, 52.

Phosphates, Arsenates, Vanadates

Cornubite $Cu_5(AsO_4)_2(OH)_4$

Only one specimen of cornubite has been found thus far. It is a thin, pale-green crust on which spherules of malachite are implanted. The specimen was found at the Calagio quarry.

Fluroapatite $Ca_5(PO_4)_3F$

Fluorapatite has been found at the Fantiscritti quarry in a zone of old abandoned quarry dumps. The crystals range in size up to 4 mm, show a tabular habit, and are colorless and transparent. The best developed crystal faces are those of the basal pinacoid and the dipyramid $\{11\bar{2}1\}$.

Cell parameters taken from X-ray powder diffraction data, using 27 reflections, are $a = 9.373$ (2), $c = 6.885$ (2) Å.

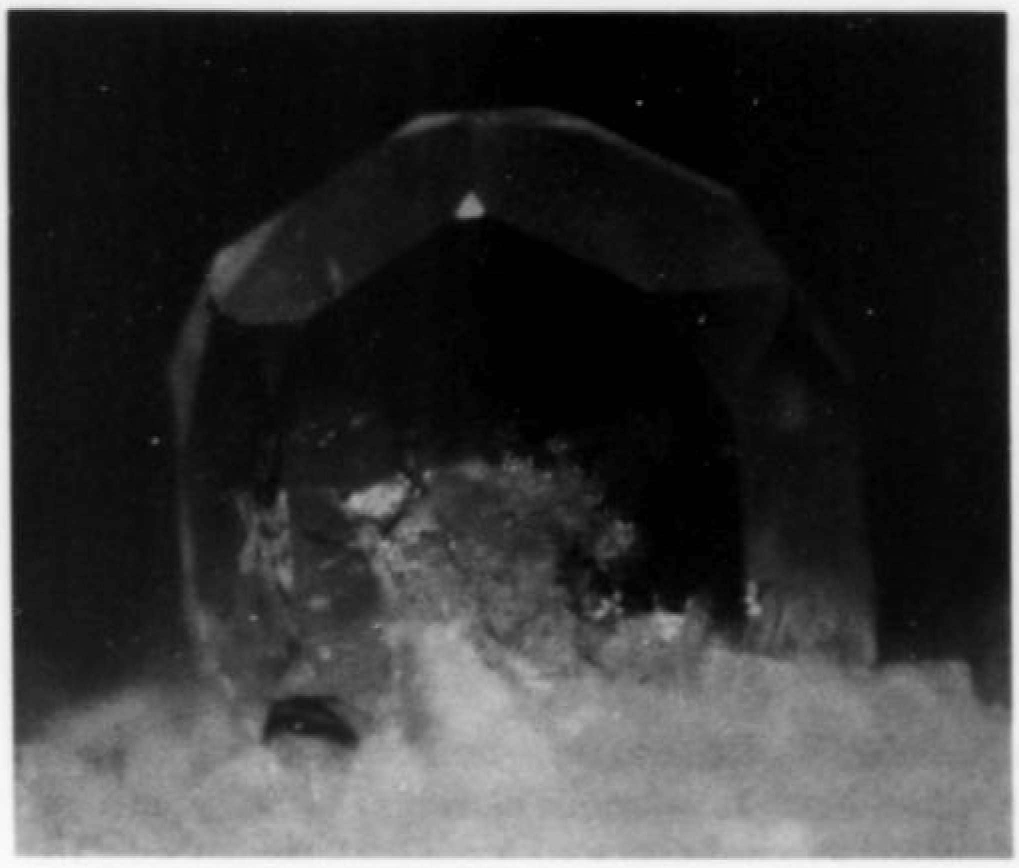

Figure 79. **Fluorapatite crystals, 2 mm, Fantiscritti dumps. Turconi collection, Orlandi photo.**

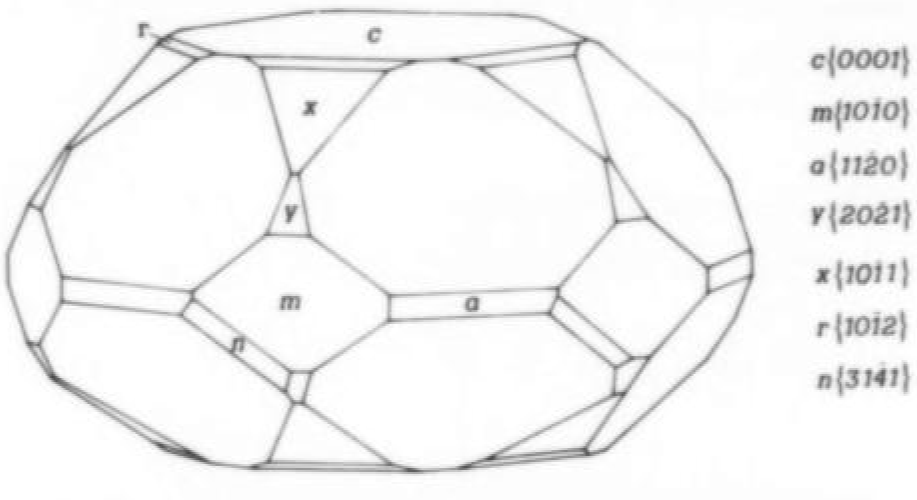

Figure 80. **Apatite crystal drawing from Boscardin *et al.* (1983).**

The refractive indices in sodium light are $\epsilon = 1.634$; $\omega = 1.630$. The specific gravity determined by the heavy liquid method is 3.185 (5).
Bibliography: 59.

Mimetite $Pb_5(AsO_4)_3Cl$
Only one specimen of mimetite (from the Calagio quarries) has been identified. It occurs as very small, prismatic, hexagonal crystals, yellow in color and transparent, associated with other sulfosalt alteration minerals.
Bibliography: 56.

Volborthite $Cu_3(VO_4)_2 \cdot 3H_2O$
This rare vanadium mineral has been found associated with mimetite, cerussite, malachite and azurite, as an alteration product of Pb and Cu sulfosalts on specimens from the Calagio and Val Pulita quarries.

It occurs as minute lamellar crystals and as small earthy masses, yellow-green in color.
Bibliography: 56.

Chalcophyllite $Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27} \cdot 33H_2O$
Only one sample of chalcophyllite (from La Facciata quarry, Lorano basin) has been found. It occurs as thin, tabular crystals, green in color to shades of blue and around 1 mm in size.
Bibliography: 59.

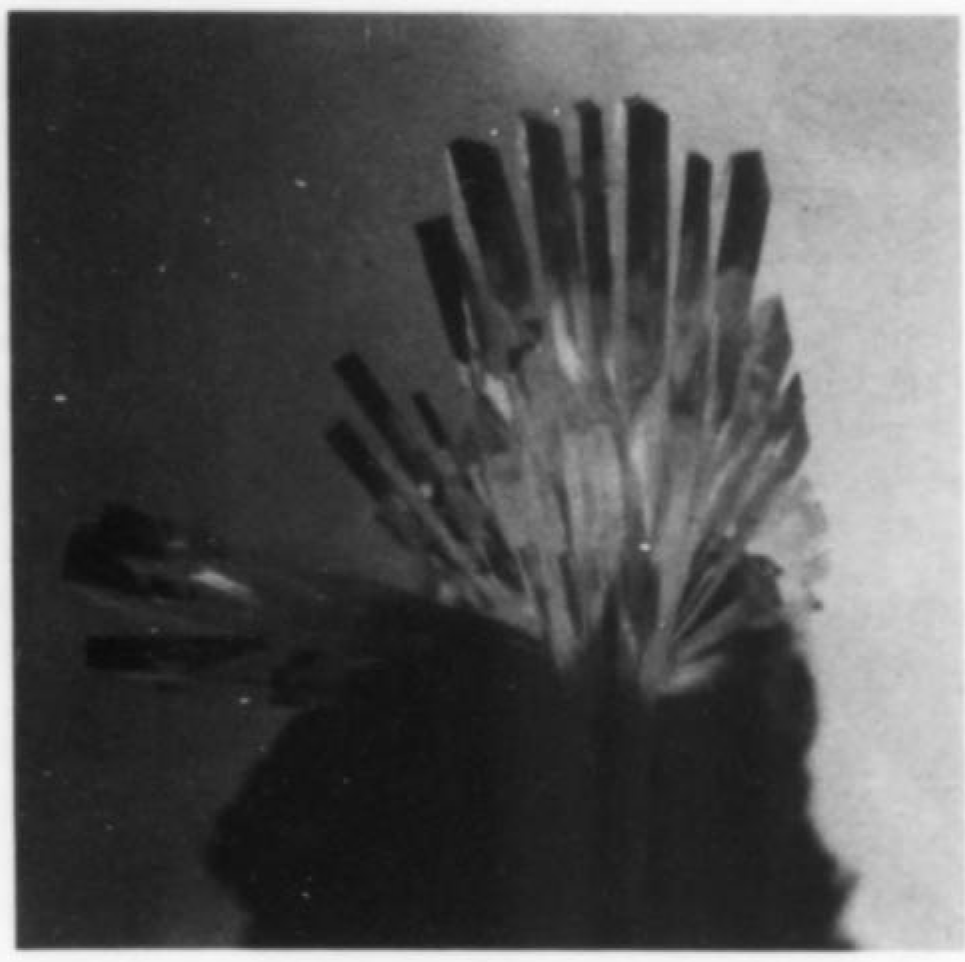

Figure 81. **Hemimorphite crystals on sphalerite, 5 mm, Montecatini quarry. Conforti collection, Gini-Orlandi photo.**

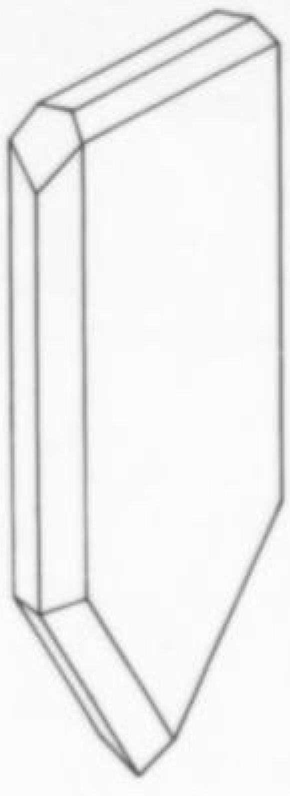

Figure 82. **Hemimorphite crystal drawing from Franzini *et al.* (1982).**

Silicates

Hemimorphite $Zn_4Si_2O_7(OH)_2 \cdot H_2O$
Specimens in which hemimorphite has been recognized come from the Fantiscritti quarry. It has been found both in small, shapeless masses, pale green in color, implanted on sphalerite nodules and in radiating divergent associations of colorless individuals to a few mm in size.

Crystal habit is characterized by dominant development of the form {010} with respect to other forms observed: {121}, {301}, {110}, {001} and {031}.
Bibliography: 46, 52, 58.

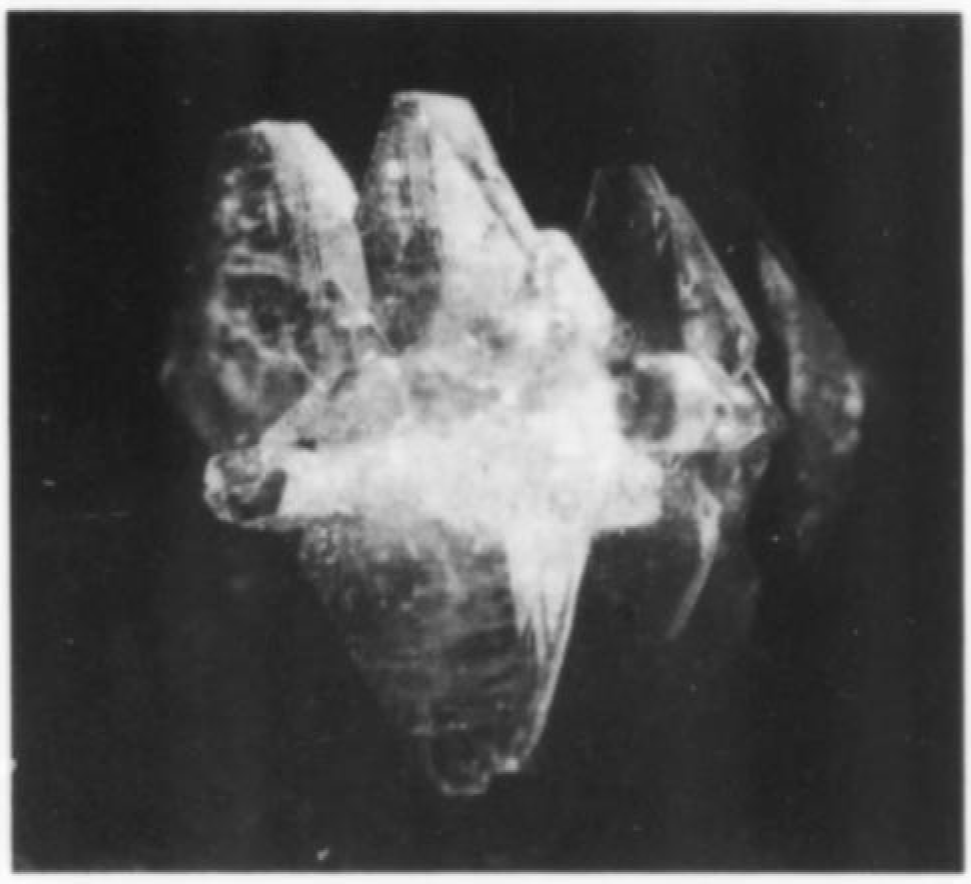

Figure 83. **Orthoclase ("adularia") in epitaxial association with albite, 4.5 mm, Calagio quarry. Lari collection, Bracci photo.**

Orthoclase $KAlSi_3O_8$
Although reports concerning orthoclase (usually referred to as the variety *adularia*) in cavities are very recent, it is rather widespread in many localities and above all in the quarries of Crestola Bassa and Gioia where it is found in crystals of remarkable size (3–4 cm).

The habit is typical, composed of the following combination of

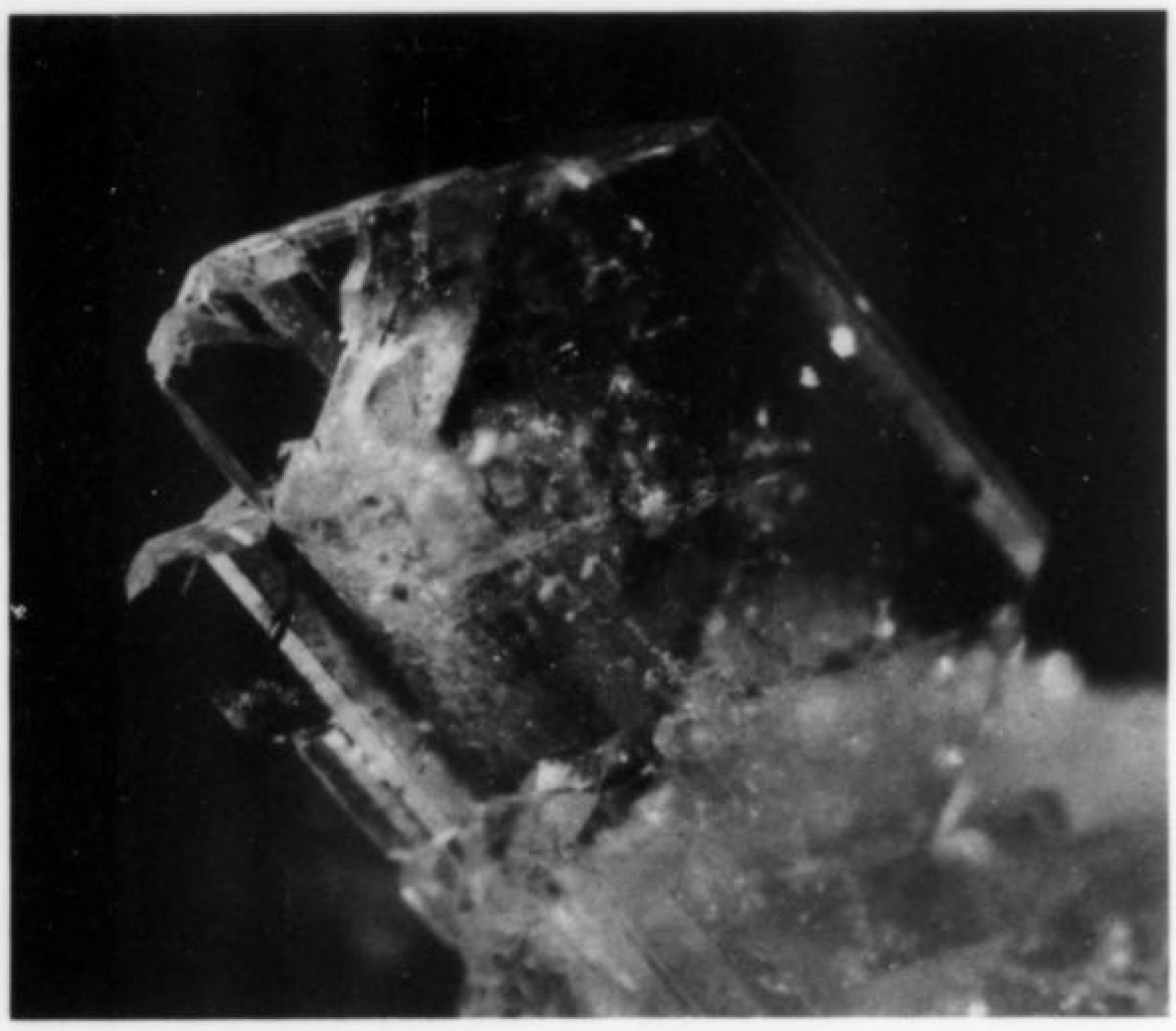

Figure 84. **Albite twins, 5 mm, Calagio quarry. Lari collection, Bracci photo.**

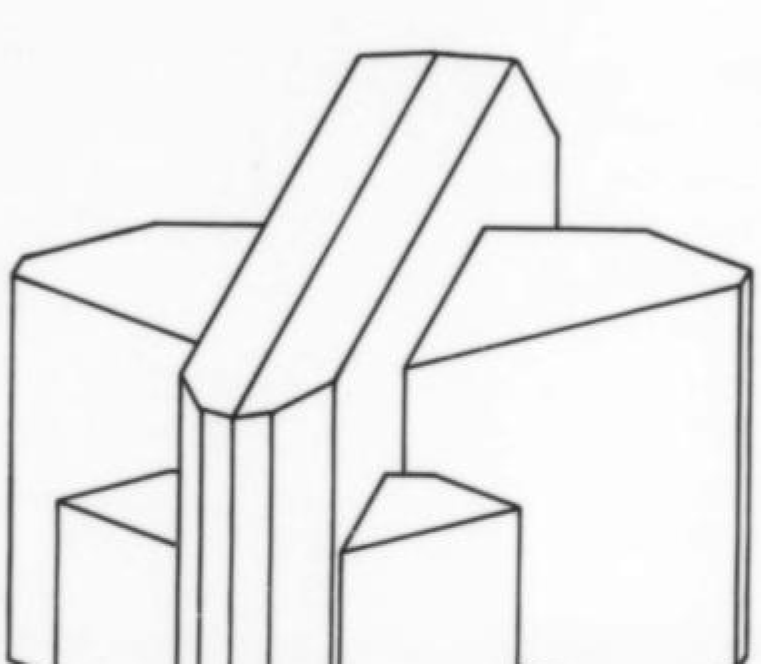

Figure 85. **Orthoclase epitaxial on albite crystal drawing from Orlandi (1974).**

forms, in order of decreasing development: $\{110\}$, $\{001\}$, $\{10\bar{1}\}$ and $\{010\}$.

Epitaxial associations with albite crystals are very typical; in this particular habit orthoclase crystals are implanted on the wide faces of albite crystals. Within the limits of the slight difference in the angular value between the axes of these two species, coincidence between faces $\{010\}$ of the two minerals and the perfect parallel orientation of x and z axes appear.

Chemical analysis of orthoclase has revealed that it is a practically pure potassium feldspar with very low amounts of albite and anorthite molecules.

Bibliography: 46, 52.

Albite $NaAlSi_3O_8$

Albite was reported for the first time in 1867 by Vom Rath. The history of this mineral is very interesting: it was considered rare by the discoverer and then by A. D'Achiardi (1873), while 30 years later in 1905 it was considered relatively common by Giampaoli and D'Achiardi.

Albite occurs as large crystals, with a typical habit visible to the naked eye and easily identified and distiguished from the other mineralogical species common in cavities; yet it has escaped the attention of researchers for a long time. But once it was identified and therefore expressly sought for, discoveries have multiplied and the species has become recognized as common. This sequence repeats itself frequently in mineral research: the reporting of a new species (utterly new, or new in the area) in deposits already well known and studied for years is followed, in a short while, by many additional discoveries. People are generally more ready to see what they are looking for than to observe new and unforeseen phenomena.

Albite in the cavities of Carrara marble occurs in well formed crystals up to about 2 cm in size, sometimes milky white, sometimes colorless and perfectly transparent were it not for the many internal cleavages which are always present and on which light reflects, generating a wonderful play of colors so much more easily appreciated under magnification.

It is perhaps the only mineral among those described that commonly occurs in groups of many individuals.

D'Achiardi commented:

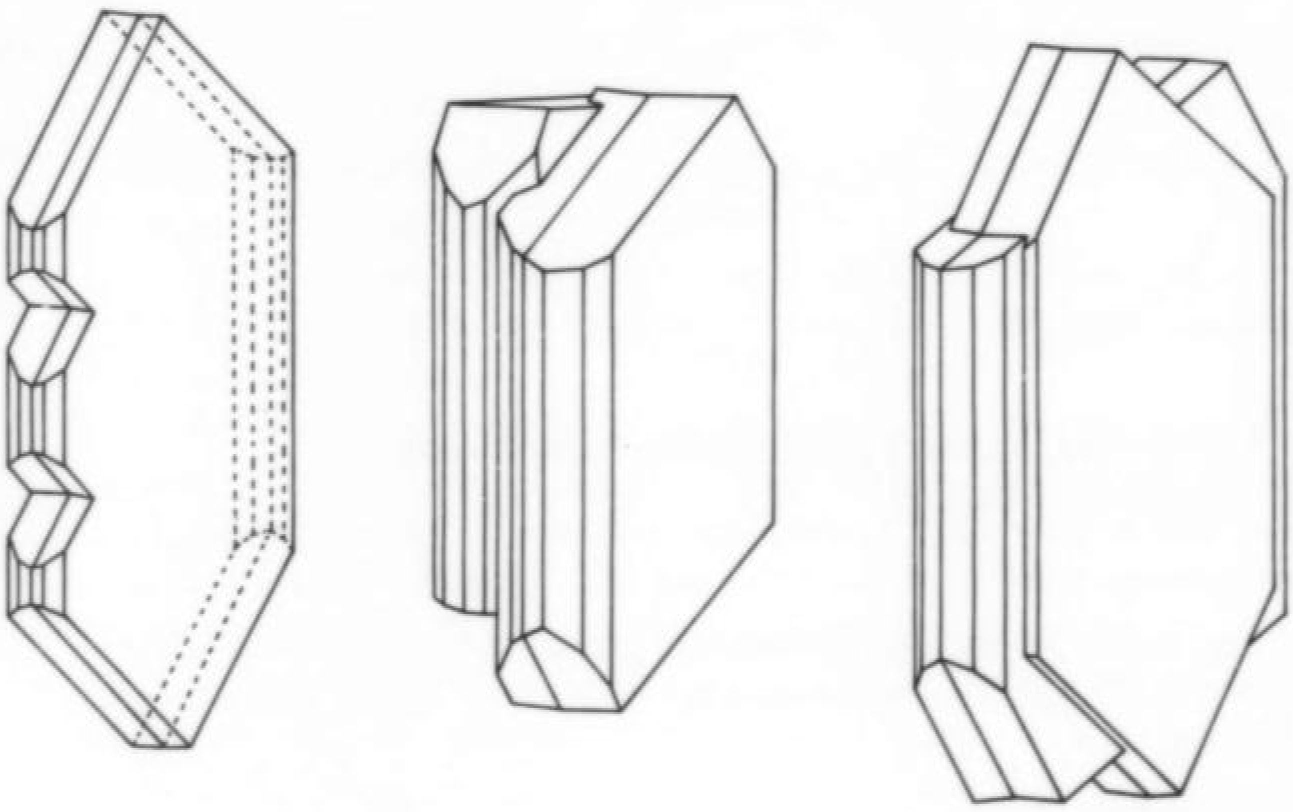

Figure 86. **Albite crystal drawings showing twinning, after Viola (1899) and D'Achiardi (1906b).**

> The crystals I have examined are very numerous, more than 200, most of which are implanted on two large specimens (Zaccagna collection) from the Para quarries. The two specimens show surfaces of maximal extent completely covered with milk-white albite crystals which are very small and associated with numerous calcite scalenohedrons, which are also very small, and with very rare small quartz crystals.

We don't know if D'Achiardi actually removed the more than 200 crystals from the specimens he examined; he surely removed quite a few since he later says: "from the samples I removed many small crystals which I used for a complete analysis . . . ." The specimens described by D'Achiardi are kept in the Museum of Mineralogy at the University of Pisa and still contain a very large number of albite crystals.

Albite does not always occur in the manner we have described; more frequently this mineral, like the others, occurs as isolated crystals, though specimens having three or four albite crystals are common enough.

The habit is always tabular because of the dominant development of the form $\{010\}$. Inside more regular crystals the outline of the tablet shows six sides represented by edges forming the small faces $\{110\}$, $\{001\}$, $\{\bar{1}01\}$, $\{\bar{1}10\}$, $\{001\}$ and $\{10\bar{1}\}$. These six edges look like a slightly deformed hexagon having internal angles of about 128° (two opposing angles) and about 116° (the other four). In the different habits this hexagon can have an almost regular development or it can be deformed into an almost rectangular shape owing to lengthening along the [001] axis or more frequently [100], or into an almost triangular shape owing to a greater development of three alternate sides with respect to the other three.

These habits can be further complicated by the development of the faces, which are always small, belonging to other simple forms (a total of 11 have been observed) among which $\{130\}$ and $\{1\bar{3}0\}$ are very common.

Besides the obvious cleavages, twinning according to the albite law (revealed by the presence of small re-entrant angles) is a common trait of all albite crystals in this occurrence. Twinning by the Carlsbad law is rarer; it never occurs alone, but always combined with albite-law twinning.

Epitaxial relations between albite and orthoclase (already described above) are very characteristic.

Apart from the larger size, albite crystals in cavities are quite exactly the same in habit and twinning as the very minute ones scattered in the mass of Carrara marble; in fact, together with quartz, albite is the most common mineral in the insoluble residue of the marble.

Chemical data show, for both occurrences, that the mineral is almost pure albite with a variable content of from 3 to 5% anorthite.

Bibliography: 9, 11, 12, 26, 28, 29, 32, 37, 46, 52.

Discredited Species

In two different reports D'Achiardi describes epidote and tourmaline among the minerals in cavities. He writes of tourmaline:

> It has reportedly been found and bought recently for a particular collection. The person who told me about it describes it as lightly wine-colored, and terminated by small rhombohedral faces.

Since the only information about tourmaline is not from an original source, we do not even consider it among the doubtful species.

Subsequently the same author identified as epidote a very thin crystal, pale green in color, dubiously identified as tourmaline, implanted on a sample in the Zaccagna collection and coming from the Lorano quarry.

The same specimen has been recently re-examined by Orlandi who, by means of X-ray diffraction, identified it as sphalerite. It has a very strange habit: the crystal is of an elongated pseudoprismatic shape terminated by a large number of small faces.

ORIGIN OF CAVITIES AND CAVITY MINERALS

Early Work

As mentioned earlier, cavity minerals of the Carrara marble have long been a focus of study. However, much effort has also been devoted to puzzling out the mode of formation of the cavities and the physiochemical origins of the minerals.

Hypotheses put forth in the early literature did not have the benefit of modern rock and mineral analysis techniques, and have generally not been supported by recent research. D'Achiardi (1905) for example, suggested:

> The formation of such cavities is due to the action of waters which, filtering through fractures, have enlarged them by solution at various points, giving the dissolved compounds the opportunity to deposit and crystallize slowly.

In apparent support of this theory were the oral traditions and ancient records describing fluid-filled cavities.

Giampaoli (1905) made a more astute observation.

> In some cases there is no relationship between the cavity minerals and the immediately adjacent wall rock. Crystallizations are primary and the wall rock has remained unaffected. In rare cases where fractures or crevices connect cavities with iron-rich layers in the rock, flowing waters have resulted in more or less reddening of the walls and corrosion of the cavity minerals.
>
> Cavities generally occur as long, thin shafts running parallel to the plane of easiest fracture in the marble. The ends are almost always blocked by vein fillings or masses of spathic calcite.

Aloisi (1909) also noticed that cavities tend to be "filled up at the back."

The hypothesis advanced by Zaccagna (1932) is closer to the mark. He suggested that cavities resulted from contraction of the marble mass during metamorphic recrystallization. At least his theory recognizes the pre-existence and independence of cavities from subsequent mineral deposition. He considered the cavity minerals to be "secretion products" of the marble and not a side-effect of the cavity formation process.

Interesting though they are, these various theories of cavity genesis have not really progressed beyond the descriptive stage. The physical conditions which resulted in cavity formation have remained essentially undeciphered from a quantitative standpoint, and the same is true for the physiochemical origin of the cavity minerals. Many authors who have studied Carrara minerals have suggested that crystallization proceeded very slowly, but this is to be expected in almost any low-temperature depositional environment.

Cavities

Bracci *et al.* (1978) recognized three different types of cavities on the basis of field relations and specimen studies. These are (1) cavities in pure white ("macchia bianca") marble, (2) cavities in irregular masses of dolomite, and (3) cavities in masses and veins of spathic calcite. Of these, the first is most illustrative of the overall cavity-forming processes.

In a rather limited zone of the marble basin (the Lorano, Fossa degli Angeli and La Facciata quarries), in the eastern part of the Carrara syncline where marble of "ordinary white" quality is prevalent, one can observe on the quarry walls bands of variable thickness (1 to 10 cm) having significantly whiter color. This is the so-called *macchia bianca*.* The planar orientation of these bands parallels the direction of easiest fracture of the marble. Structural analysis (Carmignani and Giglia, 1975b and 1979; Carmignani *et al.*, 1978) has shown this directional weakness in the marble to be a first-phase schistosity generally paralleling the original bedding except near fold hinges.

Macroscopically the *macchia bianca* is characterized by a larger grain size, which is visible to the naked eye and which aids in field identification. This is fortunate because *macchia bianca* is a strong indicator for the possible presence of cavities. Regularly spaced pinch-outs in the bands are commonly the site of cavities.

The cavities occur as extended tubular openings situated in the plane of the *macchia bianca* band. Diameter ranges up to about 10 cm, and length (though difficult to measure accurately) commonly exceeds a meter or more. Usually the top and bottom quarters of

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*Quarrymen and mineral collectors have taken to calling the veins of white spathic calcite *macchia bianca* as well, but for clarity's sake the term should be reserved for white marble.

Figure 87. **The *macchia bianca* marble veins, conspicuous by their whiteness relative to surrounding marble. Note regularly spaced cavities along the vein. Lorano quarry, Orlandi photo.**

Figure 88. **Elongated cavity with typical lateral tension fractures 14 cm. University of Pisa collection, Gini photo.**

the cavity cross-section are bound by normal marble, and the left and right sides by *macchia bianca.*

Open fractures in the surrounding marble perpendicular to the cavity axis are commonly observed, but these usually close off within a few centimeters. Such transverse fractures are not always present, but transverse streaks on cavity walls have also been seen which clearly appear to be microfaults of small displacement.

Cavities in *macchia bianca* tend to be oriented in roughly the same direction, corresponding to the direction of the fold axis of the second-stage metamorphism.

Bracci *et al.* (1978) carried out a detailed study of the chemistry, mineralogy and petrology of *macchia bianca.* The results may be summarized as follows:

1. Grain size (of calcite crystals in the *maccia bianca* marble) is two to three times that of normal marble.
2. The insoluble residue of acid-treated *macchia bianca* is greater than that of normal marble, and is also different, consisting primarily of albite and quartz with traces of sphalerite and pyrite.

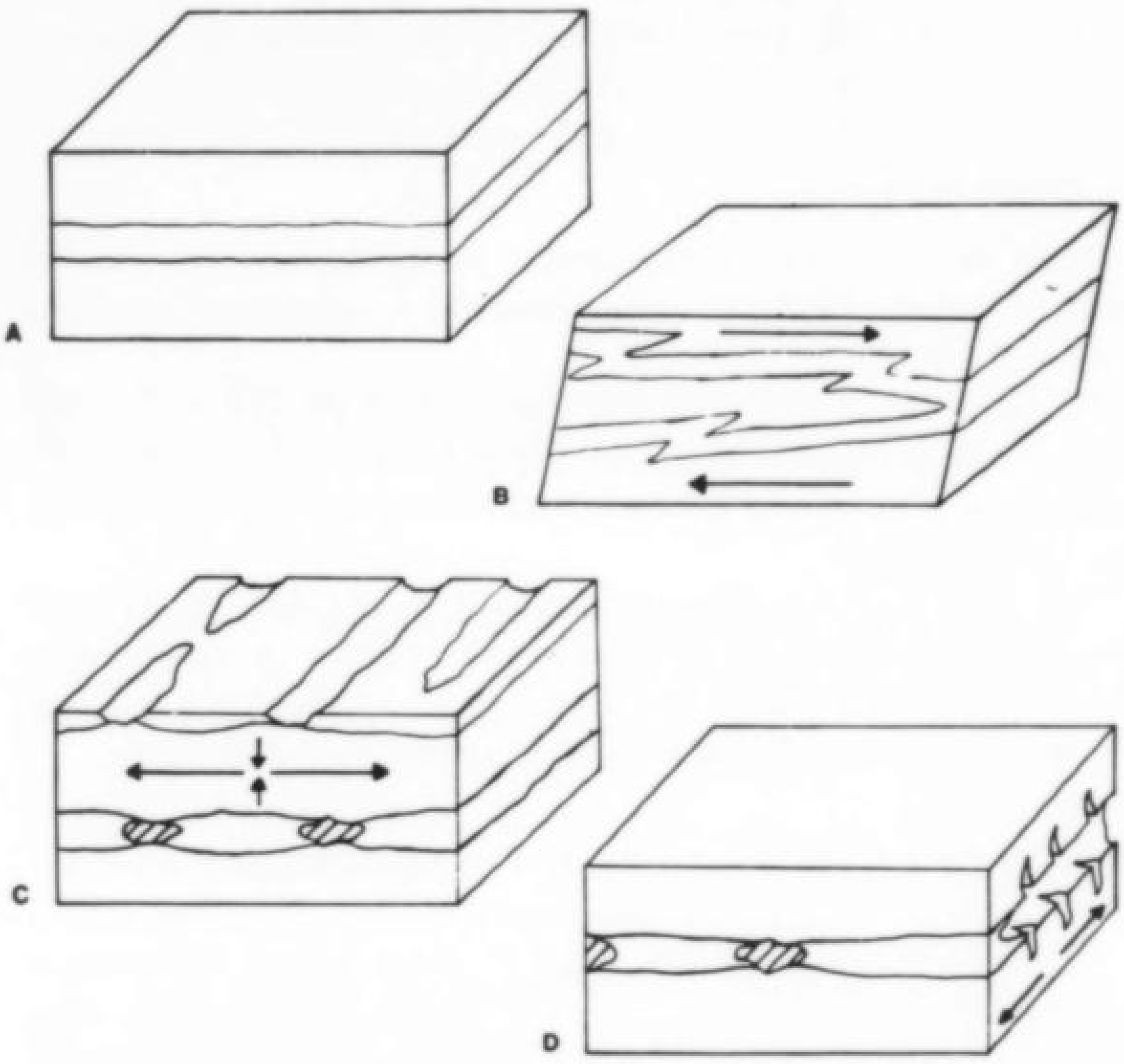

Figure 89. **Diagram showing evolution of the *macchia bianca* cavities: (A) sedimentary deposition of unusually pure calcite layer, (B) isoclinal folding and metamorphism, (C) tension deformation accompanied by boudinage in the *macchia bianca* layer which opens long, tubular cavities, and (D) tensional deformation parallel to boudinage cavities resulting in tension gashes. From Bracci *et al.* (1978).**

Normal marble residue consists of muscovite with albite, quartz and other minor accessories.

3. The strontium content of *macchia bianca* is somewhat higher (196 ppm vs. 167 ppm).

Bracci *et al.* (1978) concluded that the cavities were formed by tensional deformation in the *macchia bianca* plane, and that the transverse fractures formed also by tensional deformation in the same place but in a perpendicular direction paralleling the cavity axes (see Fig. 89).

Cavities in irregular masses of dolomite and in spathic calcite veins are ascribed to the same mechanism, but the temporal relationship of the three cavity types remains unknown.

Cavity Minerals

Physical Conditions

Because the cavity minerals could only form following the opening of cavities during the second metamorphic episode, it is possible to establish some limits on the temperatures and pressures involved. These limits are essentially those of the second metamorphic event itself, estimated through mineralogical/petrographical study of the marble and the basal schists in the Apuan Autochthon.

Various approaches and methodologies (see Carmignani and Giglia, 1979) are in general agreement that the highest temperatures achieved during the second metamorphic event were 300°–400°C (probably toward the high side of that range), and the highest pressures were 3–4 kilobars corresponding to a depth of 10 to 15 km. However, Azzaro *et al.* (1977) studied basal schists near Foce del Giovo and arrived at values of 400°–450°C and 6–8 kilobars; this temperature range is possible but the values for pressure seem too high. These results probably reflect an unusual local situation of the kind which is always possible in heavily deformed complexes.

Crystallizations of one kind or another probably took place from conditions of maximum metamorphic temperature and pressure all the way down to near-surface conditions. Very late-stage calcite is known to have formed essentially at the surface and by the action of near-surface groundwater. But, if we wish to restrict our discussion only to cavities which have not undergone such retrograde activity (during which many aesthetic species are destroyed and others covered with reddish ferruginous crusts), it becomes difficult to know where to draw the line on physical conditions.

The presence of sulfur in cavities suggests rather low crystallization temperatures, probably less than the monoclinic-rhombic transition point of 96°C at surface pressures. The presence of gypsum also suggests near-surface temperatures because the gypsum-anhydrite transition point is 42°C at 1 bar; unfortunately this point is somewhat pressure-dependent so it is not possible to draw a firm conclusion on this basis alone.

Further information might conceivably be gained from an analysis of the original pocket fluids rumored to have been encountered. Unfortunately the literature is devoid of any such data, nor have the authors ever observed such fluid.

The tentative conclusion is nevertheless that important crystallizations continued down to virtually near-surface conditions as the lower limit. Information on the temperatures of formation of individual species over the entire range are rather scarce, and data pertaining to pressure are entirely absent. Regarding temperatures, Cortecci and Orlandi (1975b) have shown that oxygen and carbon-based isotopic geothermometers are unreliable at Carrara due to lack of equilibrium.

Some information on temperature can be derived from a study of Mg partitioning between calcite and coexisting dolomite. Bracci *et al.* (1978) have shown that the Mg content of cavity calcites is always lower than that of marble calcite surrounding the pocket; furthermore, the content varies from specimen to specimen. This suggests that pocket calcite began forming at a temperature below that of marble recrystallization (i.e., 100°–300°C) (Bracci, 1978), and continued through a period of cooling.

Numerous determinations of iron content in sphalerite (Leoni and Orlandi, 1975; Dalena, 1978) indicate that sphalerite formed in the range 130°–230°C. The lack of evidence for Fe saturation precludes more detailed conclusions.

Consequently there seems to be sufficient evidence to conclude that crystallization of cavity minerals took place over a relatively wide range of conditions.

Chemical Conditions

Several general observations are critical to any discussion of chemical mineralogy at Carrara:

1. Cavity minerals (other than calcite) are volumetrically extremely rare, almost negligible.

2. Cavities themselves are volumetrically almost negligible in comparison to total marble mass.

3. The most common of the cavity species (calcite, dolomite, quartz, albite, gypsum, pyrite) are also major (calcite) or accessory components of the surrounding marble. In fact, almost all cavity minerals have been found also to occur in massive marble. The most notable exceptions are the sulfosalts which, other than colusite, have not been observed in marble. However, consider the rarity of sulfosalts, the difficulty in identifying them if present in the marble, and the small proportion of research that has been devoted to marble accessories as opposed to cavity minerals. It seems a plausible supposition that, in general, all minerals found in cavities could also be found in marble, given a sufficiently thorough search.

4. All cavities, regardless of location within the marble formation, contain essentially the same assemblage. (The only exception to this would be the three species rutile, anatase and brookite, which have thus far been found only in the Crestola Bassa and Gioia quarries.) Relative quantities of the species may vary from place to place, but qualitatively the cavities are identical throughout the Carrara marble.

From these observations it seems safe to conclude that the presence of so many different minerals in the cavities can nonetheless be satisfactorily explained without invoking exogenous chemical contributions brought in through large-scale circulation of fluids. Strictly local remobilization of trace elements in the marble is sufficient to account for all the rare and splendid crystals which have been described.

In other words, it appears that the creation of the cavities themselves in otherwise homogeneous marble produced the essential discontinuity. Resulting physiochemical gradients drove the migration of elements from the marble toward the cavity in a re-equilibration process which resulted in the crystallization of pocket minerals.

Sulfur isotope studies by Cortecci and Orlandi (197b) support this mechanism. They found that the sulfur in cavity gypsum is strictly of marine origin. Similarly, the isotopic composition of sulfur in the numerous sulfide species shows that it cannot be the result of sulfate reduction.

It must therefore be concluded that the formation of cavity minerals is substantially a function of dissolution and recrystallization of minerals in the massive marble. This earlier generation of minerals formed largely as a result of the metamorphism of original sedimentary rocks. We say "largely" because albite crystals in the massive marble are so similar in size, habit and twinning to authigenic albite from unmetamorphosed sediments that they may not have suffered recrystallization along with the other marble components.

This genetic model is compatible with the extremely slow rate of

Table 1. **Minerals found in cavities of the Carrara marble.**

Mineral	Composition	Date of Discovery inside the Cavities	Rarity
Native elements			
Sulfur	S	1820	Common
Sulfides and Sulfosalts			
Chalcocite	Cu_2S	1905	Uncertain
Digenite	Cu_9S_5	1980	Very rare
Bornite	Cu_5FeS_4	1974	Very rare
Sphalerite	ZnS	1874	Common
Luzonite	Cu_3AsS_4	1984	Rare
Famatinite	Cu_3SbS_4	1976	Rare
Colusite	$Cu_3(As,Sn,V,Fe)S_4$	1980	Rare
Sulvanite	Cu_3VS_4	1974	Very rare
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$	1905	Rare
Wurtzite	$(Zn,Fe)S$	1978	Rare
Enargite	Cu_3AsS_4	1974	Common
Galena	PbS	1905	Common
Covellite	CuS	1974	Very rare
Stibnite	Sb_2S_3	1976	Rare
Pyrite	FeS_2	–	Very common
Arsenopyrite	FeAsS	1905	Uncertain
Seligmannite-Bournonite	$PbCuAsS_3$–$PbCuSbS_3$	1974	Rare
Jordanite	$Pb_{14}(As,Sb)_6S_{23}$	1967	Rare
Geocronite	$Pb_{14}(Sb,As)_6S_{23}$	1976	Rare
Zinkenite	$Pb_6Sb_{14}S_{27}$	1980	Rare
Semseyite	$Pb_9Sb_8S_{21}$	1984	Very rare
Boulangerite	$Pb_5Sb_4S_{11}$	1976	Rare
Realgar	AsS	1899	Very rare
Orpiment	As_2S_3	1899	Very rare
Halides			
Sellaite	MgF_2	1919	Only one sample
Fluorite	CaF_2	1883	Very common
Oxides			
Hematite	Fe_2O_3	1980	Very rare
Quartz	SiO_2	–	Very common
Rutile	TiO_2	1977	Common
Anatase	TiO_2	1978	Rare
Brookite	TiO_2	1982	Very rare
Gibbsite	$Al(OH)_3$	1976	Very rare
Nordstrandite	$Al(OH)_3$	1984	Very rare
Lithiophorite	$(Al,Li)Mn^{+4}O_2(OH)_2$	1980	Very rare
Carbonates			
Calcite	$CaCO_3$	–	–
Dolomite	$CaMg(CO_3)_2$	1872	Very common
Aragonite	$CaCO_3$	1983	Rare
Dawsonite	$NaAl(CO_3)(OH)_2$	1986	Very rare
Strontianite	$SrCO_3$	1976	Rare
Cerussite	$PbCO_3$	1974	Very rare
Azurite	$Cu_3(CO_3)_2(OH)_2$	1897	Uncommon
Malachite	$Cu_2(CO_3)(OH)_2$	1983	Uncommon
Rosasite	$(Cu,Zn)_2(CO_3)(OH)_2$	1983	Very rare
Hydrozincite	$Zn_5(CO_3)_2(OH)_6$	1983	Very rare
Aurichalcite	$(Zn,Cu)_5(CO_3)_2(OH)_6$	1974	Rare
Sulfates			
Anhydrite	$CaSO_4$	1919	Uncertain
Celestite	$SrSO_4$	1974	Uncommon
Barite	$BaSO_4$	1906	Rare
Gypsum	$CaSO_4 \cdot 2H_2O$	1872	Very common
Phosphates, Arsenates, Vanadates			
Cornubite	$Cu_5(AsO_4)_2(OH)_4$	1984	Very rare
Fluorapatite	$Ca_5(PO_4)_3F$	1983	Very rare
Mimetite	$Pb_5(AsO_4)_3Cl$	1980	Very rare
Volborthite	$Cu_3(VO_4)_2 \cdot 3H_2O$	1980	Very rare
Chalcophyllite	$Cu_{18}Al_2(AsO_4)_3(SO_4)_3(OH)_{27} \cdot 33H_2O$	1983	Very rare
Silicates			
Hemimorphite	$Zn_4Si_2O_7(OH)_2 \cdot H_2O$	1974	Rare
Orthoclase	$KAlSi_3O_8$	1974	Common
Albite	$NaAlSi_3O_8$	1867	Very common

Table 2. **Crystallization sequences observed between pairs of species showing overlapping relationships (earlier species on the left).**

Albite → Celestite
Albite → Orthoclase (adularia)
Albite → Strontianite
Anatase → Dolomite
Cu sulfides & sulfosalts → Azurite/Malachite
Colusite → Sulvanite
Colusite → Wurtzite
Dolomite → Gypsum
Famatinite → Zinkenite
Fluorite → Sphalerite
Galena → Bournonite
Galena → Cerussite
Gypsum → Sulfur
Malachite → Cornubite
Malachite → Orthoclase (adularia)
Orthoclase (adularia) → Dolomite
Pyrite → "Hexagonal" Galena (flattened cuboctahedron)
Pyrite → Wurtzite
Quartz → Albite
Quartz → Dolomite
Quartz → Fluorite
Quartz → Gypsum
Sphalerite → Colusite
Sphalerite → Dolomite
Sphalerite → Enargite
Sphalerite → Gypsum
Sphalerite → Hemimorphite
Sphalerite → Hydrozincite
Sphalerite → Jordanite
Sphalerite → Stibnite
Sphalerite → Tetrahedrite
Sphalerite → Wurtzite
Sulfur → Gypsum
Sulvanite → Volborthite

Table 3. **The most abundant minerals in some quarries of the Carrara area.**

Quarry	Minerals
Crestola Bassa	Orthoclase, Rutile, Anatase, Dolomite, Pyrite, violet Fluorite
La Piastra	Quartz, Fluorite, Pyrite, Albite, Sulfur, Gypsum
Battaglino	Gypsum, Fluorite, Quartz, Enargite, Strontianite
Colle Stretto	Pyrite, Quartz, Fluorite, Enargite
Ravaccione	Fluorite, Sulfur (generally few minerals)
Polvaccio	Quartz, Fluorite, Pyrite, Albite, Sulfur, Gypsum
Bicchieri	Quartz, Dolomite, Gypsum, Sulfur, Albite, Sphalerite
La Facciata	Quartz, Dolomite, Gypsum, Sulfur, Albite, Fluorite, Colusite, Wurtzite, Galena
Fossa degli Angeli	Quartz, Dolomite, Gypsum, Sulfur, Albite, Sphalerite, Fluorite, Colusite, Celestite, Barite
Lorano	Quartz, Dolomite, Gypsum, Sulfur, Albite, Celestite, Strontianite, Sphalerite, Fluorite, Colusite, Jordanite, Geocronite
Pradetto	Albite, Quartz, Sphalerite
Galleria di Fantiscritti	Jordanite, Geocronite, Seligmannite-Bournonite, Sphalerite, Gypsum
Lucchetti	Sulfur, Gypsum, Sphalerite, Albite, Orthoclase
Montecatini	Sphalerite, Pyrite, Seligmannite-Bournonite, Jordanite, Geocronite, Galena
La Tagliata	Gypsum, Pyrite, Galena, Fluorite, Hydrozincite, Sphalerite, Jordanite, Geocronite
Tecchia	Fluorite, Pyrite, Sphalerite, Galena
Carbonera	Malachite, Azurite, Fluorite
Campanili	Violet Fluorite, Sphalerite, Gypsum
Artana	Quartz, Albite, Pyrite, Fluorite
Calagio	Enargite, Pyrite, Sphalerite, violet Fluorite, generally sulfides, Malachite, Azurite
Gioia	Malachite, Azurite, Orthoclase, violet Fluorite

crystallization of pocket minerals postulated by many earlier authors as essential to the simplicity and perfection of crystal development characterizing the occurrence. Concentration gradients must have been very slight, and temperature-pressure gradients between cavity solutions and interstitial marble solutions almost non-existence. Circulation of fluids must also have been negligible, and transport of elements into cavities accomplished by very slow ion diffusion.

Paragenesis

In the previous paragraphs we have described the processes of cavity formation and crystallization of the many different cavity species. The satisfaction gained from having understood the most relevant points and arriving at a satisfactory hypothesis encompassing a wide class of phenomena and data should not be dimmed by what remains unanswered. It must be admitted that, for any particular specimen or single crystal, we could not even answer the simplest questions, such as: why do the different faces of one crystal form have unequal development?

This confessed ignorance serves only to show that it is not the scientist's obligation to answer such questions. Perhaps, if many specimens showed an identical type of irregular development, some explantion would be called for. The scientist's duty is to observe only the regularities in nature and interpret them. Until some regularity has been found we do not even look for an explanation. Those who, approaching the natural sciences for the first time, feel unjustified disappointment at such unanswered questions should be consoled by the fact that such questions were merely badly asked.

Unfortunately there are other more valid questions about cavities that cannot currently be answered. Did the different species form simultaneously or in some particular sequence? Which parameters control the varying quantities of particular species at the different localities examined?

The difficulty in determining crystallization sequences, if any, is mostly the result of the extreme scarcity of the accessory minerals; they almost never form on top of each other (except that virtually all form on calcite). Instead they usually form as separated individuals, and no overlapping relationships can be seen.

A sparse few regularities have been observed, so we will report these in the hope that future research will contribute more to a full explanation. From hundreds of samples studied a small number of overgrowth samples have been found, many of which are illustrated here. (All such cases observed are reported on Table 2.) Nevertheless, the number of sequences observable is quite small compared to the complexity of the assemblage. Firm conclusions from this meager data are not possible, but some working hypotheses have been formulated:

1. Sulfides/sulfosalts have not formed on quartz, albite or gypsum, *and* vice versa (except sphalerite-gypsum).
2. Gypsum and dolomite have formed on sulfides, silicates, oxides and fluorite.

Some effort has been made to quantify the distribution of cavity species at the various quarries. Such studies are very difficult to accomplish with any degree of statistical significance. Too many variables enter the observational system. For instance, it is quite difficult to observe a whole cavity; normally we only have a portion of it to study. Furthermore, not all quarries are exploited with equal intensity, nor by the same quarrying techniques, nor are all discoveries reported, and so on.

Field observations, the study of large numbers of museum and private collection specimens, and data from interviews with quarrymen and collectors are nevertheless sufficient for the construction of a distribution framework for at least the most abundant species.

In addition to what we have shown on Table 3, at least two more important observations can be made:

1. Almost every species can be found at every quarry examined; only the proportions of the species vary. Quartz, for example, is very abundant in the Lorano quarries (which are poor in sulfides), whereas sulfides are more common at the Fantiscritti quarry (which is poor in quartz).
2. In every cavity it is possible to find the most varied species coexisting.

Considering above all that every species occurs at every locality, the distributions observed might be most simply attributed to local differences in the bulk chemistry of the marble. This is probably the explanation for the limited occurrence (only two quarries) of the titanium oxide minerals, and the increased abundance of quartz near the marble contact with cherty limestones. In fact, where quartz is more abundant in cavities, the composition of the surrounding marble is also higher in silica. But this explanation does not fit with other observations, and is unsupported by bulk chemical analyses in general which show the marble to be remarkably homogeneous over distance.

An alternative hypothesis can be built on the presumption that the temperature-pressure range of formation varies for different species. Some might crystallize over a wide range of conditions, whereas others might form only in restricted circumstances regardless of chemical availability. Variations in cooling history or pressure conditions throughout the marble formation would thereby result in varying mineralogical abundances. Distribution variability would increase for species with narrower ranges of deposition.

Varying assemblages observed among cavities at one locality can probably be ascribed to incomplete samples. As mentioned earlier, complete cavities are almost never available for detailed study.

CONCLUSIONS

The total volume of Carrara marble remaining to be quarried and mineralogically examined is vast. Consequently this fascinating locality will probably be capable of producing specimens, albeit very slowly, for centuries more.

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The bibliography has been divided into two sections. In the first part are listed all the studies and memoirs, numbered in progressive order and arranged chronologically, that contain original information about cavity minerals of the Carrara marble. These works we have referred to by number in the mineral descriptions.

In the second part are listed alphabetically those notes and memoirs of a more general character; these are referred to in the text by author's name and date.

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Figure 90. **Turn-of-the-century postcard showing a team of oxen hauling a large marble block. Brizzi collection and photo.**

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What's New in Minerals?

by Wendell E. Wilson

THE 79 MINE AURICHALCITE STORY

In my Tucson Show report in the previous issue reference was made to Tom McKee's prize-winning case of minerals, which included what is probably the world's finest specimen of aurichalcite. I promised to picture it in the future, and so here it is (Fig. 1).

Because I collected this specimen myself and know the history behind it, I will indulge in a short, personal narrative here to tell the tale. It is one of my fond memories which will perhaps have some points of interest for other collectors. The find is not exactly "new," being 16 years old, but I hope readers will overlook that for the sake of history relating to some truly unique specimens.

I spent two years, from late 1969 to late 1971, in Arizona working on my Master's Degree in mineralogy at Arizona State University. Naturally almost every free minute was spent crawling into bat-ridden and rat-infested black holes from one end of the state to the other, getting to know what we all revere as the Famous Localities. By my second year I was something of a veteran. One afternoon a couple of newly arrived graduate students approached me out by the pool at the graduate dormitory. As I recall, they weren't even geology students or mineral collectors. They said they were looking for some adventure and thought it would be great to visit an old mine and muck around underground for a while . . . what locations could I suggest? I listed a couple of easy and safe choices appropriate to beginners, but recommended against the famous 79 mine because of its extensive, complicated, and in some places dangerous workings. Of course this was where they wanted to go, and they would not be dissuaded, so I reluctantly gave them directions and turned back to sunning myself. They set off happily, with their shiny, unscratched Estwing hammers in hand.

The next afternoon they found me in the same place. Both were looking quite filthy and somewhat worse for the wear, but they were sporting big smiles and carrying several dusty beer flats which they set down in front of me. When the lids came off I saw a stunning array of exquisite, turquoise-blue aurichalcite specimens, thumbnails to cabinet sizes, seven full flats of them! No one to my knowledge had ever found anything nearly this good at the 79 mine, much less seven flats of it. While I sat there with my mouth open they cheerfully described breaking into a pocket in the ceiling of what was known as the "aurichalcite room." Then they said the magic words: "We didn't finish the pocket . . . half of it is still there if you'd like to go get some yourself."

Well, a senior graduate student must maintain his dignity. I nodded sagely, congratulated them, asked them absently if they planned to sell the lot (they hadn't decided, but later sold it at a swap meet), and mused that perhaps I might amble out to the mine sometime when I had nothing better to do.

As soon as they had disappeared into the dorm to wash up I suddenly decided that I had nothing better to do. For a moment I considered going out to the mine alone, and hogging what remained of the pocket. But my next thoughts were of being found three weeks later pinned under a rock on the Fourth Level, dead of thirst. So with great reluctance and generosity to match their own, I called a collecting buddy of mine, and in short order we covered the 100 miles out to the mine.

I agreed to split the take with him, but wanted to do the actual extraction by myself, so he went off to the "wulfenite room" elsewhere on the Fourth Level, with a friend of ours who had tagged along but was not in on the split, and I retired to the "aurichalcite room" to see if the fellows had been pulling my leg. They had not.

The "aurichalcite room" was no larger than an average kitchen; the floor was mounded high with rubble and sloped upward to within a few feet of the ceiling. At the back one could sit and work in the ceiling. At first I didn't see anything, but I took my hardhat off as they had instructed and forced my head up into a very tight and irregular fissure, and from there I could just see a dark, horizontal opening perhaps 5 or 6 cm high and 20 or 25 cm wide. I couldn't really see into it, but I could reach it, and inside I felt loose pieces so I carefully slid one out onto my other hand. That specimen, the first one I removed, was the one pictured here.

Aurichalcite is universally thought of as being finely acicular, pale blue, and extremely delicate. This specimen, however, has no matrix . . . it is a hard, solid crust of aurichalcite about 1 to 1.5 cm thick and 14 cm (5½ inches) long. The individual crystals are so large that they are very dark turquoise-blue-green instead of pale blue, and they actually have individual termination faces which sparkle as the specimen is turned. In the course of a couple of hours I removed three flats of aurichalcite from the pocket, but only a few specimens had the dark blue color and sparkling terminations, and the first was the biggest and best.

The hundred miles home were long ones as I balanced the best flat on my lap, cushioning it from road bumps, petrified that a sudden pothole would cause the big piece to flip upside down and destroy itself. Because of the delicacy of the aurichalcites, I had packed all of the specimens open-face and could not relax.

Once back at poolside I spent some hours just staring at the big piece and wondering what to do with it. It was intimidatingly gorgeous, clearly out of my league relative to the rest of my collection, and frighteningly fragile – at least I imagined it to be so, although it is in fact surprisingly sturdy. In the end I sold it because I couldn't stand the pressure of worrying about breaking it someday. I kept a smaller piece, sold the big one to Tom McKee (for an excrutiatingly low sum, but what did I, a mere student, know about the dollar value of world-class specimens?), and the rest of my half of the split to a local dealer. Tom has been faithful to his trust; the specimen is still as perfect as the day I collected it. Where the rest of the specimens have all gone I don't know. But in all the time since, during which my knowledge of minerals has broadened considerably, I have never seen another aurichalcite from any locality worldwide that is as good as even the twentieth best from that pocket.

I took one photo underground, of the first flat I packed with specimens. It is shown in my short article on the 79 mine (vol. 3, no. 6, p. 269, Figure 7). The big piece is at upper left in the flat, and one of the others is shown on the page facing it.

I don't remember much about the best pieces found by the first two collectors, but some of them were of comparable quality, and two were of the best very dark blue color. One of the fellows, Dr. Kent Knock, now of Trumbull, Connecticut, still owns the better of the two and it is nearly as large and fine as the one McKee now owns.

The discovery became quite famous among Arizona collectors, and in the following years the little aurichalcite room at the 79 mine

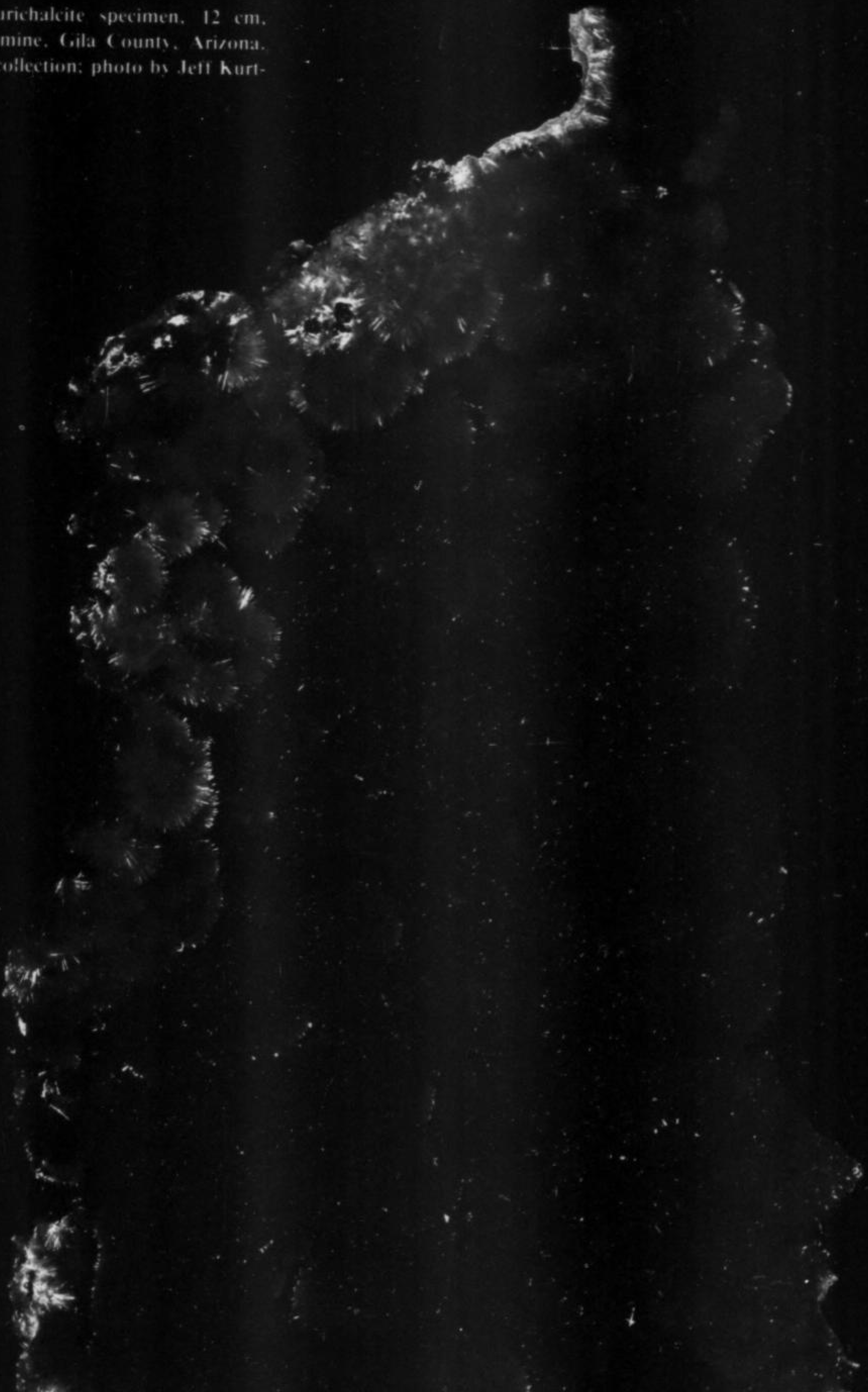

Figure 1. Aurichalcite specimen, 12 cm, from the 79 mine, Gila County, Arizona. Tom McKee collection; photo by Jeff Kurtzeman.

was reamed out to several times its original size. Unfortunately, no specimens even remotely similar to those from the "great pocket" were ever found. Because I found the best piece and it ended up in a prominent Arizona collection, I think I am sometimes given more credit for the discovery than I deserve; but it was Dr. Knock who found the pocket and so kindly shared it with me.

NEW TUCSON MUSEUM

Early this year the Old Pueblo Museum opened in Tucson, Arizona, at Foothills Center, Ina Road and North La Cholla Boulevard. The museum is dedicated to presenting a wide variety of exhibits and programs on the art, culture and natural history of the American Southwest. As a fan of Western art I can say that some of their recent exhibitions have been excellent. However, what will be of most interest to mineral collectors is the permanent subterranean gallery devoted to minerals of the Southwest. Approximately 60 quite fine specimens including Tiger minerals, Bisbee minerals, a full case of wulfenite, and a 45-kg pyrite crystal are arranged in spacious, black-background cases. The specimens are all on long-term loan from the vault of the Arizona-Sonora Desert Museum which, like many museums, owns considerably more fine specimens than they themselves have space to exhibit.

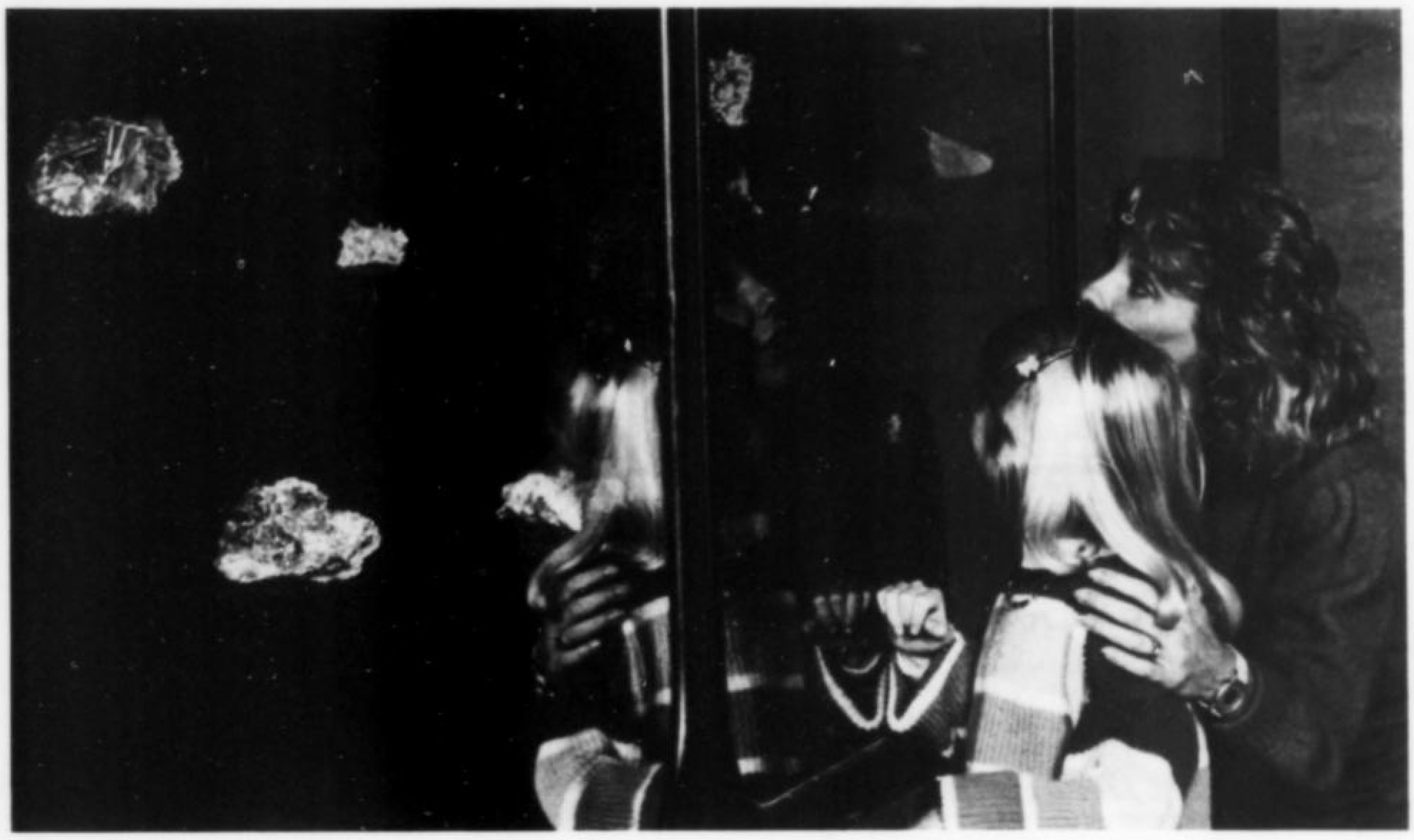

Figure 2. **Roomy exhibit cases at the Old Pueblo Museum, Tucson.**

WHAT'S NEW IN SPAIN?

[The following report is from Professor Curto i Mila, curator at the Geological Museum in Barcelona, and J. Fabre, a Barcelona mineral dealer. Ed.]

We read with interest George Robinson's review of recent mineral discoveries worldwide, which appears in *What's new in minerals?* last year (vol. 17, no. 5, p. 339). The coverage of the various countries was very complete, except that no mention was made of discoveries in Spain.

Usually it is very difficult to obtain reliable data on mineral collecting in Spain, even for people actively involved in mineralogy. Nearly all published information relates only to the technical aspects of mining and ore analysis, and not to crystallized material. Attempting to extract useful mineralogical information from the literature is often difficult and frustrating. Nevertheless, we can offer the following summary of the mineral "harvest" for 1986.

Many "classics" appeared on the market which were extracted during the year, particularly fluorites. Some large, superb, transparent deep blue fluorite crystals collected at La Collada (Asturias province) were available at the PLM (Paris) Show. Exceptional violet fluorite crystals on barite matrix were found once again at Berbes (Asturias province), and some fine, cubic, honey-yellow fluorites with yellow and white scalenohedral calcite and white to blue tabular barite came from the well known Moscona mine, Solís (Asturias province). At the El Papiol quarry near Barcelona, small (about 5 mm), deep green octahedral fluorites were collected.

Pyrite groups and single crystals have come once again from Amejún (Soria province, Castilla-León community). A few very fine, apple-green pyromorphite specimens have been found at the San Andres mine, Villaviciosa de Cordoba (Córdoba province, Andalucia community), with crystals to 1.5 cm, on barite and limonite.

Excellent cinnabar specimens have been coming from the ancient locality of Almadén (Ciudad Real province, Castilla-La Mancha community). The crystals are gemmy, lustrous, deep red, and up to 2 cm in size.

"Book" aggregates of sharp, bright, transparent white barite crystals have recently come from La Unión, Cartagena (Murcia province); some of these specimens were available at the Torino and Barcelona shows.

Among the more surprising and exciting discoveries made this year are bipyramidal scheelite crystals to 6 cm (2⅓ inches). The crystals are orange-red in color, lustrous, sharp and translucent to gemmy. Associations include prismatic cassiterite crystals (black at the termination and transparent brown along the body of the prism), well crystallized arsenopyrite and pyrrhotite, all on a matrix of quartz crystals or muscovite. The find was reportedly made at Bejar (Salamanca province, Castilla-León community), and specimens were available at the Munich, Torino, Copenhagen and Barcelona shows.

Gypsum crystals have recently come from Pina de Ebro (Zaragoza province, Aragón community). They are sharp, bright and gemmy, on alabaster matrix, and commonly measure 2 to 5 cm long, but extraordinary crystals can reach 10 cm. Sharp, clean gypsum crystals of classic monoclinic habit have also been found at Alcanadre (Logroño province, Rioja community).

Finally, we should mention the bright exfoliation masses of native antimony on quartz from Motril (Córdoba province, Andalucia community). ⊠

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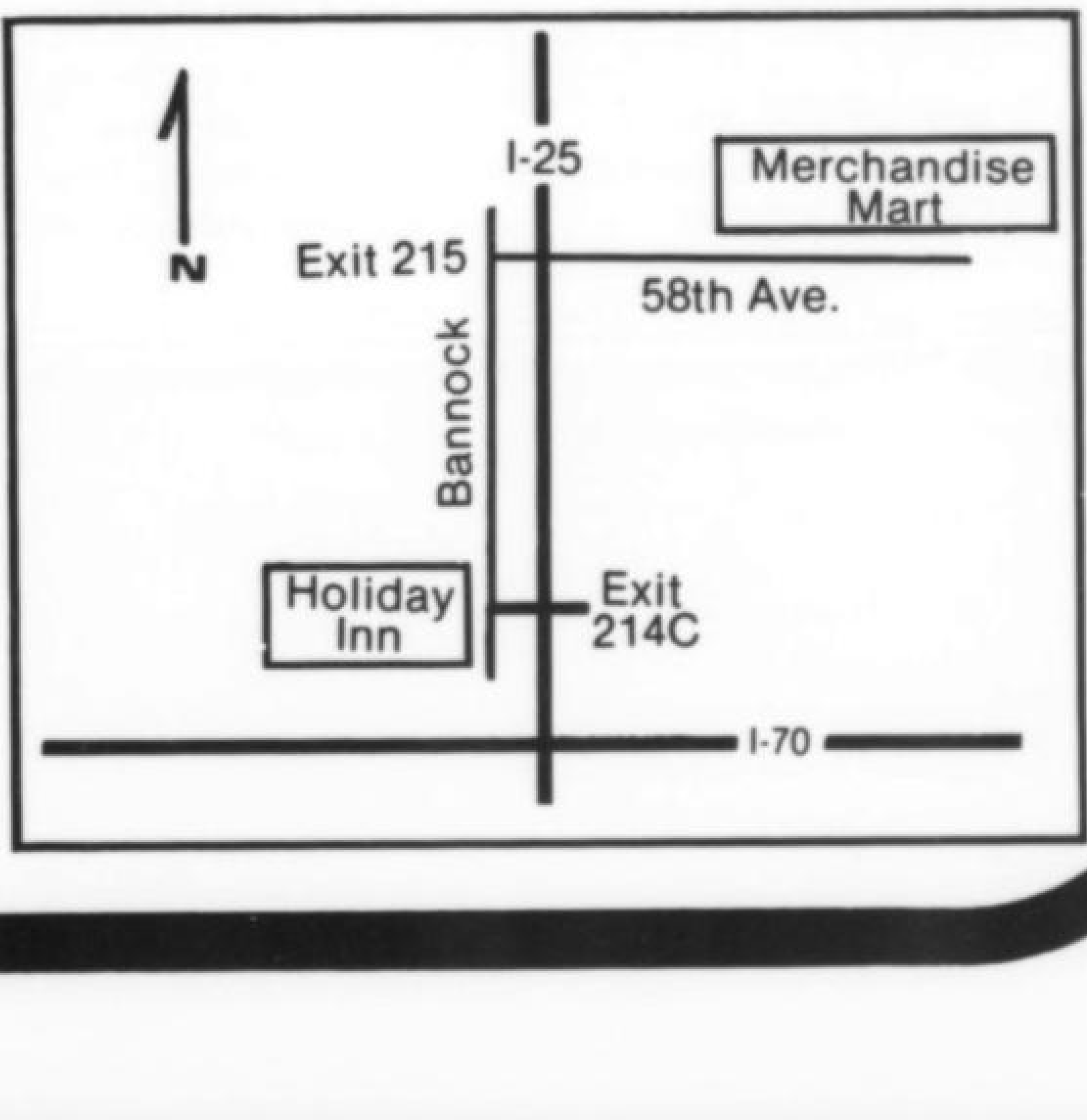
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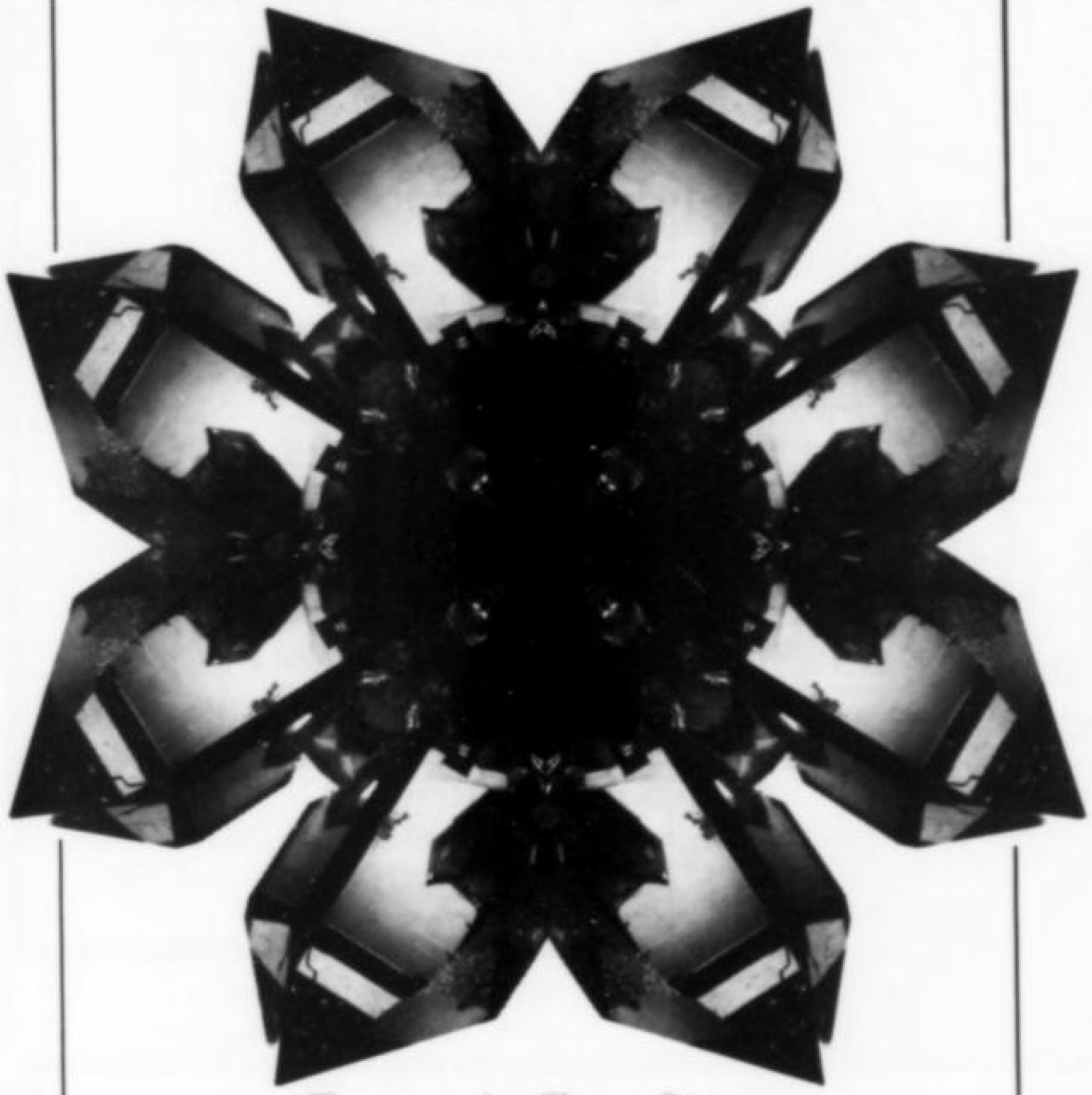

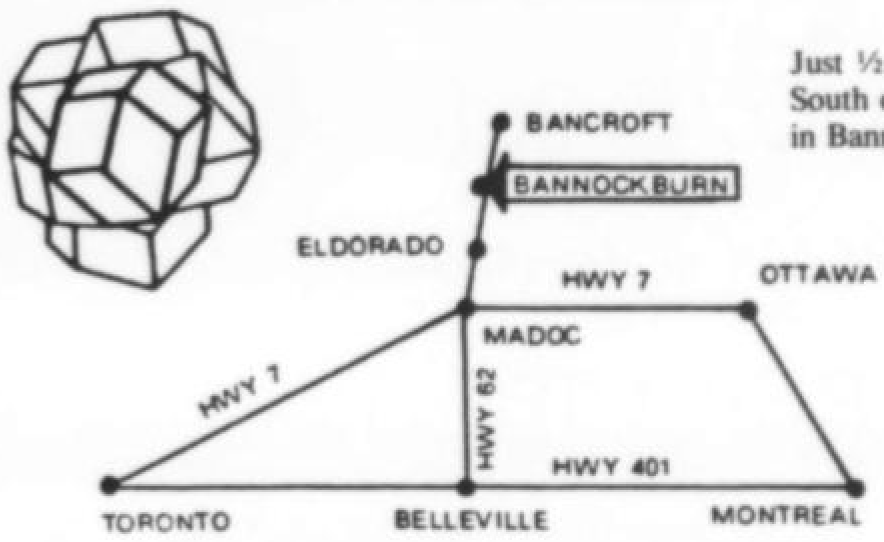
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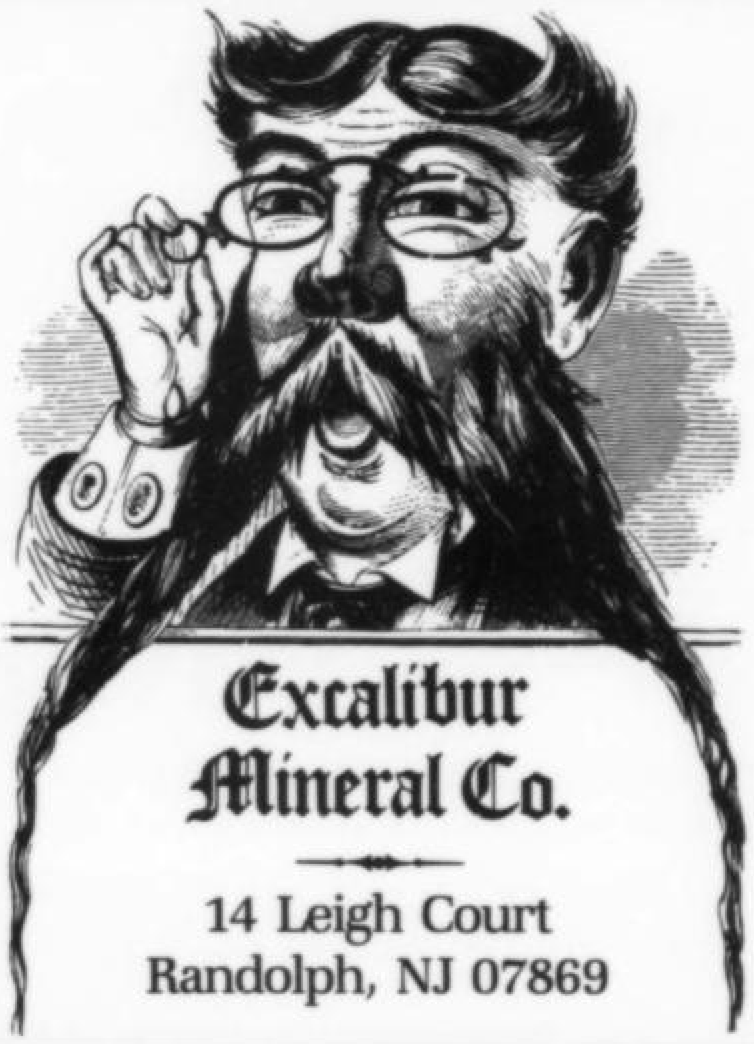

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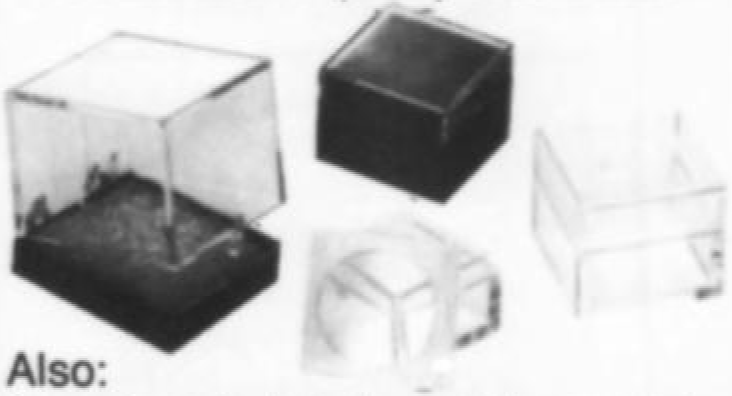

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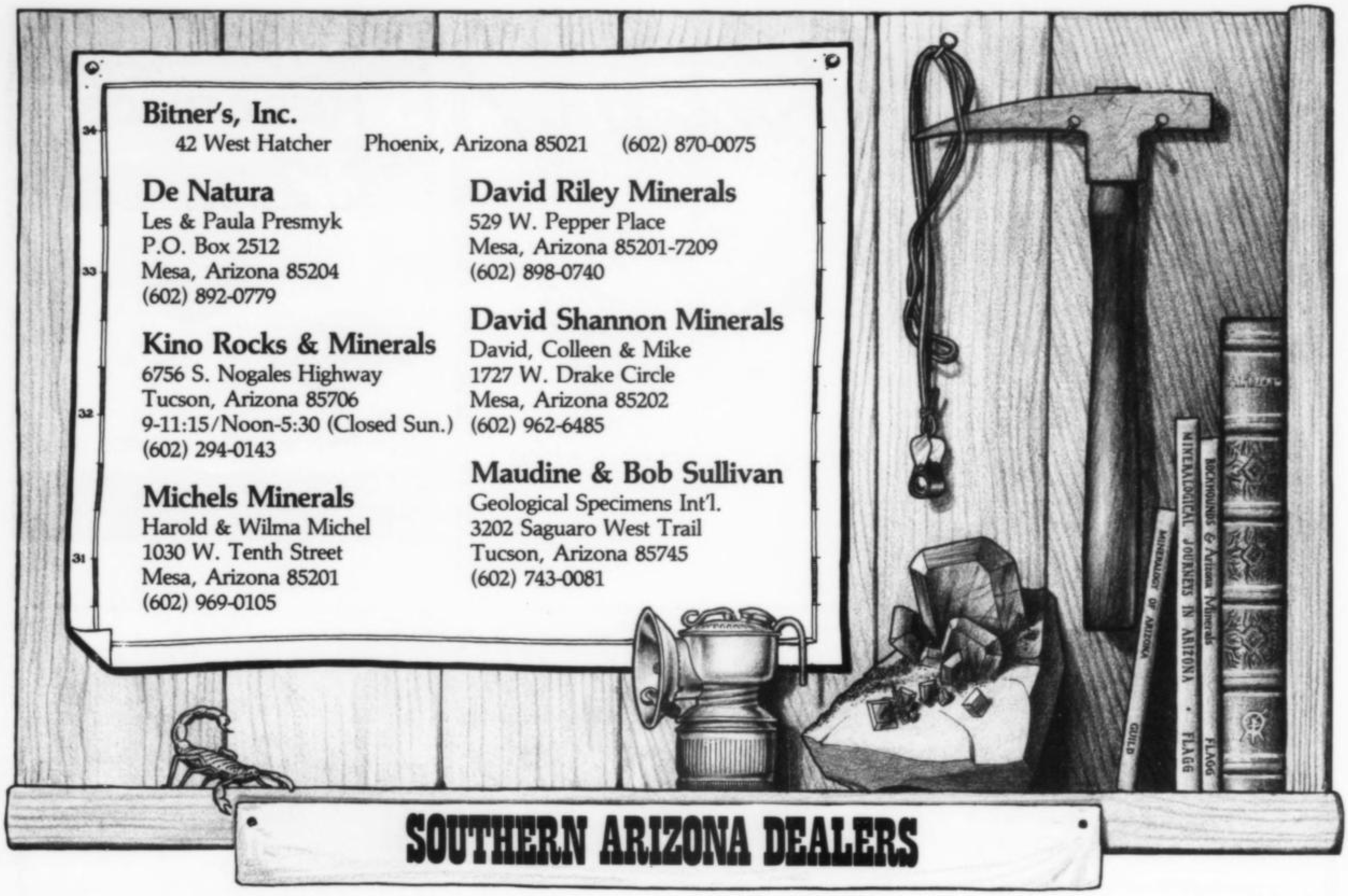

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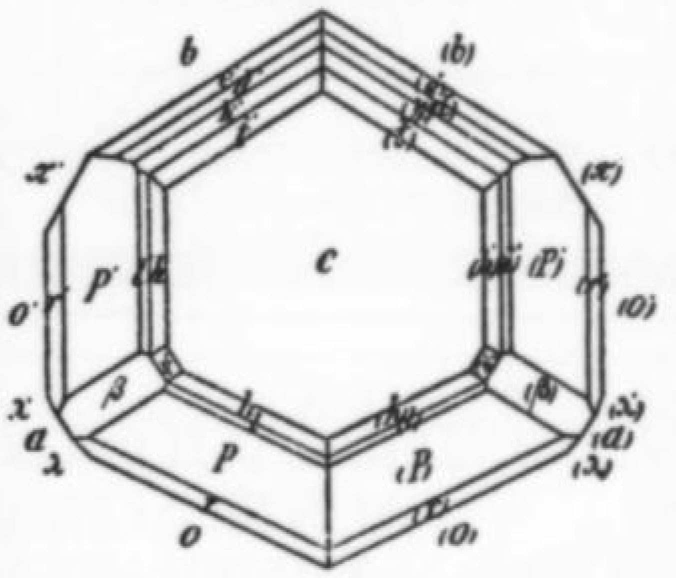

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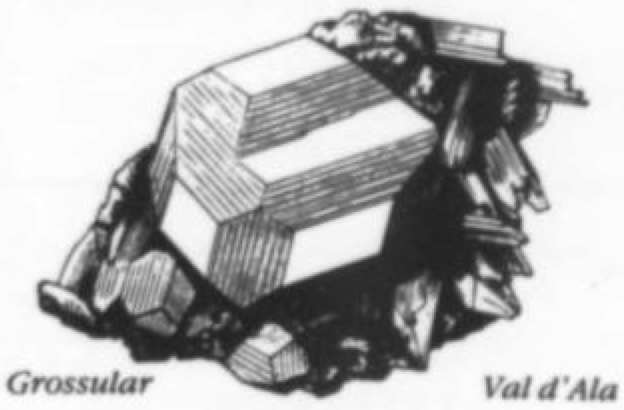

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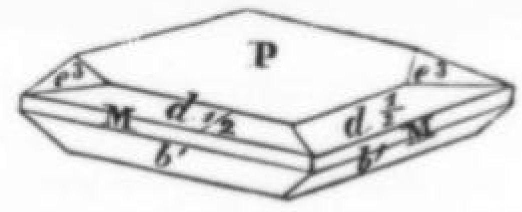

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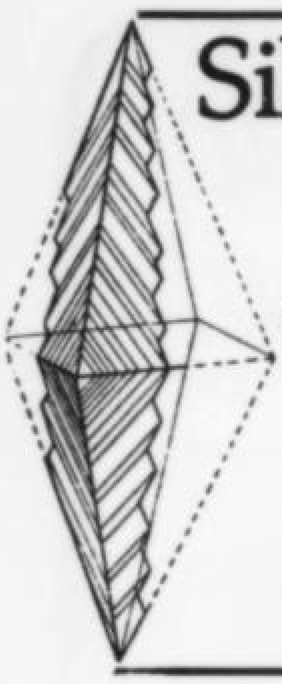

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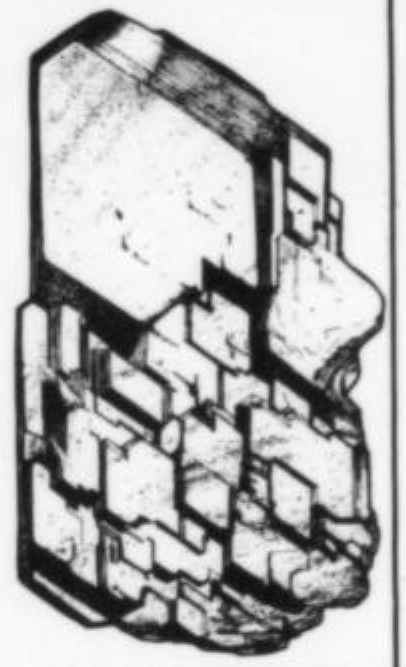

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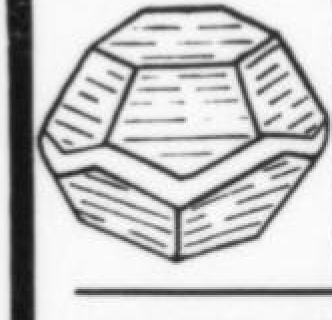

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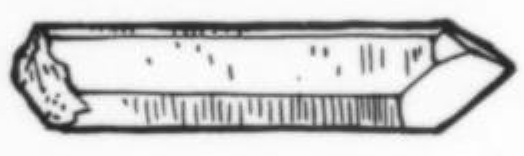

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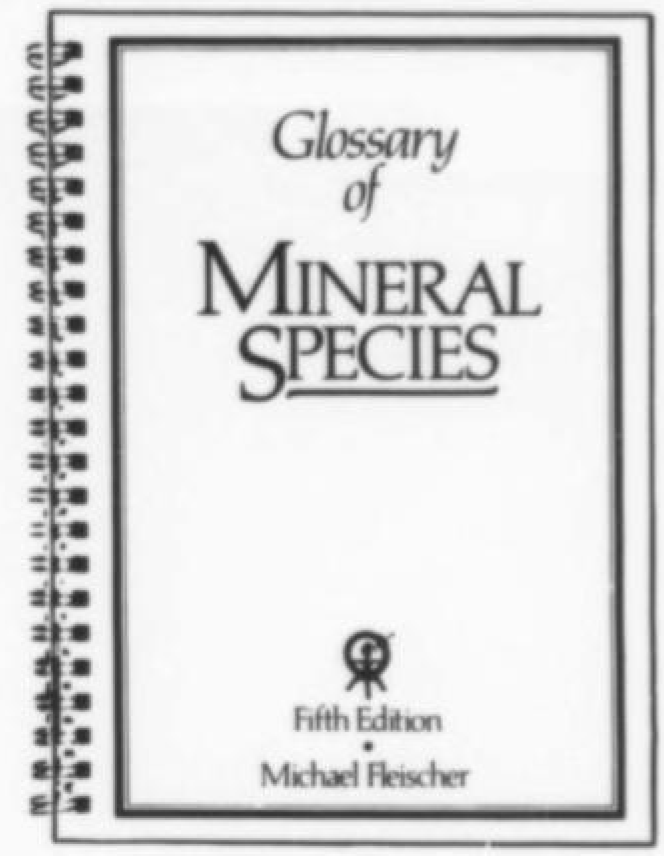

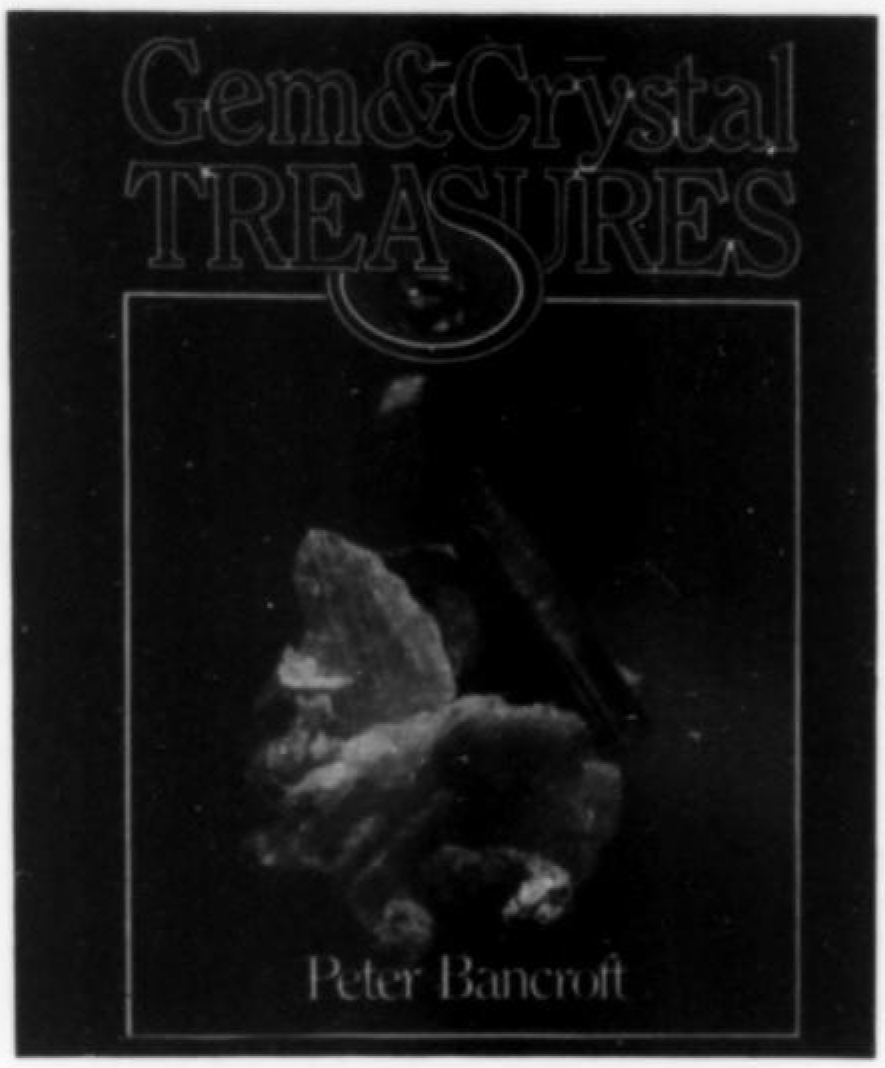

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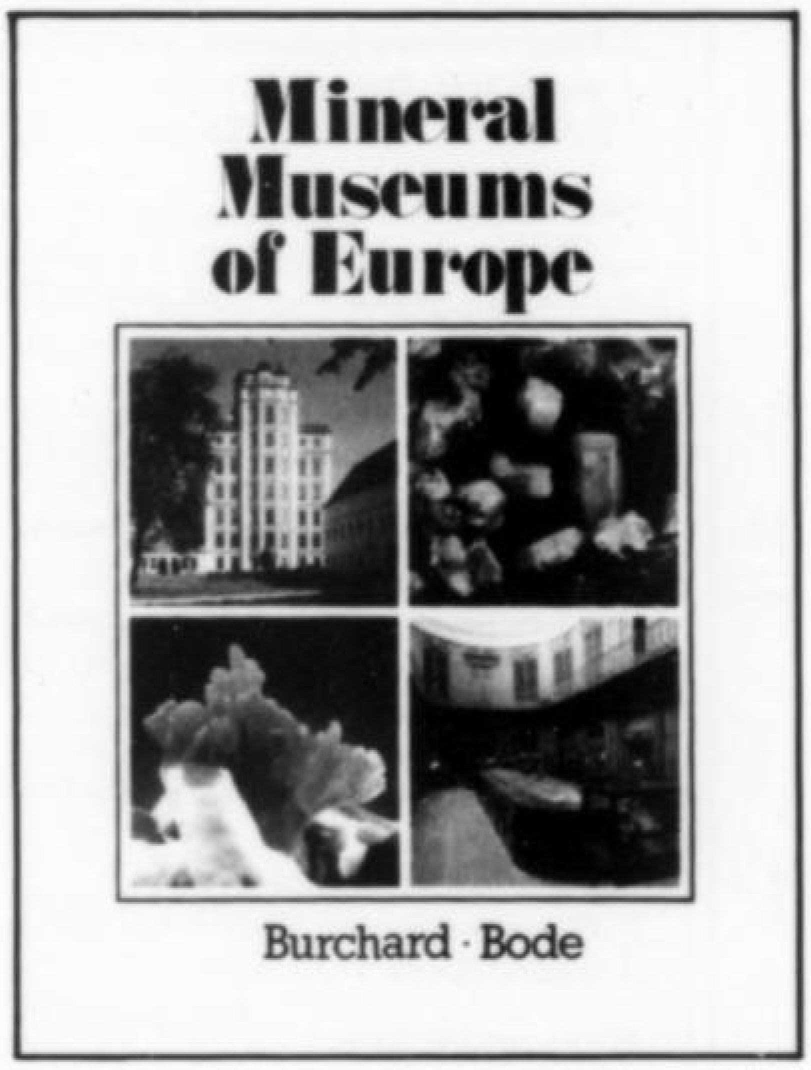

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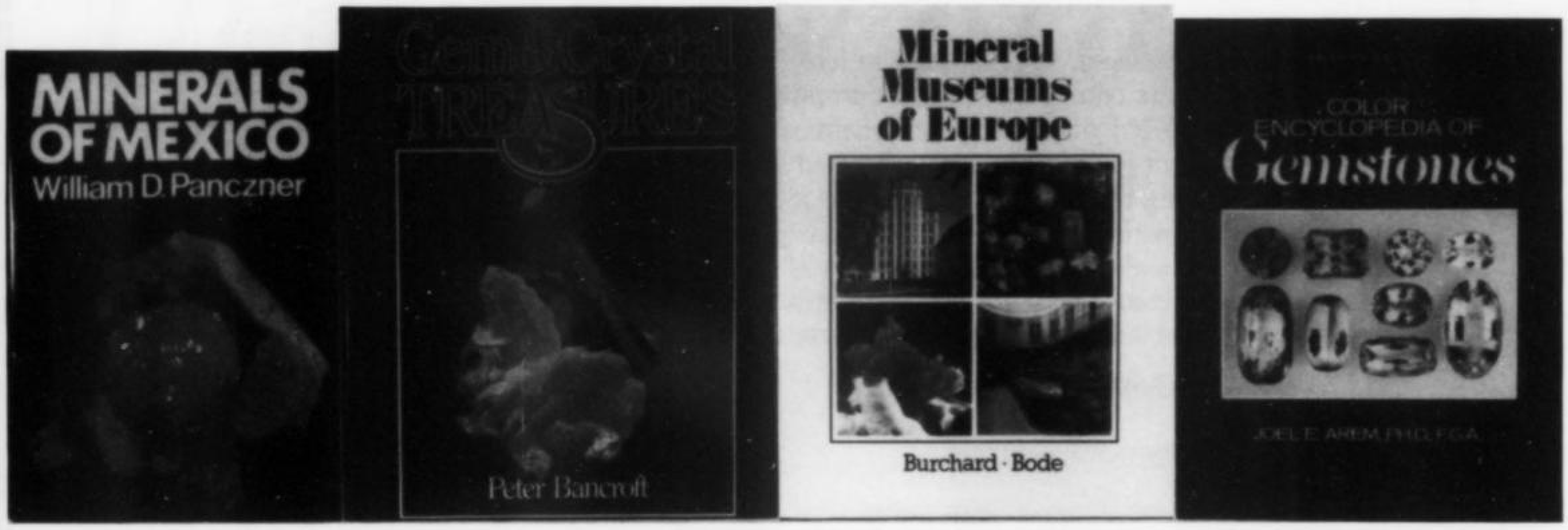

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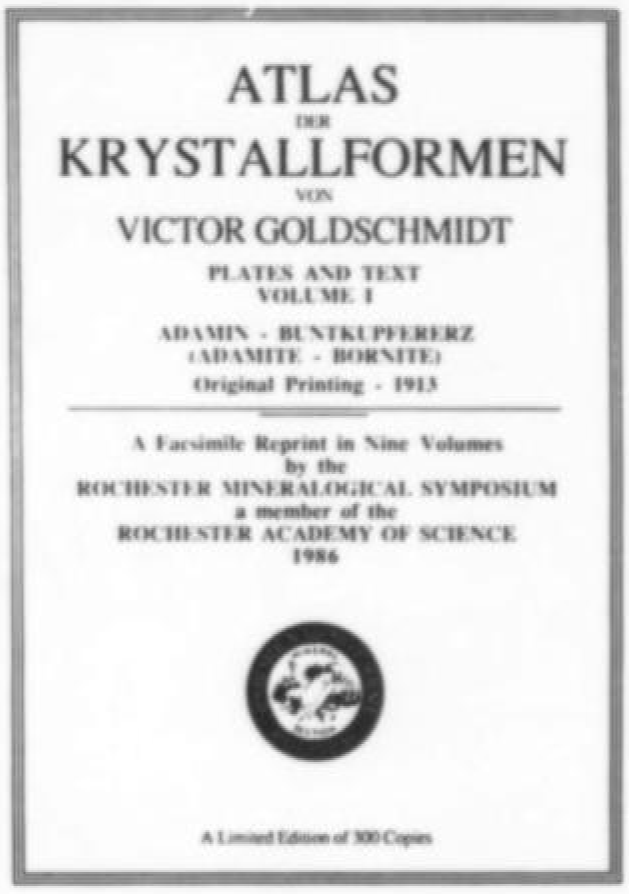

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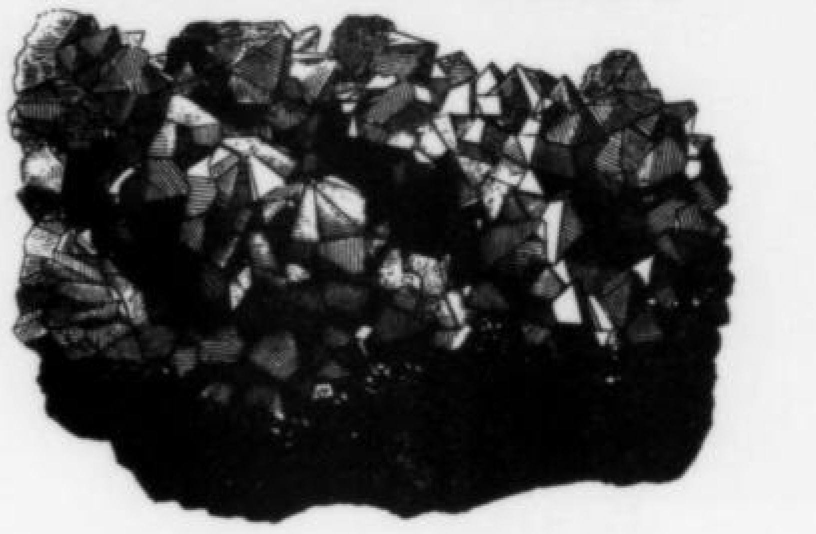

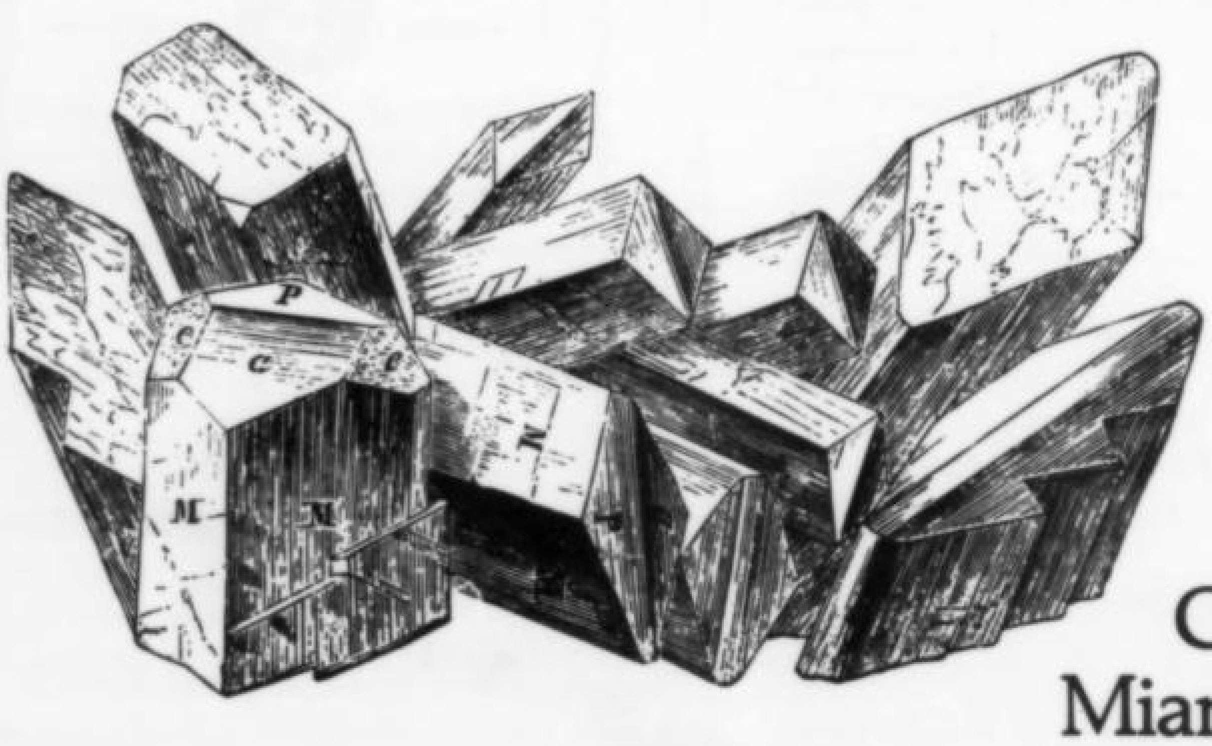
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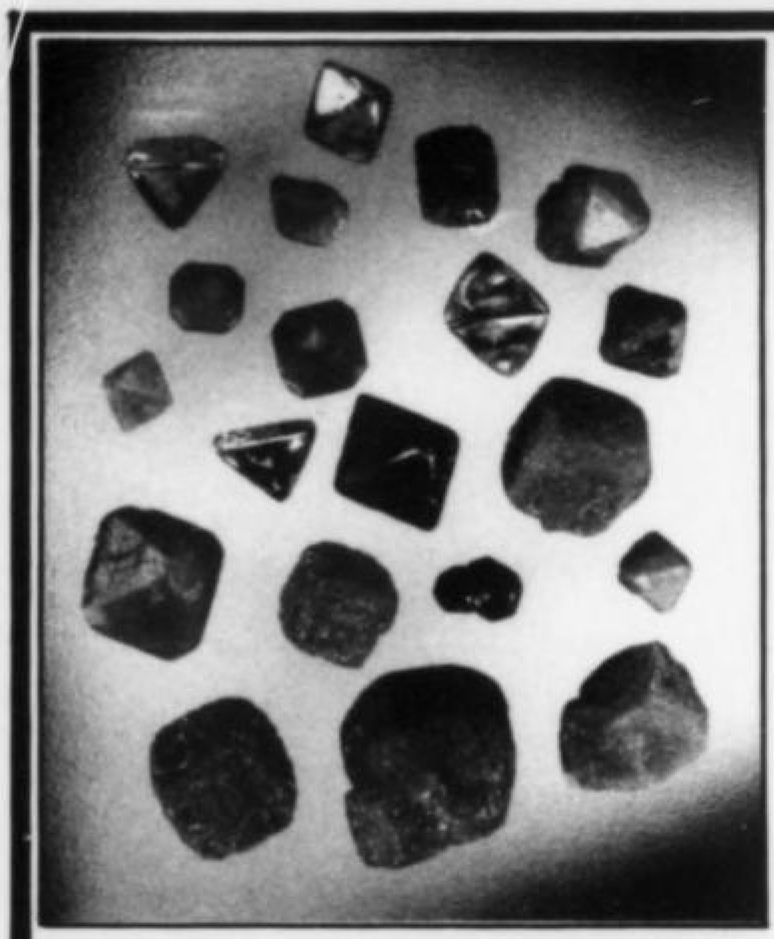

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