THE MINERALOGICAL RECORD

MARCH–APRIL 2009 • VOLUME 40 • NUMBER 2

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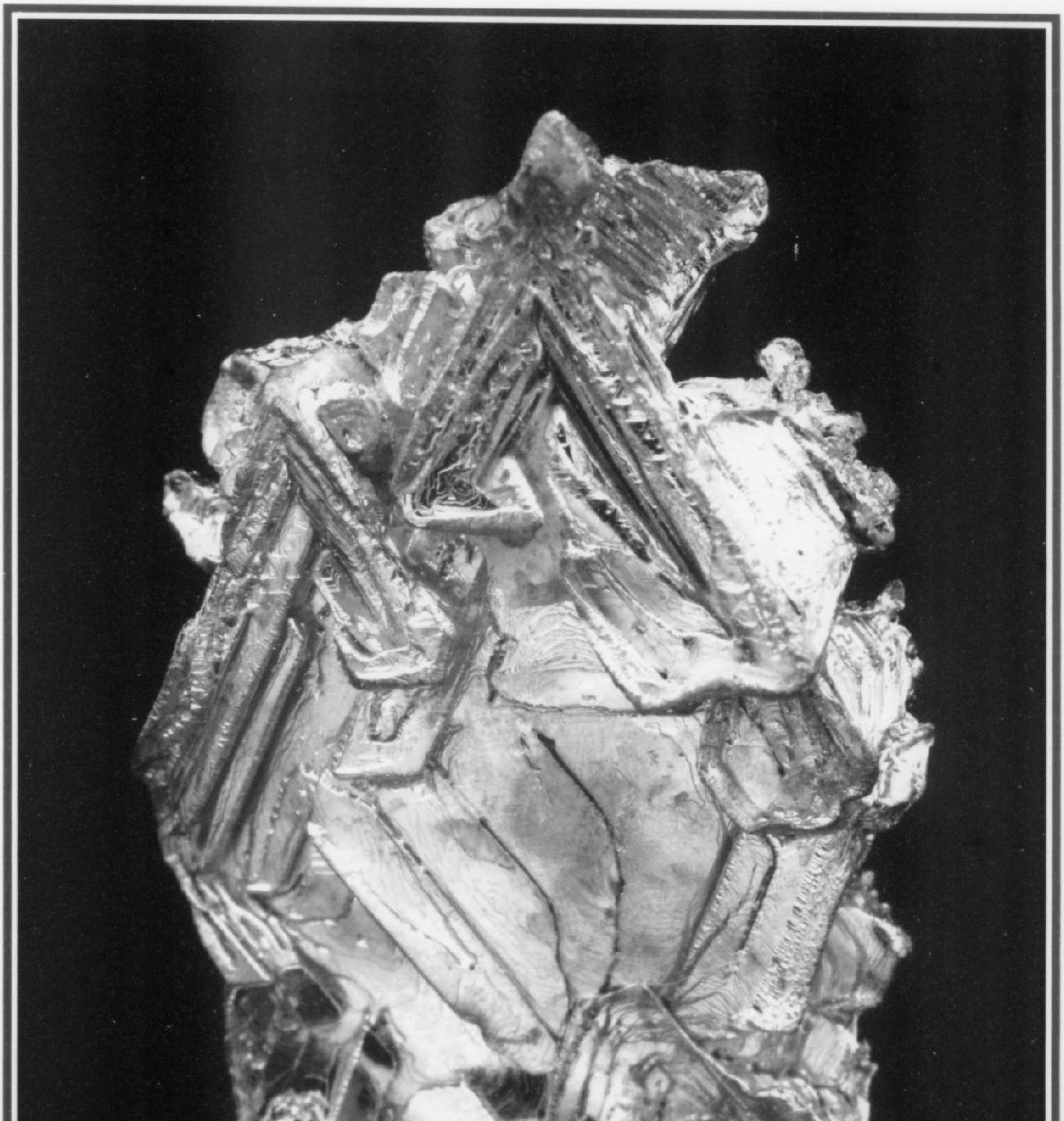

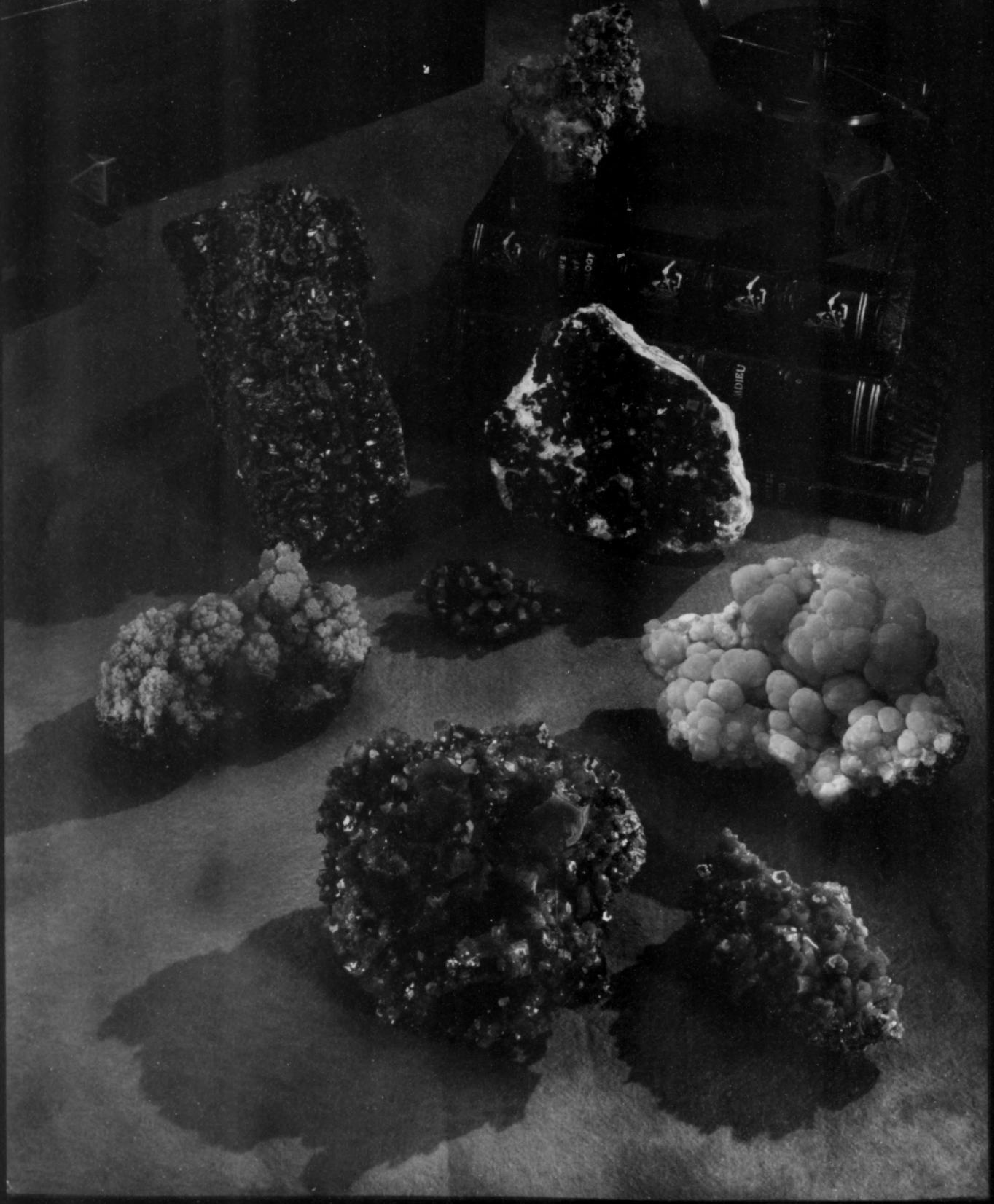

The Mineralogical Record

The International Magazine for Mineral Collectors

VOLUME 40 • NUMBER 2 MARCH–APRIL 2009

Articles

Columns

Notes from the Editors:

COVER: GOLD, 2.3 cm, from the Round Mountain mine, Nye County, Nevada. See the article on this occurrence beginning on page 105 of this issue. Keith Proctor and Scott Rudolph collection; Jeff Scovil photo.

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Continued on page facing inside back cover

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George E. Burnham (1914–2008)

Died, George Burnham, 94

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On January 1, 1946 George and his brother Wayne opened a mineral business out of George's three-car garage at 128 S. Encinitas Avenue in Monrovia, California, calling it the *Burnham Mineral Company,* or "BURMINCO" for short. Their first ad that month in *Rocks & Minerals* advertised Los Lamentos wulfenite (square tabular and prismatic) at 45¢ per square inch of crystal-covered matrix, and diaboleite at 50¢ per square inch, up to 16 square inches (for $8). A few issues later he offered well-formed benitoite and neptunite crystals on natrolite for $1 to $2.

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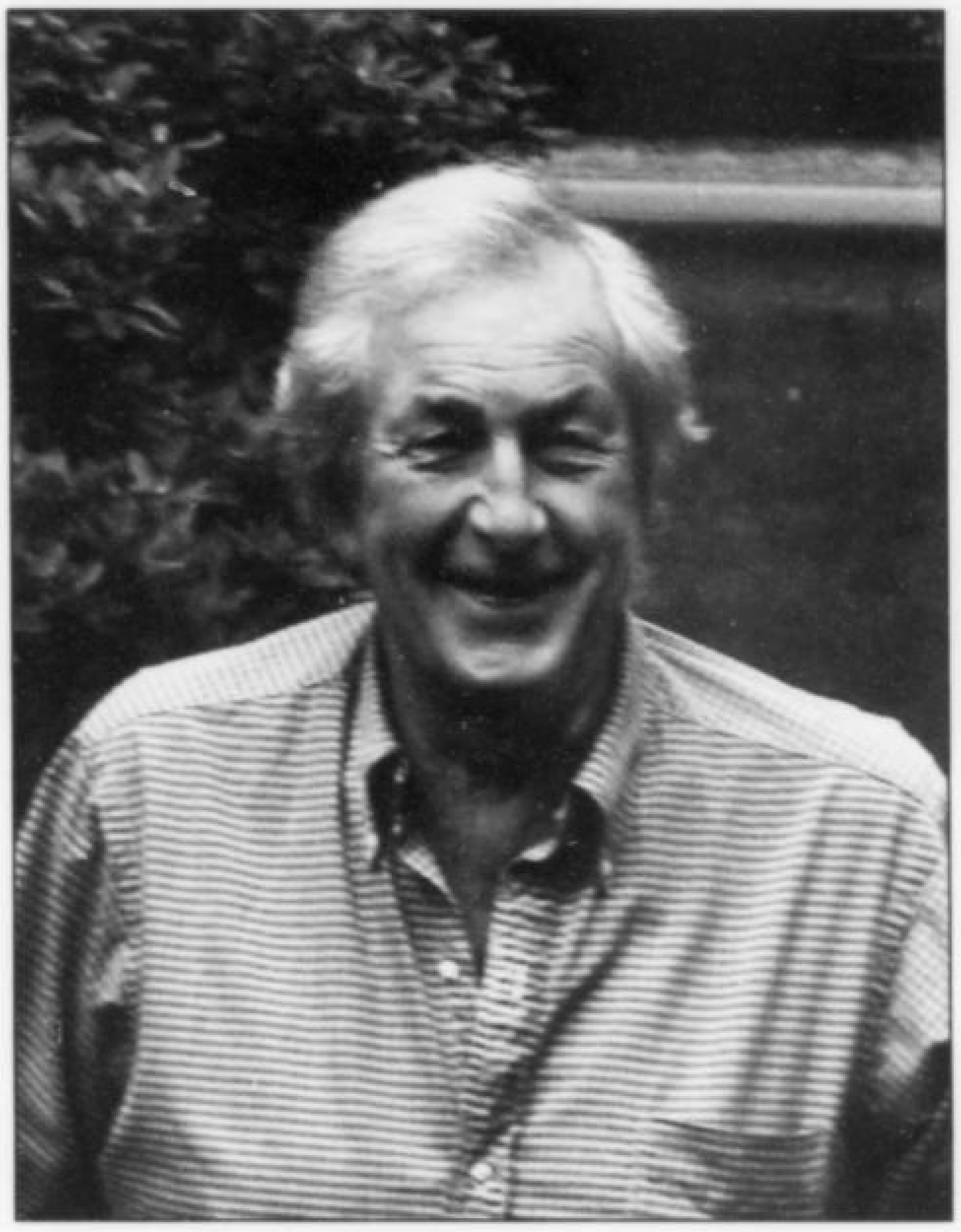

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After graduating from St. Mark's, John decided to pursue his interest in minerals and took a summer job at the Homestake mine in Lead, South Dakota. He also applied and was accepted into the Geology Department at Harvard University. During his four years at Harvard John continued his interest in minerals by working at different mines during the summer, including mining underground at Butte, Montana. He also pursued another passion, playing hockey, while at Harvard and later with the Berlin Maroons. After graduation from Harvard in 1954 with a BS Degree in Geology, John enlisted in the army and was stationed in Europe, where he developed an appreciation for European culture, and as a result he visited England and the continent frequently during the years that followed.

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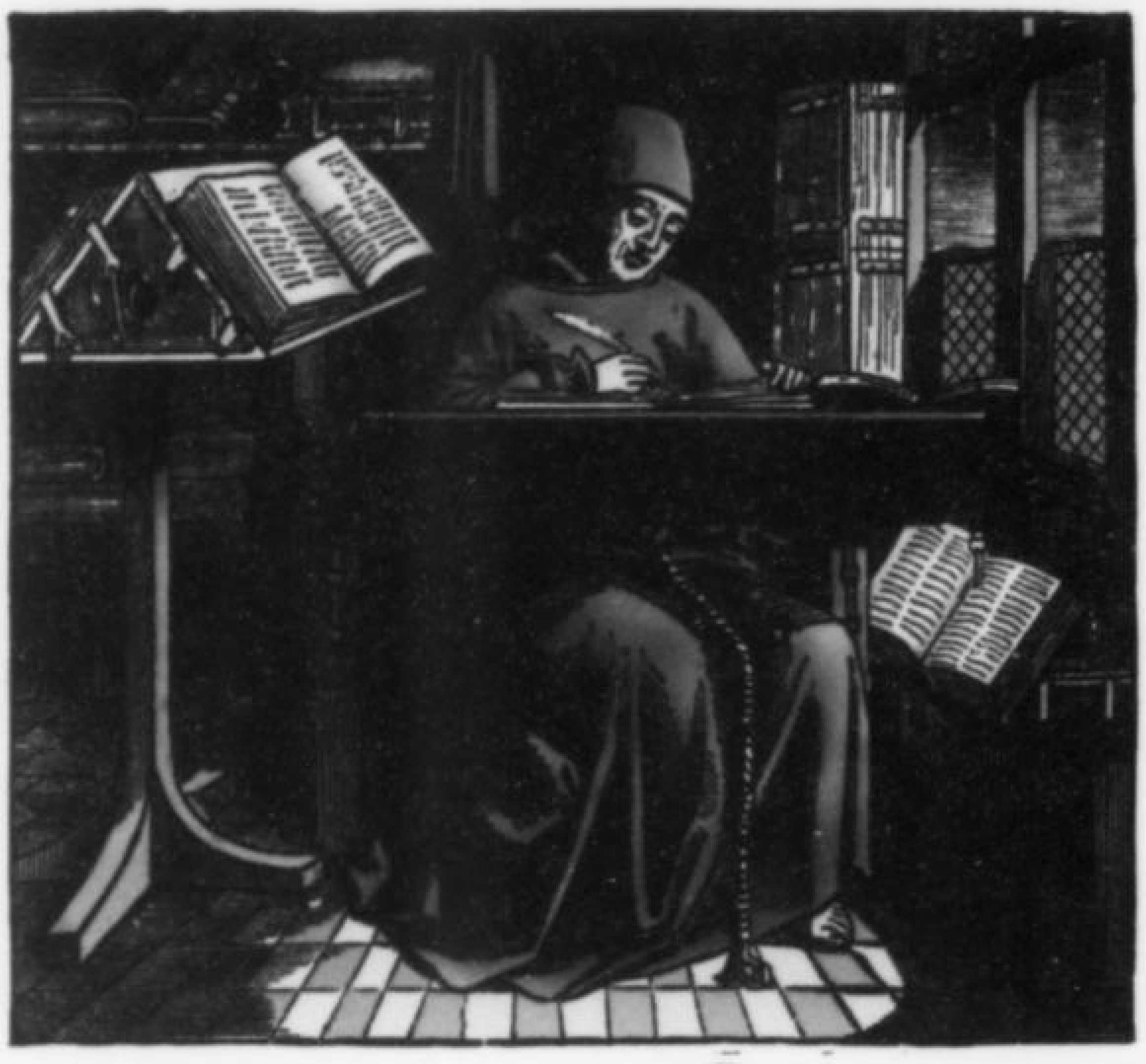

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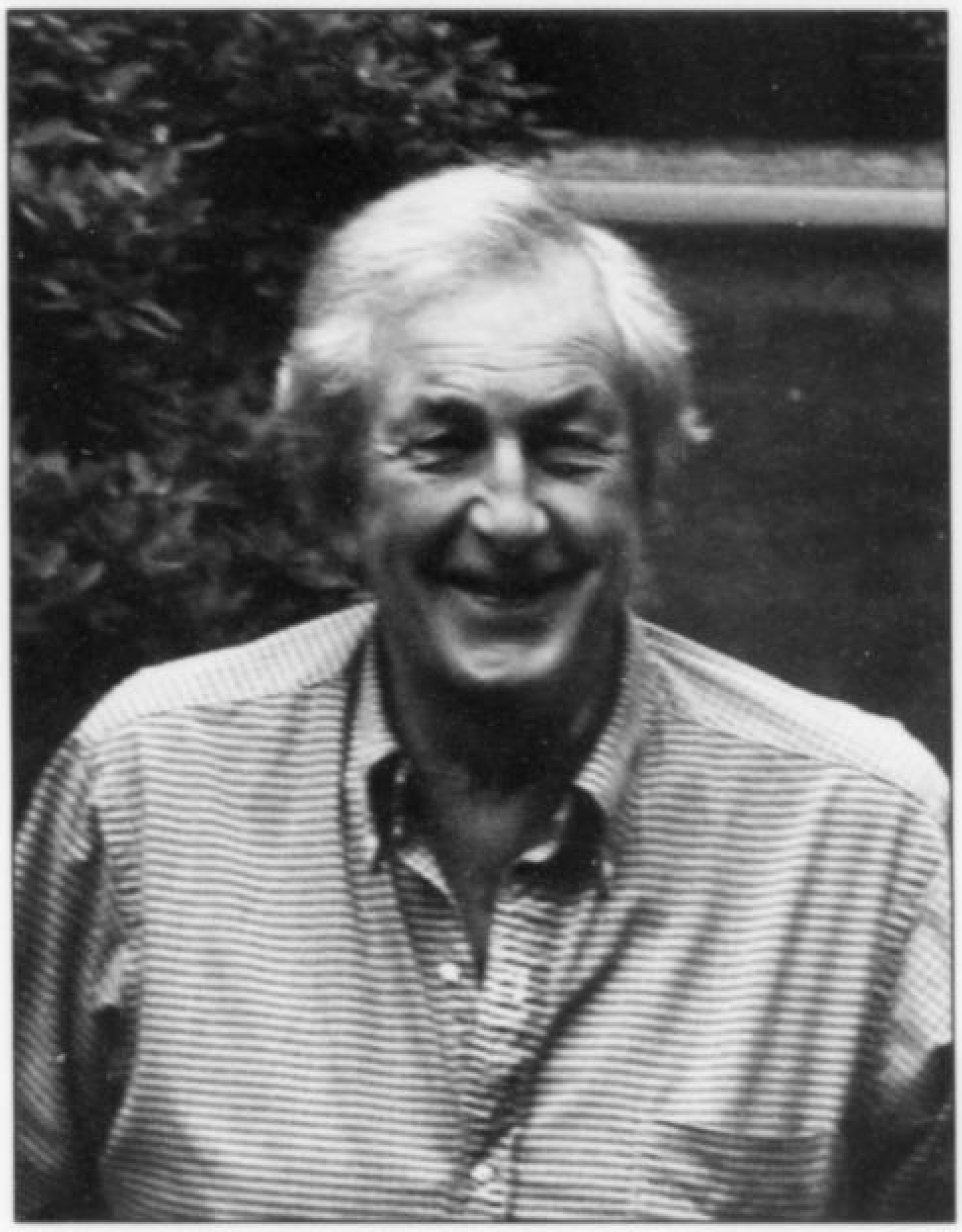

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Newly discovered photo of mineral dealer George L. English (1864–1944), taken in 1893, with his daughter Gwendolen. Darryl Powell collection.

From these visits John developed a deep interest in Colorado mining history and started a Colorado mineral collection that grew to several hundred specimens. In 1999 John arranged to donate his Colorado collection, together with custom-built cases, to the Ouray County Museum and Historical Society. A link to the museum mineral room can be found at www.ouraycountyhistoricalsociety.org/MineralRoom.htm.

Over the years he has also donated specimens to St. Mark's School, Harvard University, and to the Colorado School of Mines.

John was dedicated to enhancing and preserving our mineral heritage. By supporting activities that would expand the knowledge and appreciation of minerals, providing financial support for worthy publications (including Mick Cooper's book on the history of British mineral dealers) and donating collections for others to enjoy, he made important and lasting contributions to the mineral community.

Shields Flynn

"New" Photo of George English!

Darryl Powell in Manchester, New York recently wrote to us about a newly discovered photo of the early Philadelphia mineral dealer George Letchworth English (1864–1944). English, who established his mineral business in 1887, was the main competitor of Albert E. Foote, who had opened the first major mineral dealership in America in 1876.

In early August Darryl purchased on eBay (for $9.99) an autographed copy of English's book *Getting Acquainted with Minerals* (1934). An additional item that was "thrown in" with the book was a cabinet photo of George L. English with his first daughter, Gwendolen. The photo was taken in July 1893 when Gwendolen, born March 26, 1891, was "2 years 4 months" old (according to the handwritten information on the back of the card) and George (born June 14, 1864) would have been 29 years old. This appears to be the earliest known photo of English.

The associated copy of *Getting Acquainted with Minerals* was published in 1934 by the Mineralogical Publishing Company of Rochester, New York, and must be one of the earliest printings because it was published later that same year by the McGraw-Hill Company in New York. It is autographed by the author, in the same hand as the writing on the back of the photo. In 1958, this book was published once again, in a revised edition under the editorial leadership of David E. Jensen at Ward's Natural Science Establishment; Dave had been associated with Ward's since 1930, and had worked there with English until English's retirement in 1934. It is interesting to note that the revised edition was copyrighted jointly in the name of Gwendolen English Burleson, the girl in the photo shown here, and David Jensen. ⊠

Rhodochrosite - Colorado   *Frederick Wilda©*

The Denver Spring

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Fri. & Sat. 10-6, Sun. 10-5

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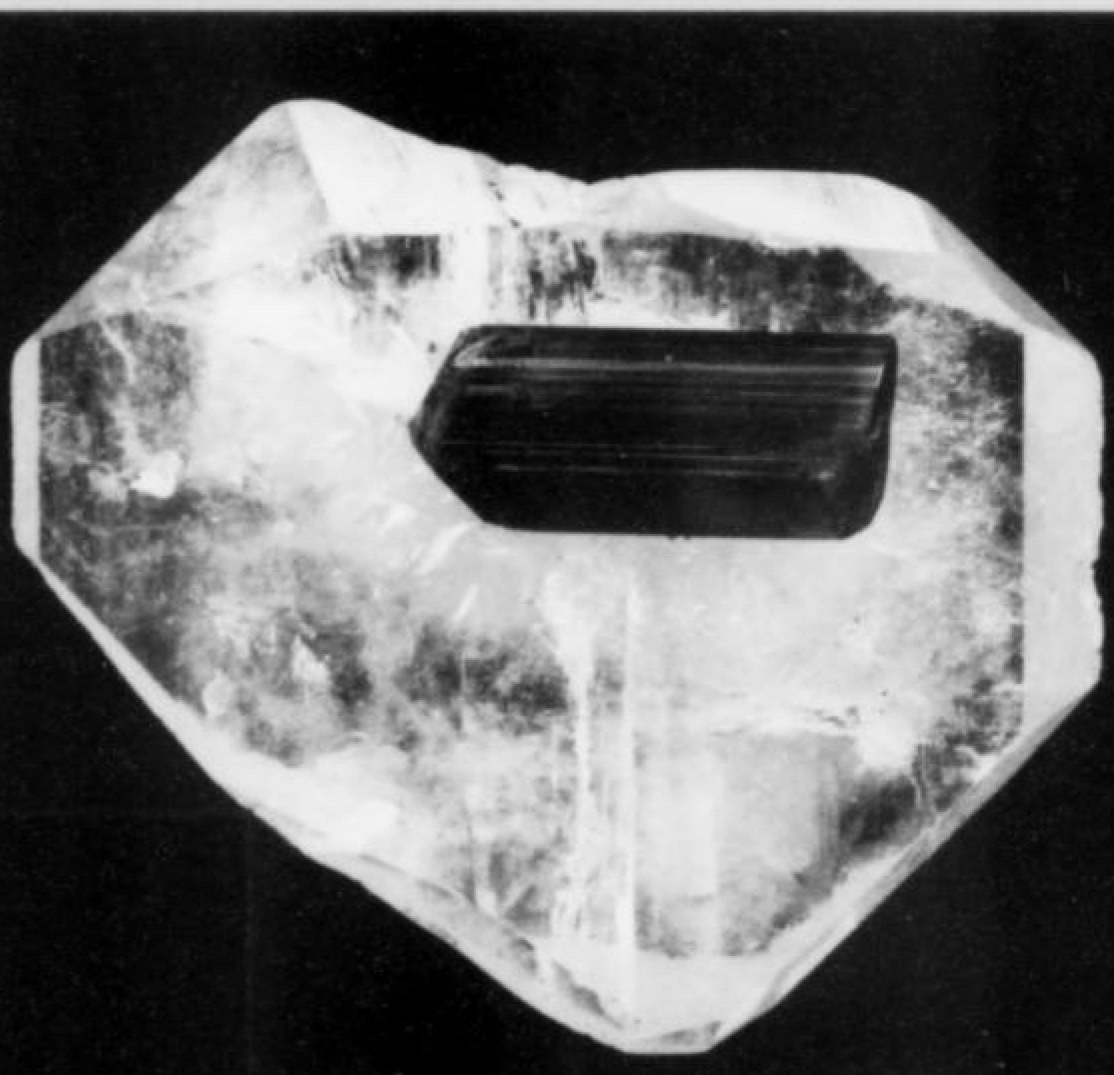
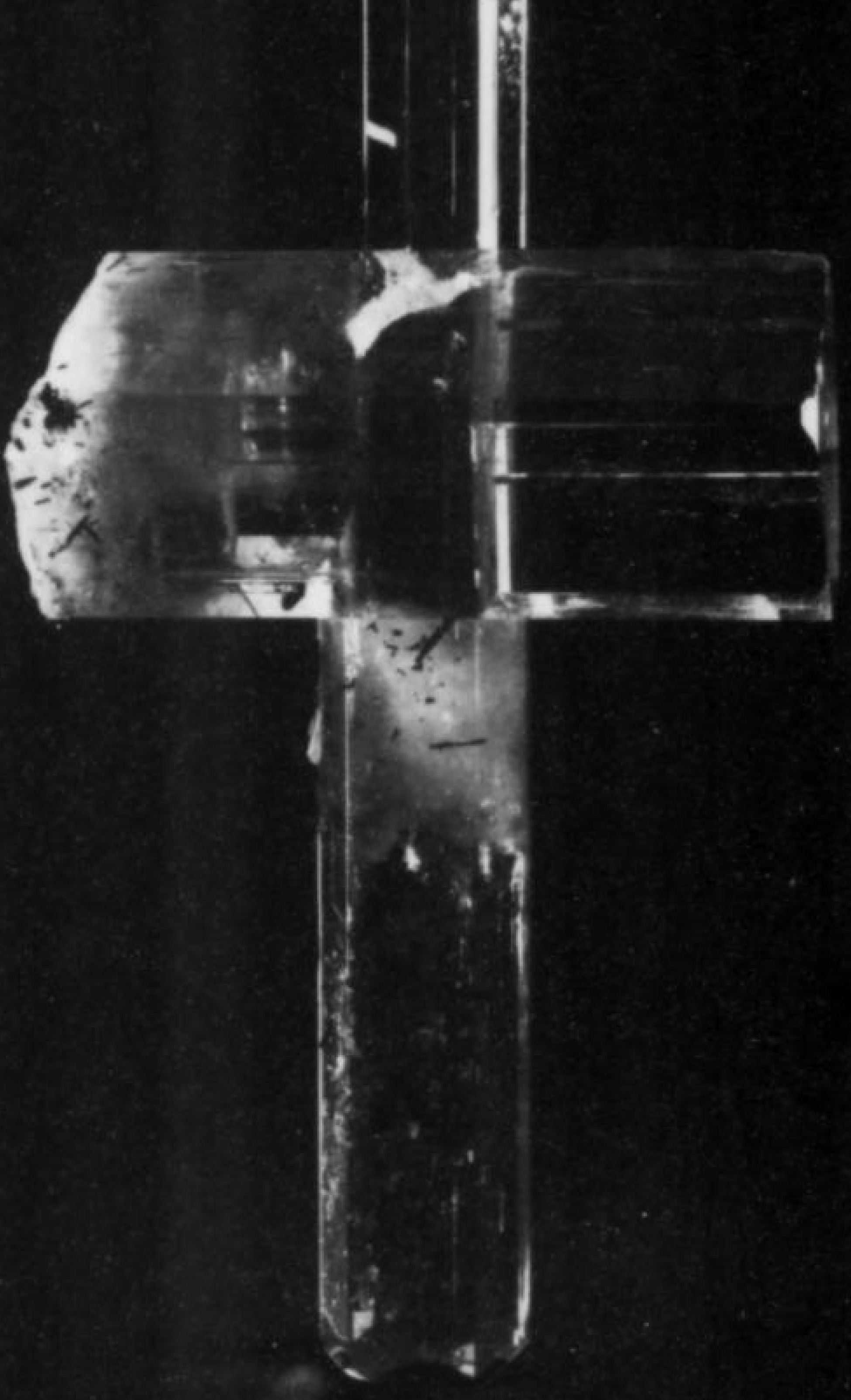
West Coast Gem & Mineral Show Costa Mesa, CA

May 15-16-17, 2009

Holiday Inn Costa Mesa
3131 S. Bristol Street
Fri. & Sat. 10-6, Sun. 10-5

Wulfenite - Red Cloud Mine, AZ   *Frederick Wilda©*

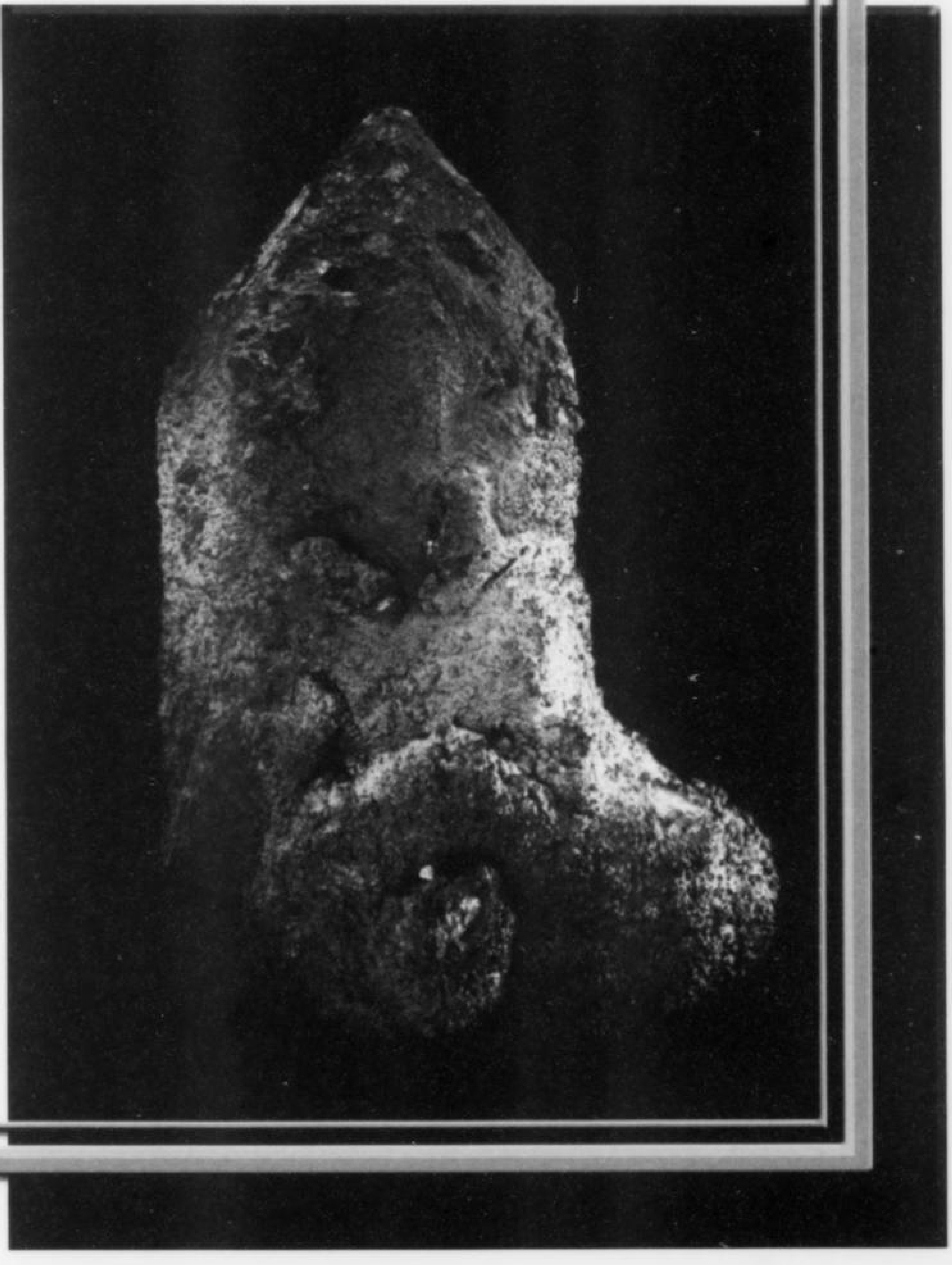




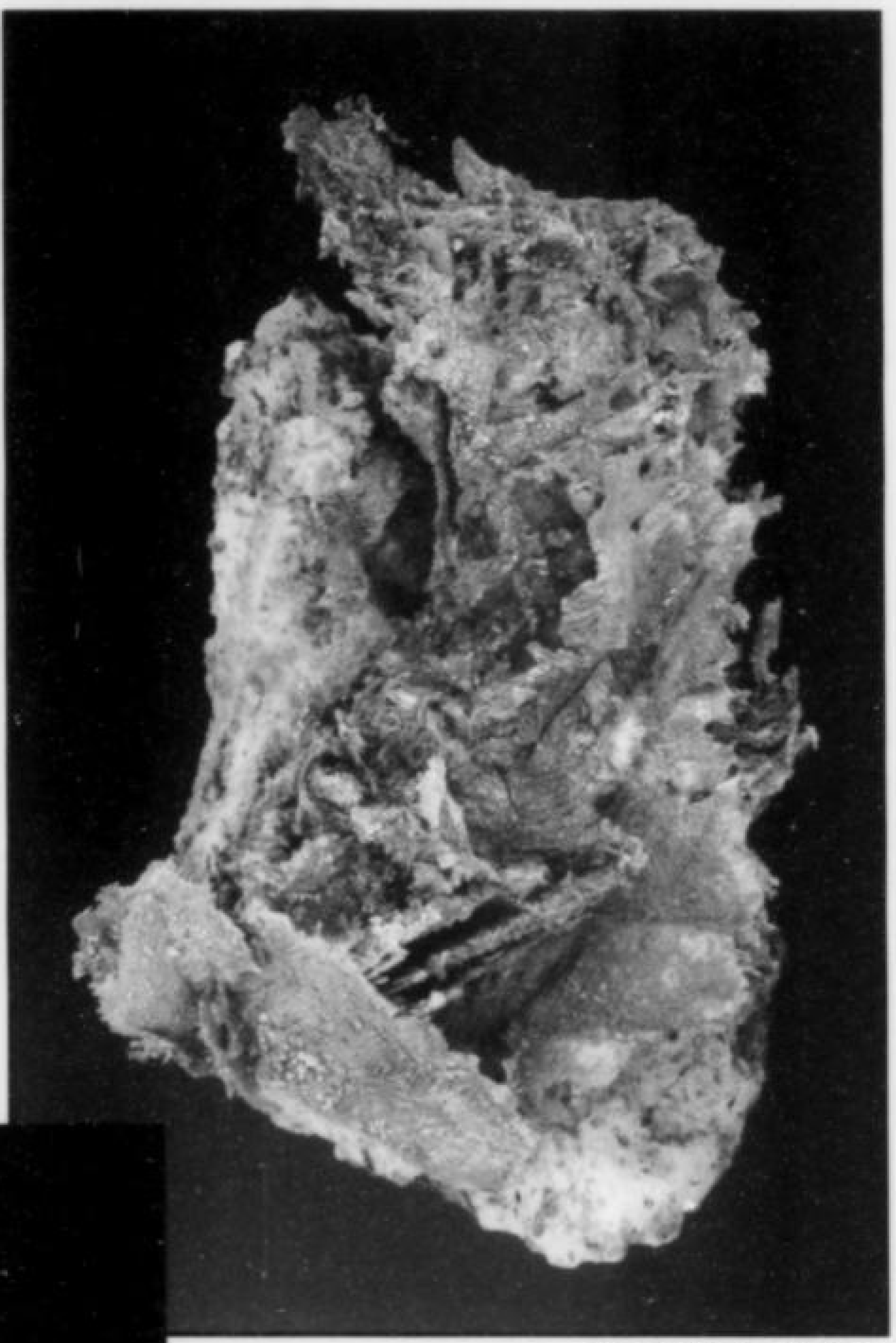
ELBAITE on Quartz (above),
7 cm, from the Jonas mine, Itatiaia,
Minas Gerais, Brazil

AQUAMARINE (left)
15.5 cm, from Shigar,
Northern Areas, Pakistan

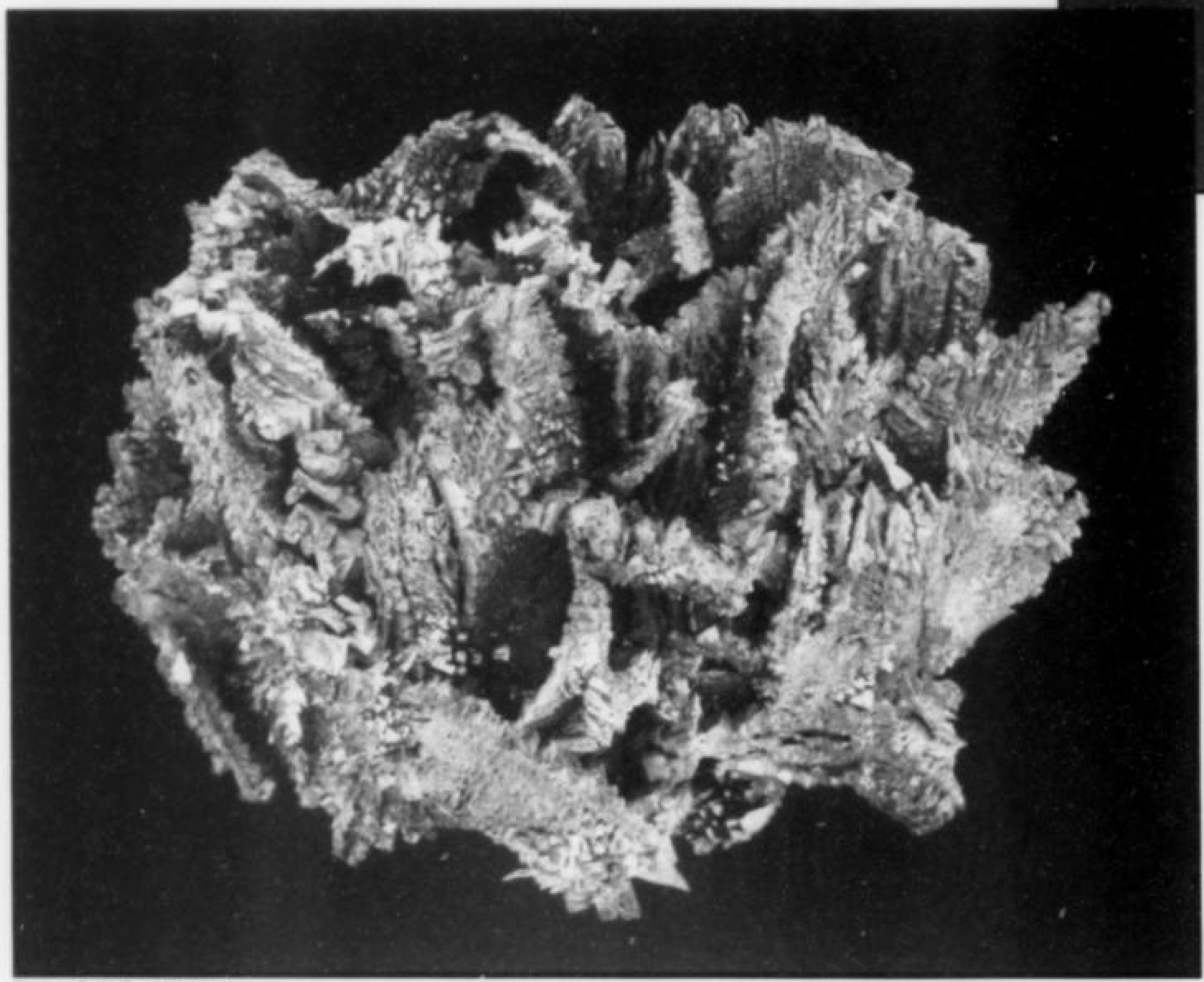
Photos by Joe Budd



7.6 cm; Joe Budd photo.



10 cm; Jeff Scovil photo.



5 cm; Jeff Scovil photo

THE ROUND MOUNTAIN MINE,

Nye County, Nevada

Wendell E. Wilson
Mineralogical Record
4631 Paseo Tubutama
Tucson, Arizona 85750
minrec@comcast.net

Although the average ore grade at the Round Mountain mine is only around 0.02 ounces of gold per ton, spectacular finds of hundreds of ounces of beautiful crystallized gold have yielded substantial numbers of attractive specimens, the finest ever found in Nevada; finds in 2005 and 2006 were particularly dramatic. The enlightened policies of the Kinross Gold Corporation, which operates the mine, have permitted the recovery and sale of specimens for over 20 years. The mine will remain in operation for the next few years and may well produce more specimens.

INTRODUCTION

Round Mountain is a small hill situated in a remote, arid, high desert region on the east flank of the Toquima Range in central Nevada. The Round Mountain open pit gold mine, operated by the Kinross Gold Corporation, is located 55 miles north of Tonopah in northern Nye County, about 250 miles from Las Vegas and Reno, at an altitude of 5,800 to 6,800 feet. Access is by State Highway 376, a paved two-lane highway connecting U.S. Highway 6 in Tonopah (don't forget to visit the Mining Museum there) to the south and U.S. Highway 50 near Austin to the north. Most of the 750 people employed at the mine live in the nearby communities of Hadley and Carver. A paved airstrip suitable for small aircraft is maintained near the mine site.

HISTORY

Gold has been produced in the Round Mountain district for over 100 years, and old abandoned workings are common throughout the area. The first spectacularly rich gold vein was discovered there in 1906 by Lewis D. Gordon, who sold his interest in the claim a few days later for $87,000 (Cavender, 1985). By the following year several hundred miners had moved into the area and stagecoaches were arriving daily from Tonopah. Production from 1906 through 1969 (based on U.S. Bureau of Mines records) approached 350,000 ounces of gold and 362,000 ounces of silver (Tingley and Berger, 1985), though unreported production was probably significantly higher.

Early companies actively involved in mining in the district included the Round Mountain Mining Company, the Round Mountain Daisy Mining Company, the Fairview Round Mountain Mining Company, the Round Mountain Red Top Company, the Round Mountain Sphinx Company, and the Round Mountain Red Antelope Mining Company. By 1929, Nevada Porphyry Mines, Inc. had consolidated many of the claims and had thereby gained

Figure 1. **Southeast end of the Round Mountain mine open pit. Larry Workman photo.**

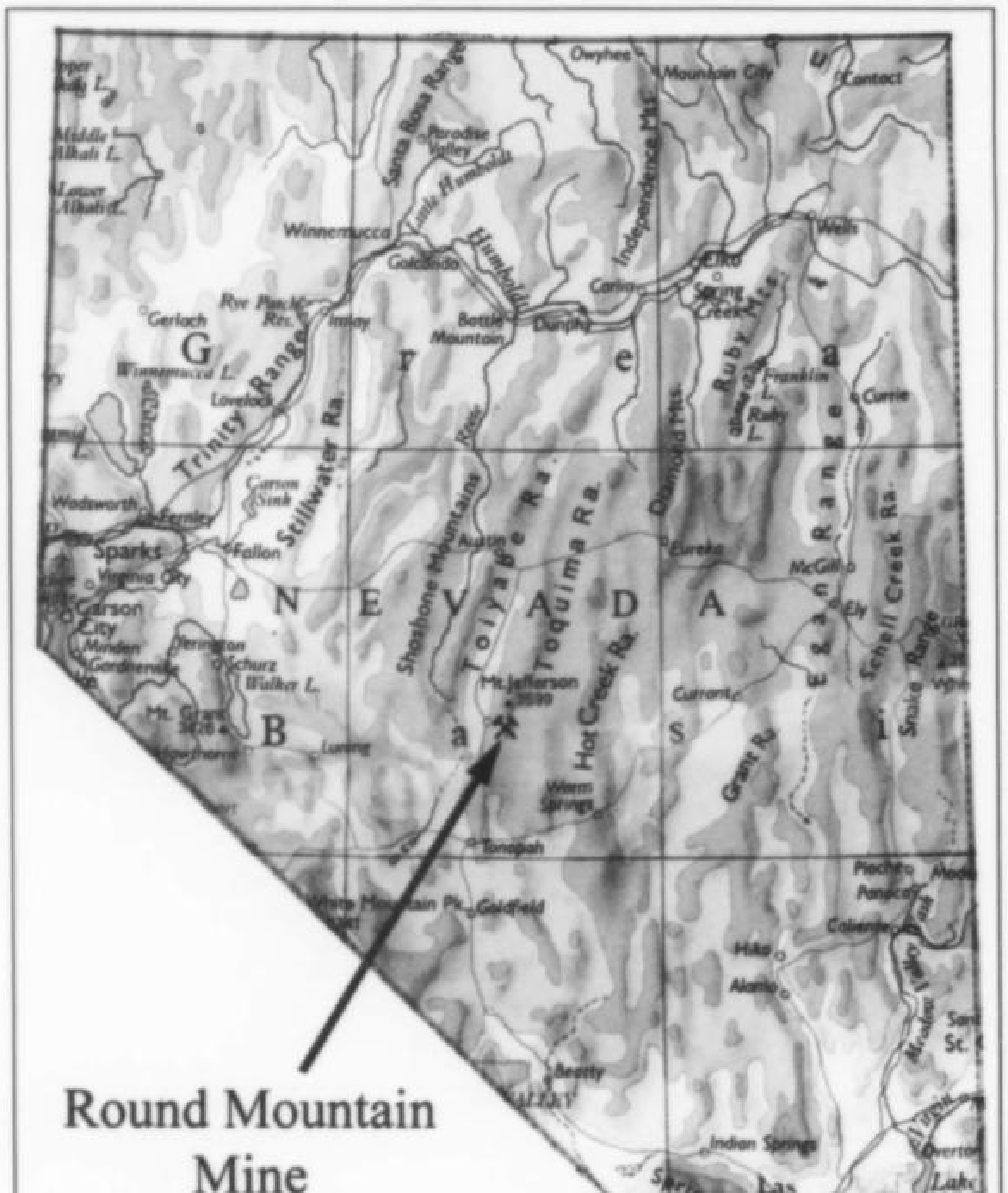


Figure 2. **Location map, Round Mountain mine.**

control of most of the district. In 1946 through 1962, the Yuba Consolidated, Fresnillo, and Consolidated Goldfields corporations developed and mined the placer deposits flanking Round Mountain and Stebbins Hill. By 1969, the Ordrich Gold Reserve Company had acquired control of the property from Nevada Porphyry Gold Mines. In 1969, the Copper Range Corporation leased the property from Ordrich (Hanson, 2006).

The Round Mountain mine was opened in 1975 by the Smoky Valley Common Operation (jointly owned by the Copper Range Company, the Felmont Oil Company, and Case Pomeroy Company). Commercial production began in 1977. Homestake Mining Company then acquired a 25% interest in 1984 (increased to 50% in 2000), and Echo Bay mines acquired a 50% interest in 1985. Barrick Gold Corporation merged with Homestake in 2001, acquiring their 50%, and Kinross Gold Corporation acquired the other 50% through a merger with Echo Bay in 2003. The joint venture at Round Mountain controls the mineral and surface rights of the mine through the ownership of 109 patented lode claims, 2,689 unpatented lode claims, and 355 unpatented placer claims covering a total area of 52,384 acres (Hanson, 2006).

By the time of the district's centennial in 2006 the total production had topped 10 million ounces. Over 35 million tonnes of ore were mined in 2004, and as of 2006 the proven and probable reserves were estimated at 4 million ounces of gold (Hanson, 2006). With the price of gold recently flirting with the $900/ounce level, these reserves could be worth in the neighborhood of $4 billion. Gold

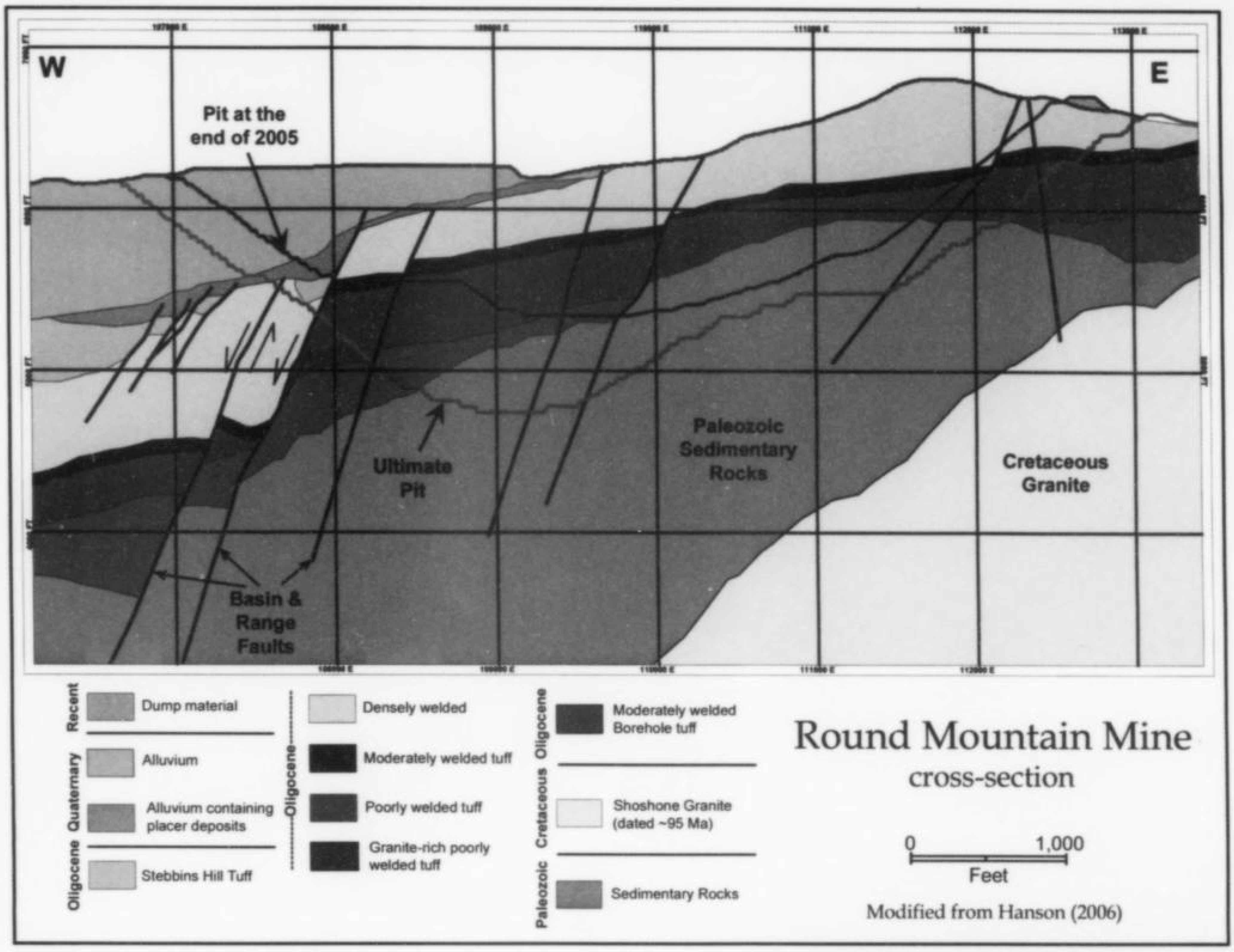


***Figure 3.* Geologic cross-section of the Round Mountain mine showing the extent of the open pit in 2005, and the eventual extent of the pit according to current plans.**

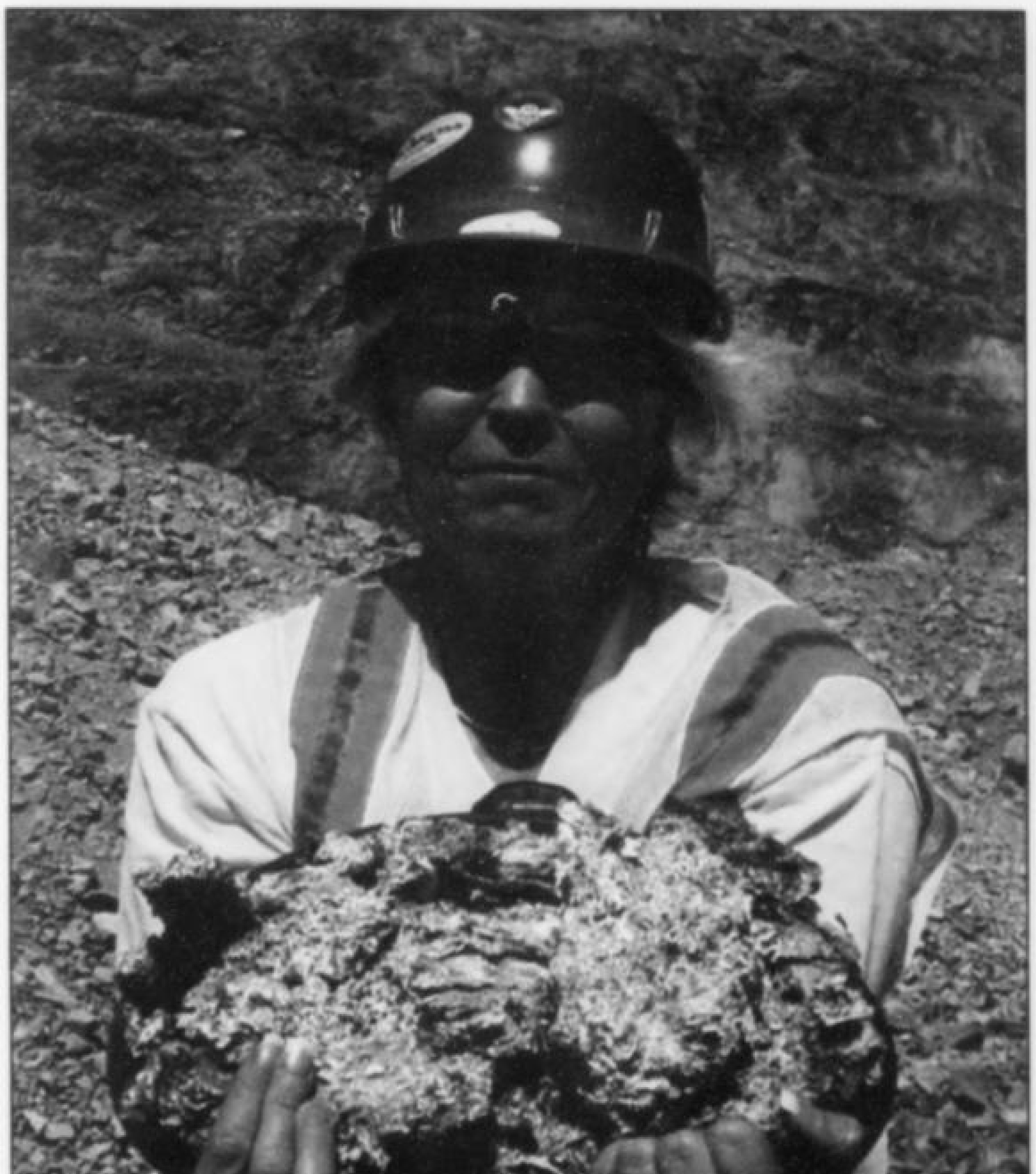


***Figure 4.* Miner holding a 25-kg mass of gold crystals recovered at the Round Mountain mine on May 18, 2006.**

production at the Round Mountain mine in 2007 yielded over $105 million (Kinross, 2008).

The current Round Mountain mine open pit is approximately 1 × 1.54 miles in extent. Mining operations are based on 35-foot benches worked by electric shovels and front-end loaders; ore is hauled out of the pit in 150, 190 and 240-ton haulage trucks. Extraction of the gold is accomplished primarily by heap-leaching. With the opening of the Gold Hill pit to the north, the operations are expected to extend into late 2015, though it is unknown whether veins containing crystalline macrospecimens of native gold exist in the Gold Hill area. Nevertheless, while the Gold Hill area is being opened up, the Round Mountain pit will be expanded as well, so the prospects for the discovery of more specimen-grade gold are promising.

GEOLOGY

The Round Mountain deposit is underlain by highly deformed Cambrian through Permian sedimentary rocks intruded and locally metamorphosed by several Cretaceous-age granitic plutons. These rocks are overlain by Oligocene to Miocene-age rhyolitic ash-flow tuffs.

Figure 1. **Southeast end of the Round Mountain mine open pit. Larry Workman photo.**

Figure 2. **Location map, Round Mountain mine.**

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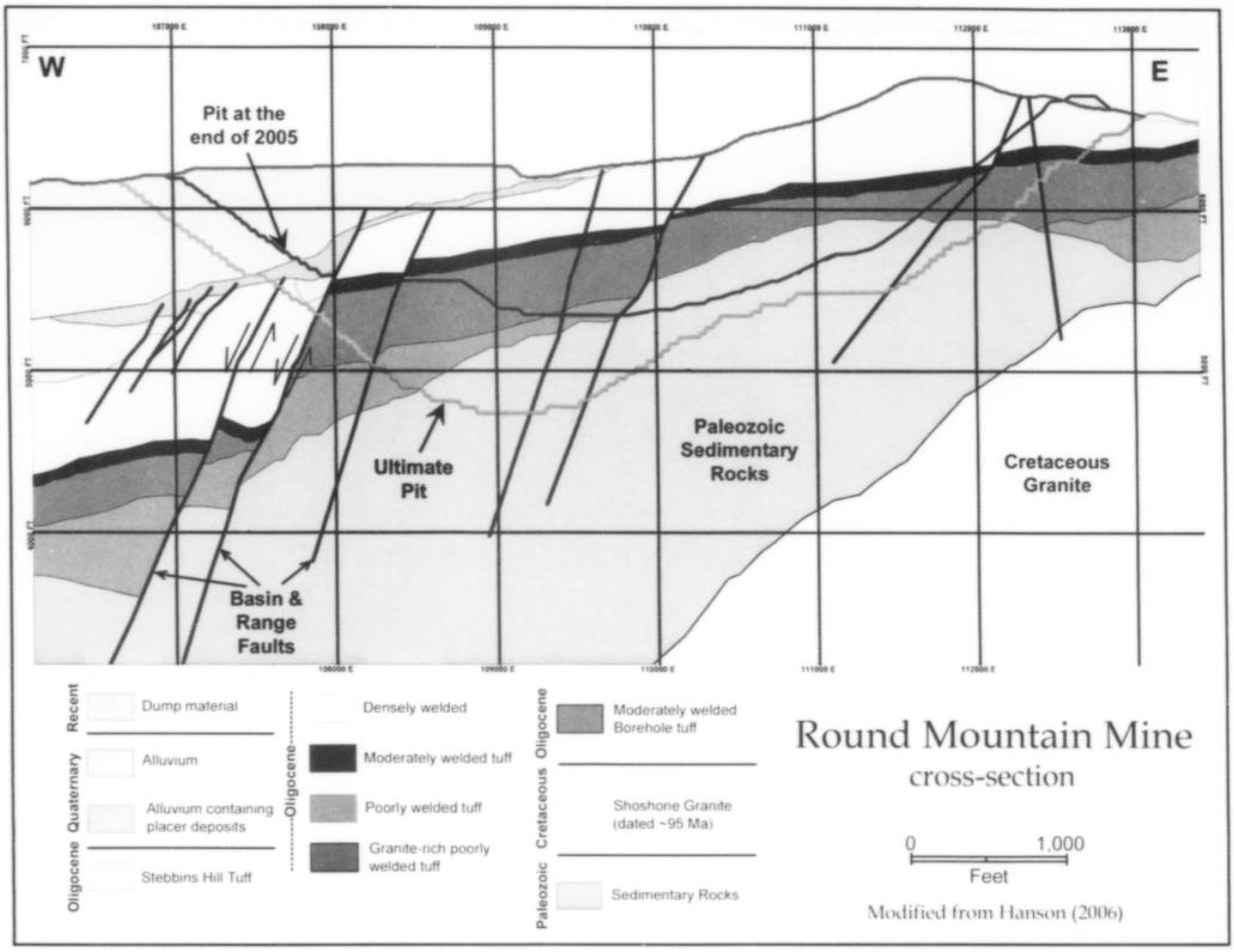

Modified from Hanson (2006)

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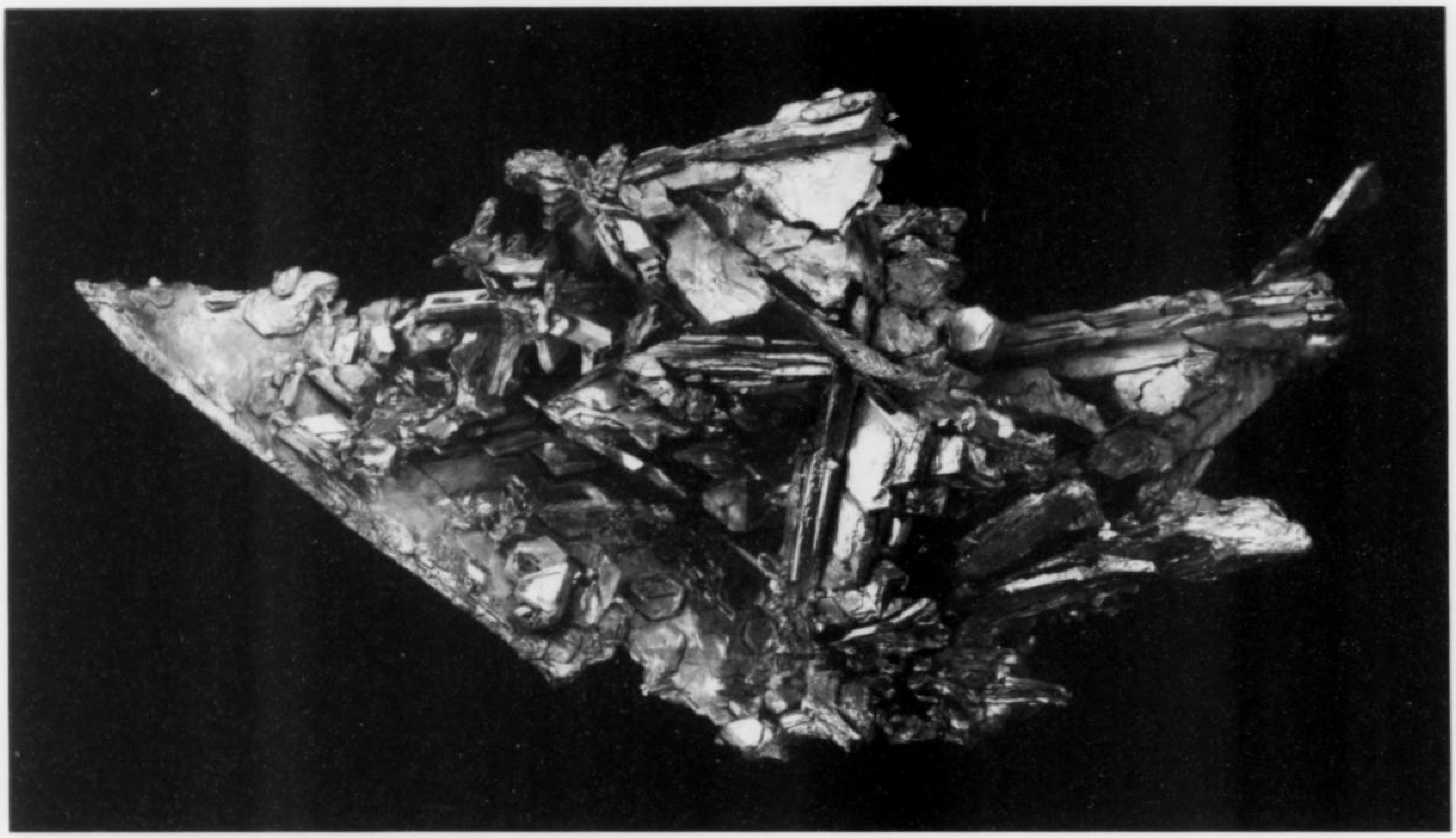


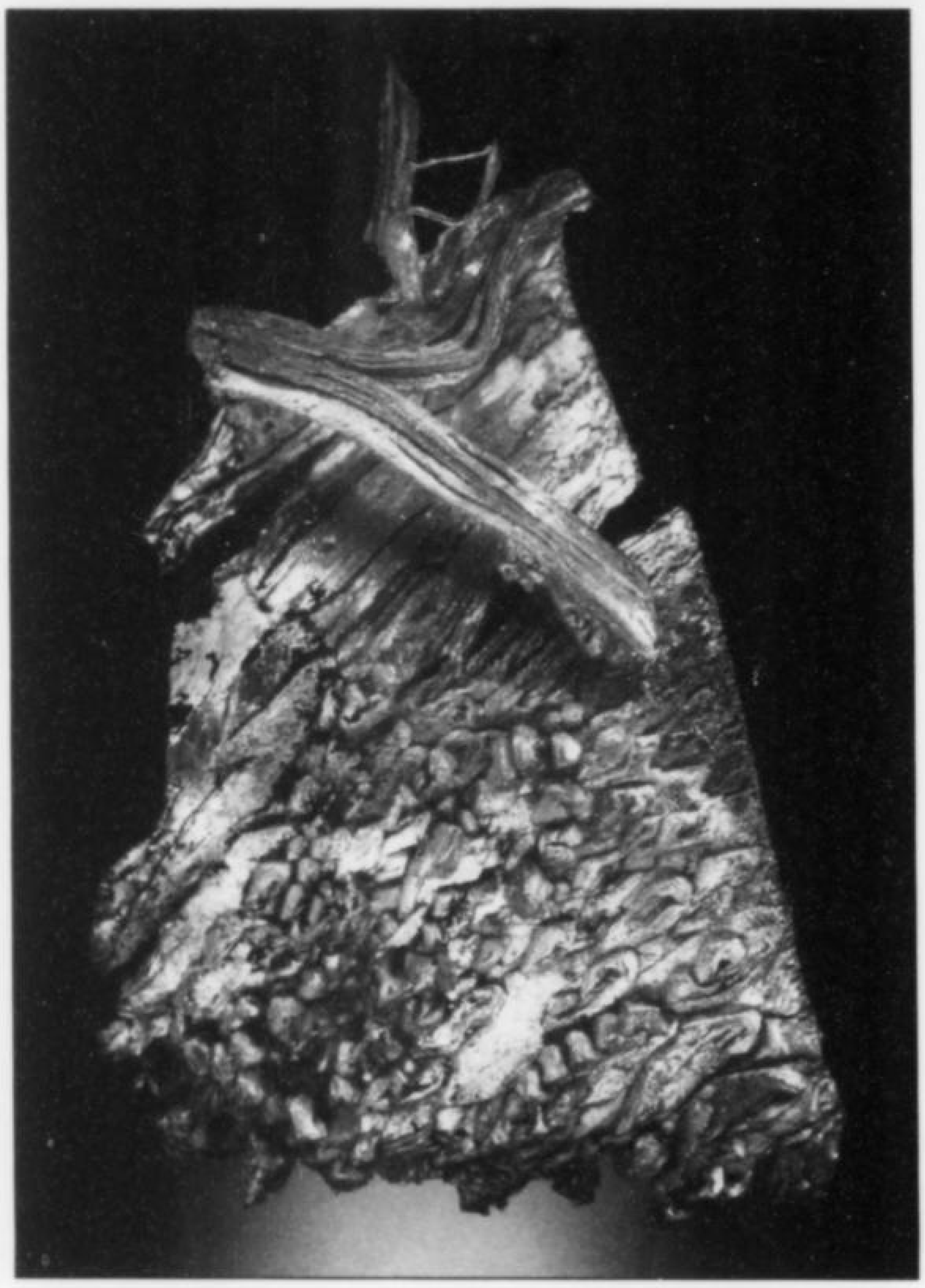


Figure 5. **Gold, in flattened and elongated spinel-law twins, 6 cm, from the Round Mountain mine. Wayne Thompson specimen; Jeff Scovil photo.**

Figure 6. **Gold, in a flattened sheet, peeling off into layers, 3.3 cm, from the Round Mountain mine. Larry McMaster collection; Jeff Scovil photo.**

The Paleozoic sedimentary rocks, dominated by marine clastic and carbonate rocks, form a series of at least three stacked thrust sheets. These units include carbonates (limestone and dolomite), argillite, siltstone, quartzite, phyllite and schist. Deformation probably began in the late Paleozoic and continued through the Mesozoic.

The Oligocene to early Miocene-age rhyolitic ash flow tuffs which host the gold ore apparently originated from a number of eruptive centers in the Toquima and Toiyabe Ranges (Boden, 1986). The Round Mountain Caldera, which is among the most prominent geologic features of the southern Toquima Range, is of unknown extent as most of the caldera is covered by alluvium, and faulting has offset the western portion. The upper and lower tuffs layers were erupted from the caldera approximately 26.5 million years ago (Henry *et al.*, 1996).

In the area of the mine a thick sequence of ash flow tuffs and volcaniclastic rocks rest on pre-Tertiary basement rocks. Although the caldera margin is buried, it can be clearly seen in the pit area as a progressively steeper dipping contact between the volcanic rocks and the older basement rocks. The caldera margin and other caldera-related structures provided the shear zones and fracture pathways for hydrothermal (epithermal hot-springs type) fluids that deposited the gold mineralization, primarily in the volcanic rocks but also in the Paleozoic rocks along the caldera margin (Henry *et al.*, 1997). The strongly welded Type I tuff tends to fracture, with gold deposited in the fractures, whereas the weakly indurated Type 2 tuff contains finely disseminated gold. An intermediate Type 3 tuff contains both fracture fillings and disseminations of gold. Alteration of the tuff to varying degrees has produced chlorite, clay, sericite+quartz, adularia+quartz+sericite, and quartz+adularia assemblages which tend to contain more gold than the unaltered tuff (Sander, 1988).

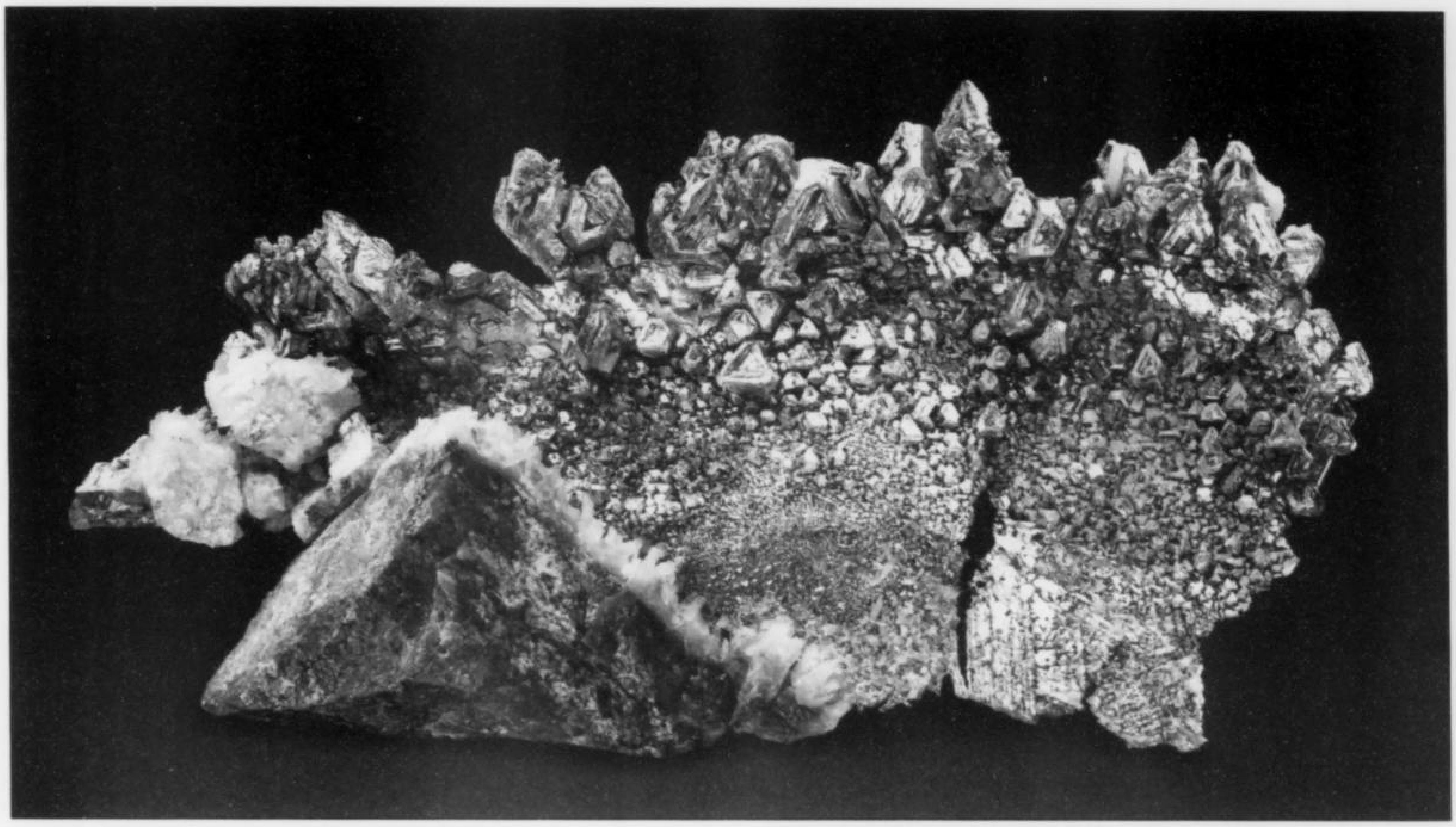


***Figure 7.* Octahedral to cuboctahedral gold crystals (silver-rich) in twin-based parallel growth on quartz, 10 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Joe Budd photo.**

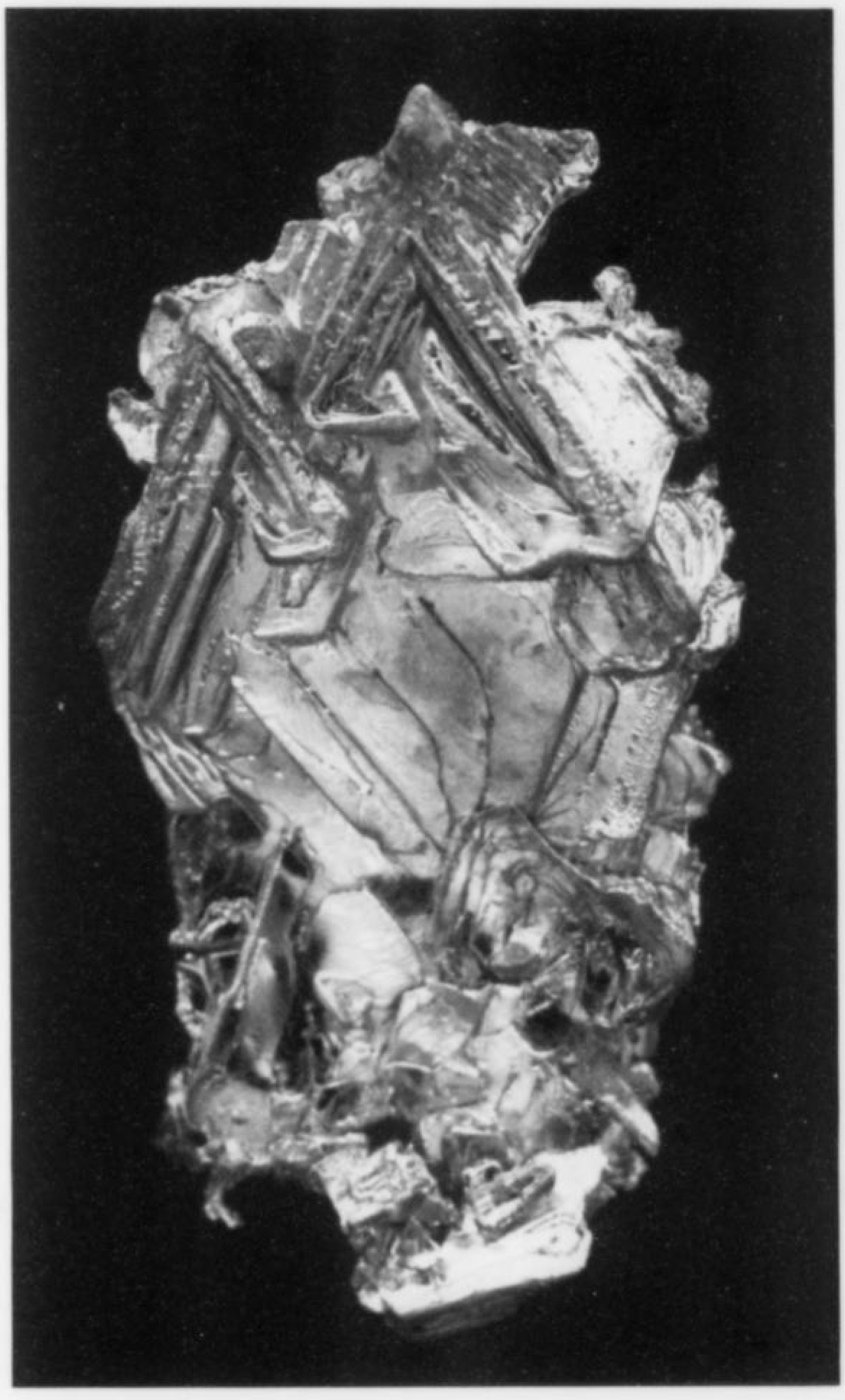


***Figure 8.* Gold crystal (flattened spinel-law twin), 2.3 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

GOLD

Gold occurs in the Round Mountain mine primarily as finely divided electrum associated with quartz, pyrite and adularian orthoclase in fractures and as disseminations. Iron oxides are also common where alteration has taken place. The electrum is usually too finely dispersed to be visible in hand specimens. However, narrow quartz-orthoclase-gold veins have yielded at least modest amounts of crystalline specimen gold (the miners call it "bonanza gold") for over 20 years. The specimens were usually sold at bullion value to employees, who kept them as souvenirs or gave them to family and friends. In the late 1980s, some pieces showing leafy and crystalline gold were sold to mineral dealers by the miners (Werschky and Day, 2004), and some "very rich native gold specimens" from Round Mountain appeared on the market a few years later (Robinson and King, 1993).

As the gold-bearing veins are only occasionally accessed in the course of expanding the pit, specimen gold from the Round Mountain mine may be expected to appear only sporadically—but some of the specimens marketed in 2005 are of significant quality. In these pieces, dark yellow cubic microcrystals of gold are arrayed in interlocked leaves with herringbone patterns on their surfaces; the leaves jut in dense formations from chalky white massive quartz, in specimens measuring to 10 cm (Moore, 2005). Consisting mostly of gold, not matrix, these are extremely impressive specimens.

On May 18, 2006 a substantial strike of specimen-grade gold

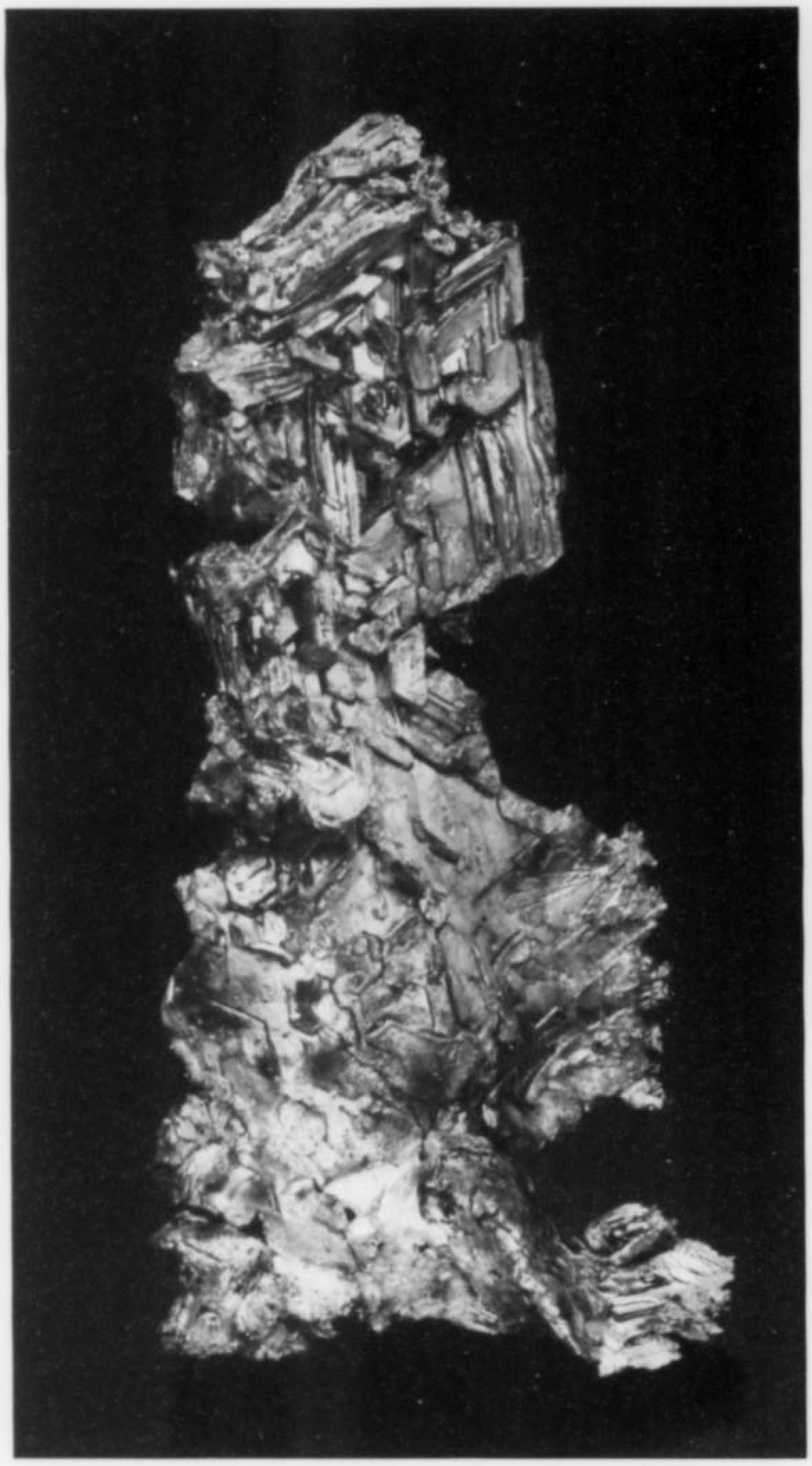


Figure 9. **Gold in cavernous to flattened spinel-law twinned crystals, 6.7 cm, *Miner's Lunchbox* specimen; Jeff Scovil photo.**

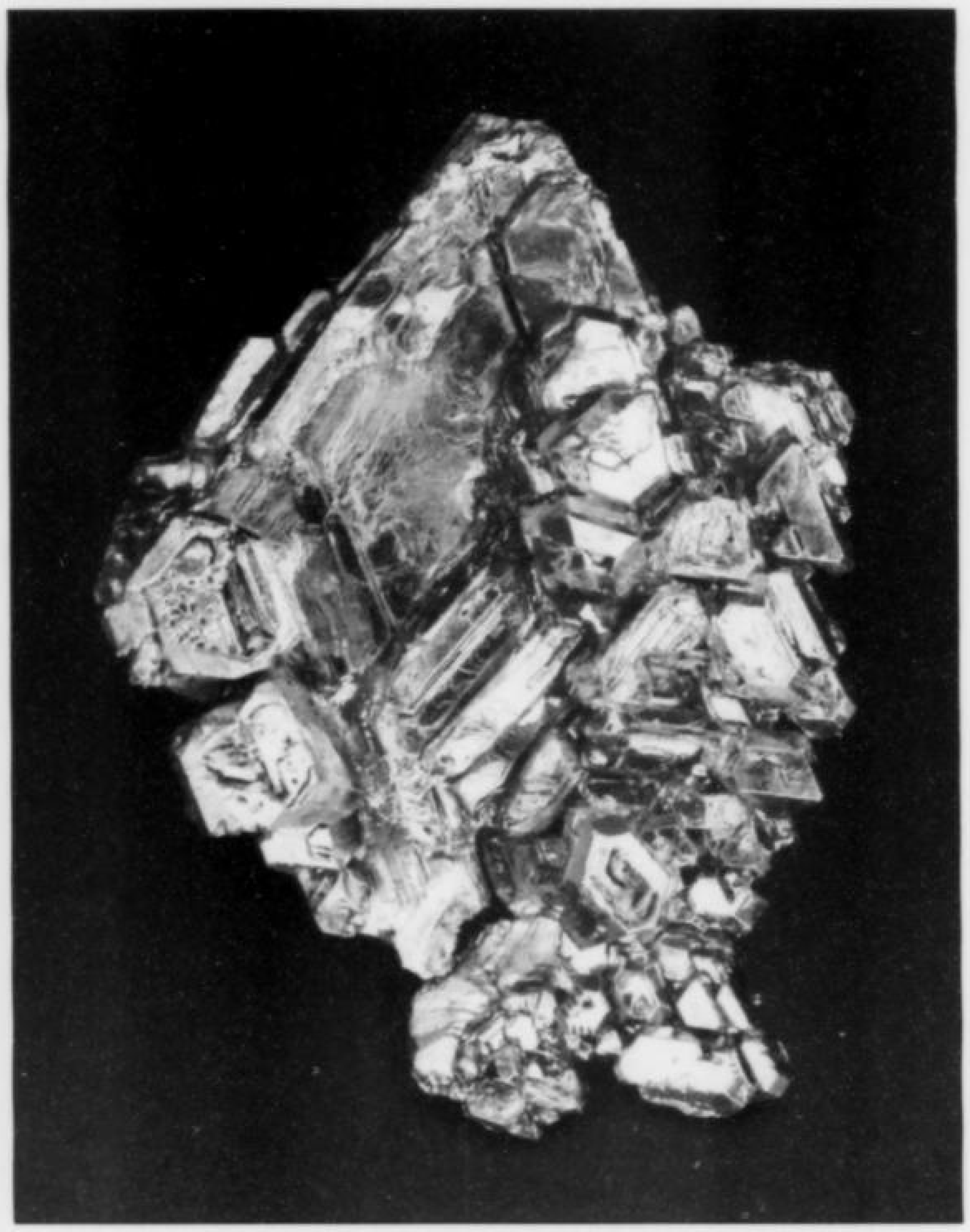


Figure 10. **Gold in flattened spinel-law-twinned cuboctahedral crystals, 2.6 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Joe Budd photo.**

was made at the mine, in what has been called the "Girls Pocket." Although a number of other pockets were found in 2006, this one was by far the best. The specimens were collected within a few hours by mine employees and held until March of the following year. In the past, small amounts of specimen gold had been offered for sale to employees at the end of the year; however, this find was far too large to be purchased by employees alone. Mining company officials invited several mineral specimen dealers to participate in a sealed-bid auction. Fifty-six lots of beautifully crystallized gold, from 9 grams to 796 grams, were disposed of in this way, and the specimens were soon made available to collectors. Larger specimens in excess of 200 ounces were found, but company policy forbade the sale of any larger than 235 grams; the others were apparently melted down.

Gold Morphology

Morphologically the specimen gold from the Round Mountain mine occurs in a range of attractive, well-crystallized habits and appearances, from highly lustrous to dull or frosty, in thumbnail and miniature to cabinet size clusters. The gold crystals are generally

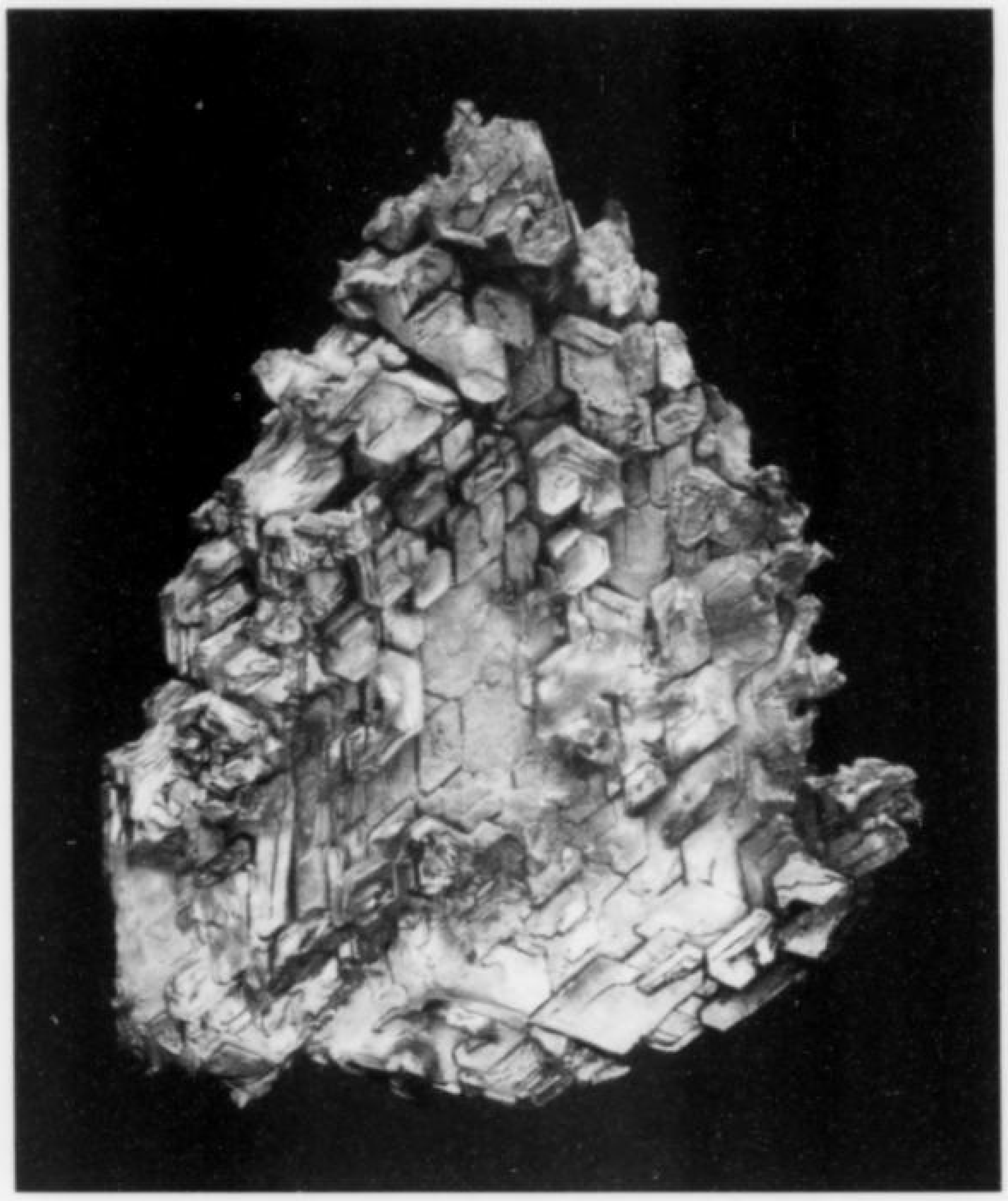


Figure 11. **Gold in parallel, flattened, spinel-law-twinned cuboctahedrons, 5.7 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

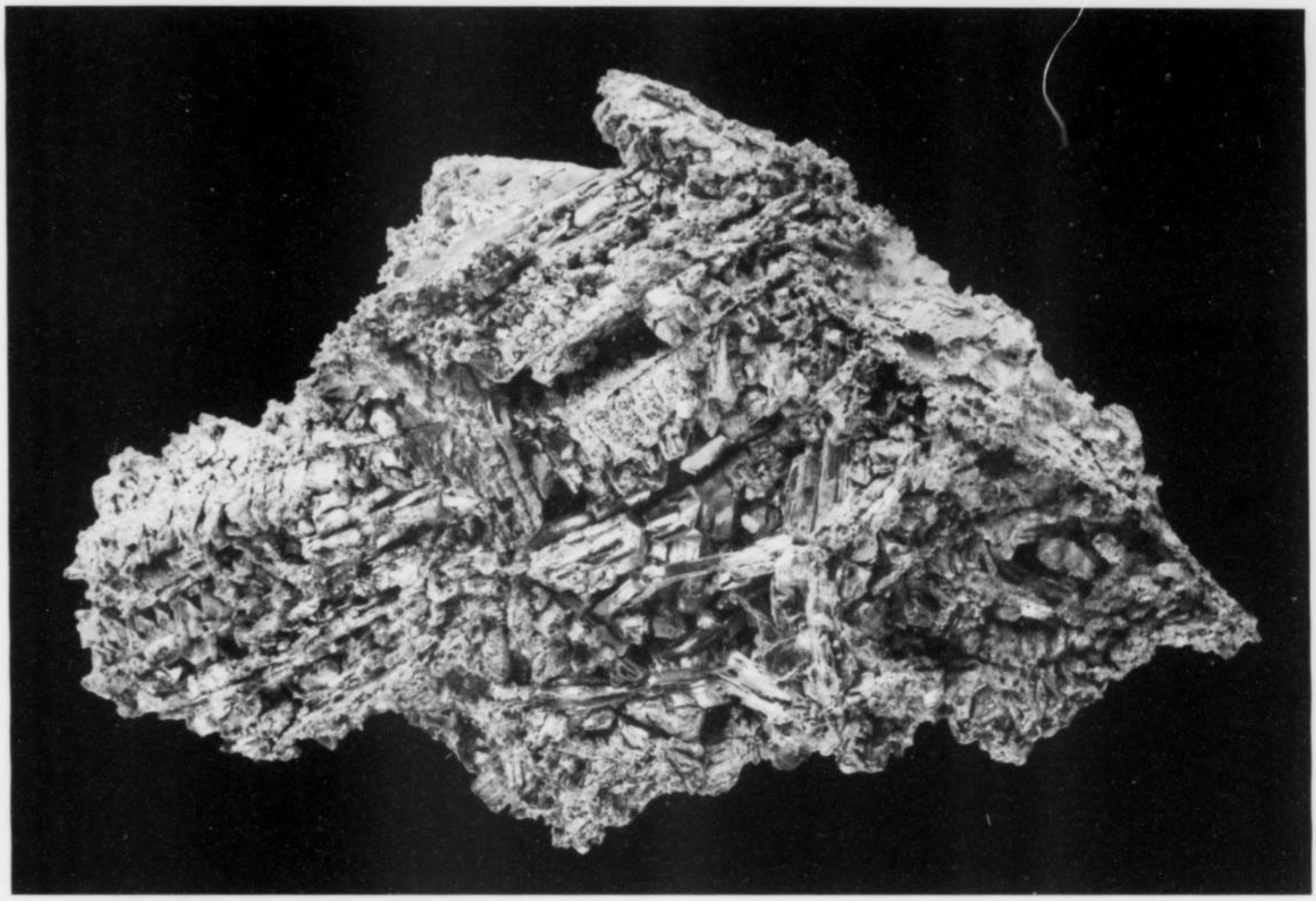


Figure 12. **Gold in flattened and elongated spinel-law twins, 14 cm (13 ounces!), from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Joe Budd photo.**

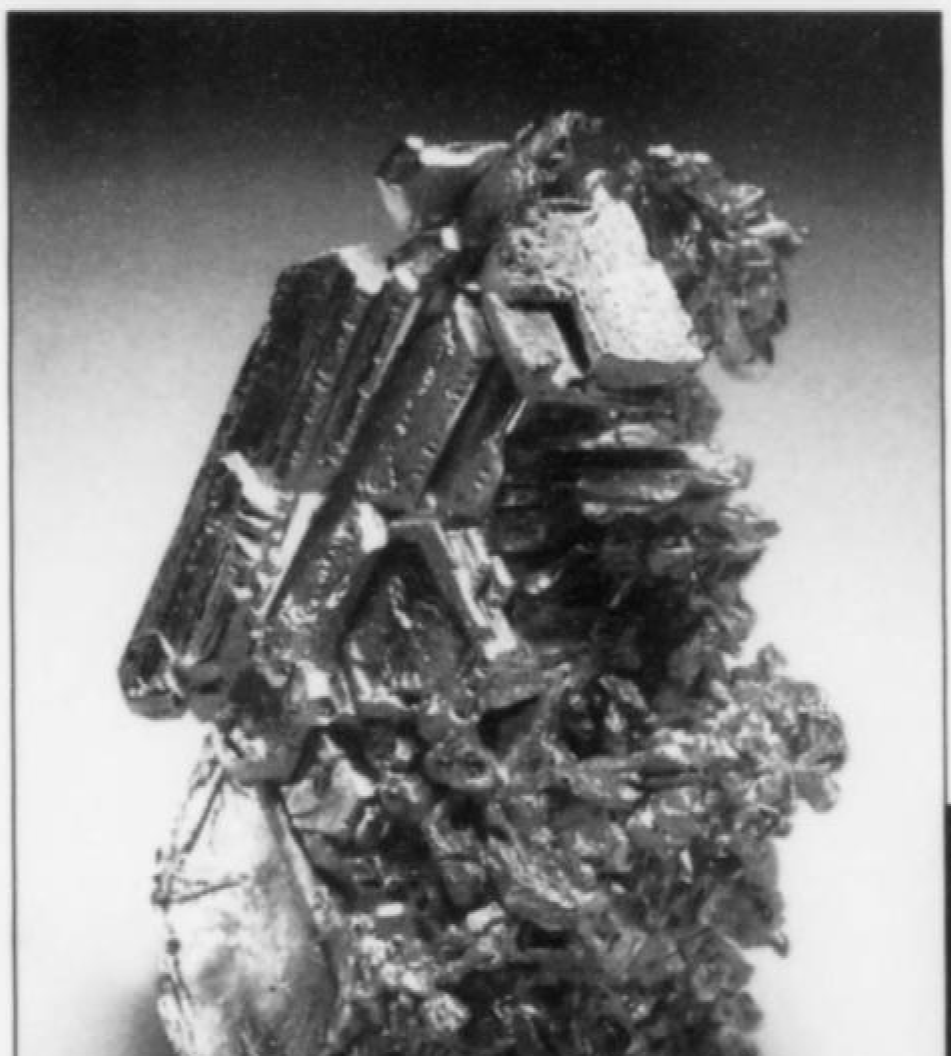


Figure 13. **Flattened and elongated spinel-law-twinned gold crystals, 2.4 cm, from the Round Mountain mine. Allan Young collection and photo.**

Figure 14. **Peculiar split leaf of flattened spinel-law-twinned gold, 3.8 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Joe Budd photo.**

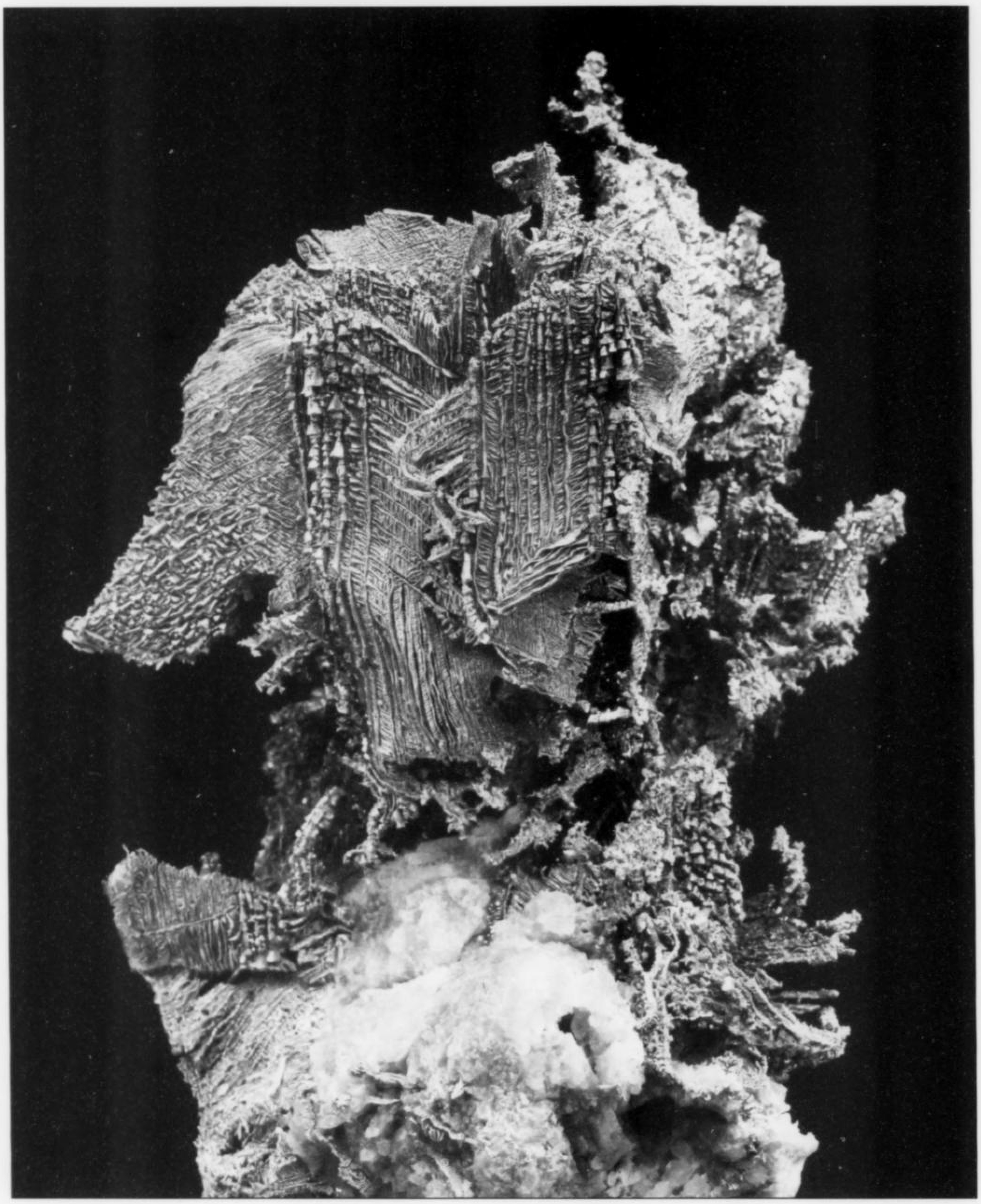


Figure 15. **Intricately woven herringbone leaves of cubic gold crystals on quartz matrix, 11 cm, from the Round Mountain mine. Wayne Thompson specimen; Jeff Scovil photo.**

very sharp, hoppered, octahedral to cuboctahedral to fully cubic in form, with flattened individuals to over 3 cm. Some specimens consist of flattened or elongated spinel-law twins with smaller crystals along their sides; others are undulating "leaves" with faint trigon patterns, rimmed by rows of smaller crystals in parallel growth. Still others are treelike groups of loosely attached elongated crystals, and in some cases the gold forms richly woven herring-bone sheets and thin, parallel, crystalline wires. The flat-surfaced leaves and trigon-covered surfaces are contiguous octahedral faces parallel to the twin plane (the plane of elongation), whereas the twinned gold of cubic form tends to occur as herringbone growths and plates covered by a myriad of tiny cube corners. Most of this gold has a rich yellow color, but some is much paler, being silver-rich enough to qualify as the electrum variety, i.e. having more than 20% silver (Polityka, 2007; Moore, 2008); many specimens contain around 40% silver (Castor and Ferdock, 2003).

CONCLUSIONS

The zone which has been sporadically producing specimen-grade gold at the Round Mountain mine may well be intersected again in

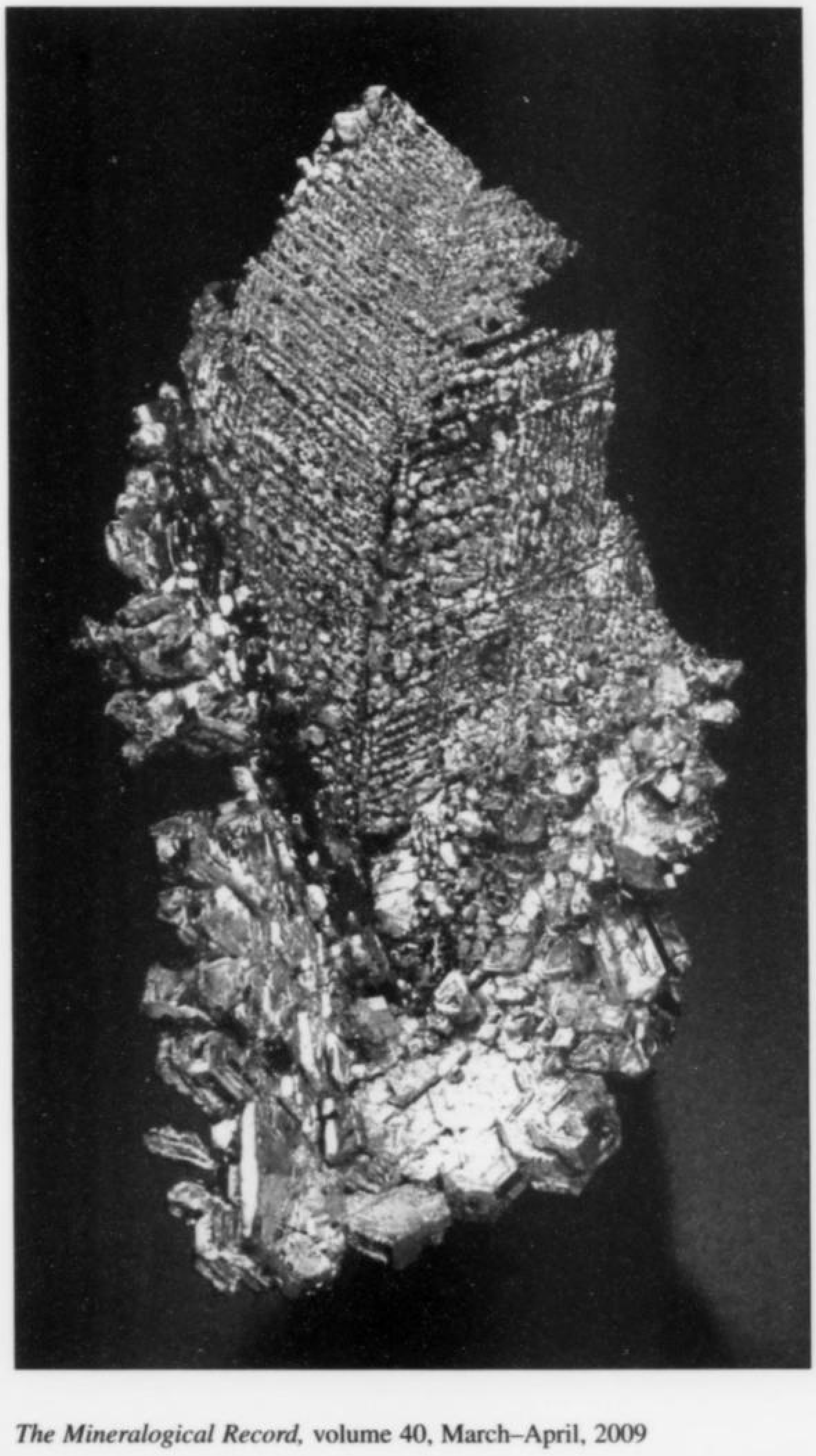
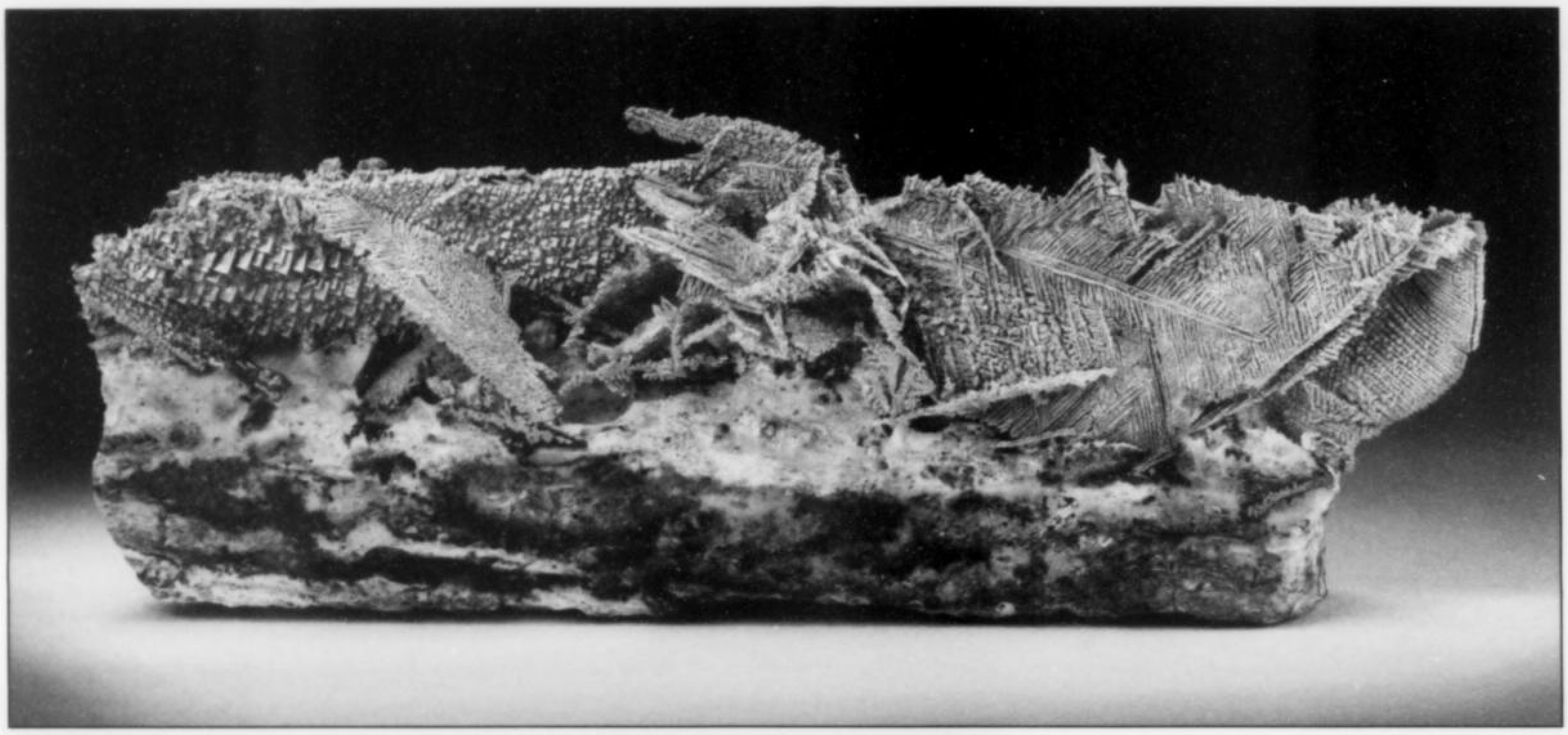


Figure 16. (above) **Herringbone leaves of silver-rich cubic gold crystals on quartz, 13 cm across as shown, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

Figure 17. (left) **Herringbone leaf of cubic gold crystals with plates of spinel-law-twinned cuboctahedrons, 7.6 cm; Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

Figure 18. (below) **Parallel wires composed of oriented cubic gold crystals, about 5 cm as shown, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**



Figuire 19. (above) **Herringbone leaves and plates of gold, composed primarily of tiny cubes, on matrix, 12 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

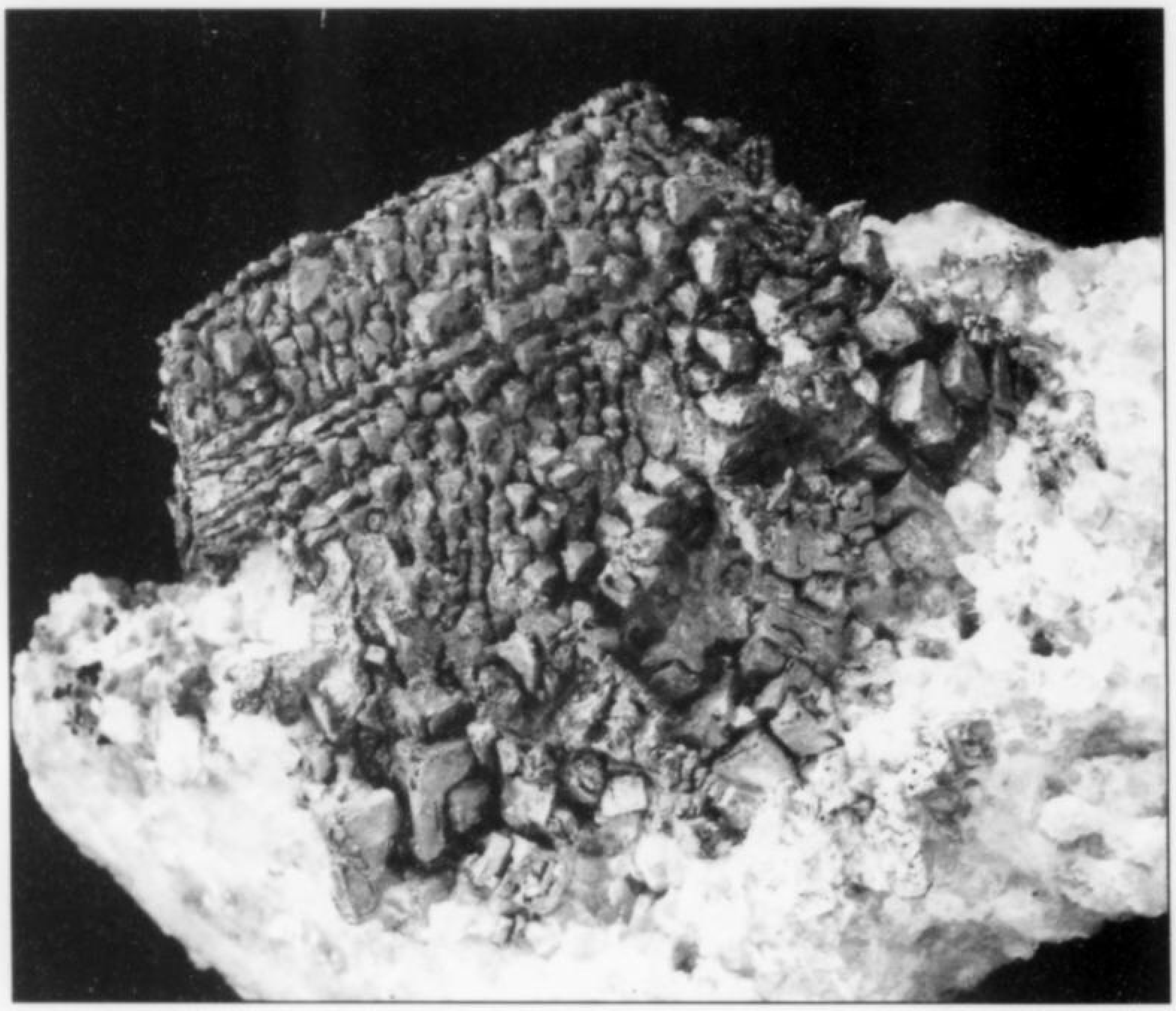


Figure 20. (left) **Plate of oriented cubic gold crystals (probably spinel-law twinned parallel to the plane of elongation), on quartz, 5 cm, from the Round Mountain mine. Keith Proctor/Scott Rudolph collection; Jeff Scovil photo.**

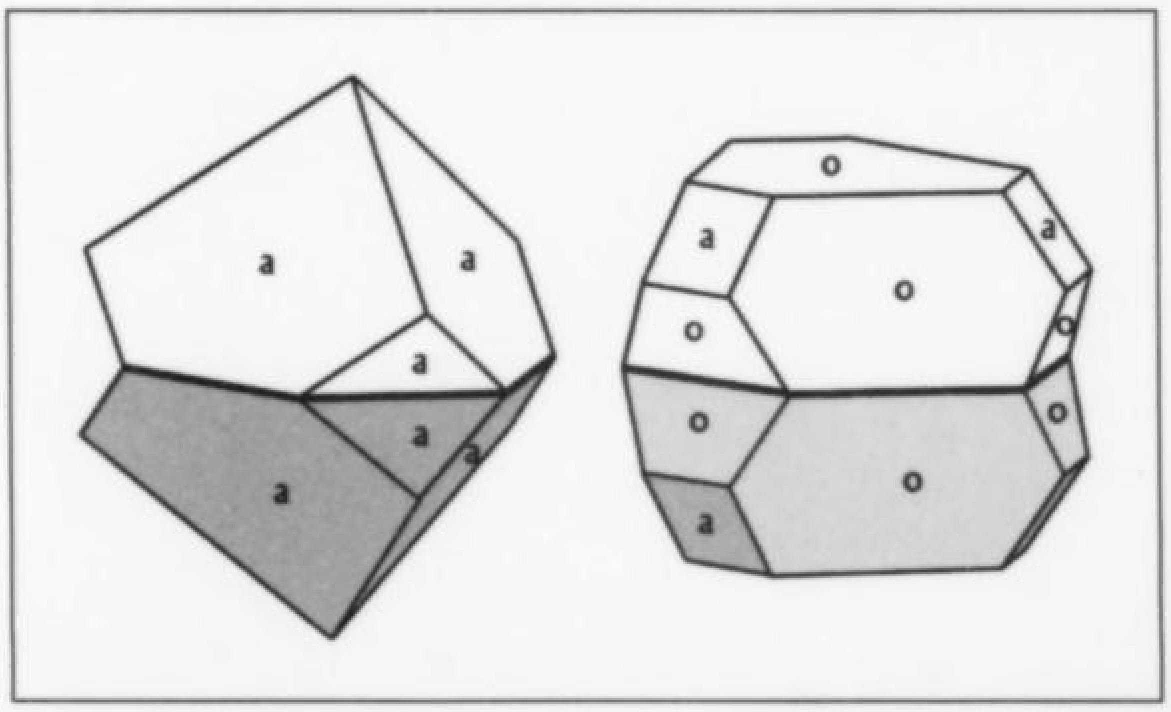


Figure 21. (below) **Spinel-law twinned cube (left) and cuboctahedron (right). Note that when elongated parallel to the twin plane (red lines), the twinned cube will become a sheet covered with parallel cube corners, whereas the twinned octahedron will become a smooth sheet or leaf. The three-fold axis in a spinel-law twin is perpendicular to the twin plane, resulting in triangular surface features on the flattened twins—three sided corner points for the cube and flat triangular surface features (trigons) on the octahedron. Growth can be accelerated in the three directions of the re-entrant angles, resulting in a herringbone habit of the flattened twins.**

the future, inasmuch as it is a working mine. The officials of Kinross Gold Corporation are to be complimented for their willingness to salvage specimens of great cultural and aesthetic value, as well as mineralogical interest, and make them available on the specimen market where they can be distributed to museums and private collectors. Nevertheless, the mine has a limited life expectancy and will probably close within the next seven or eight years. After that, we can expect no more specimens to emerge.

ACKNOWLEDGMENTS

My thanks to Keith Proctor for providing most of the specimen photos, and to Art Soregaroli, Allan Young, Bryan Lees and Tom Moore who kindly reviewed the manuscript and offered helpful suggestions.

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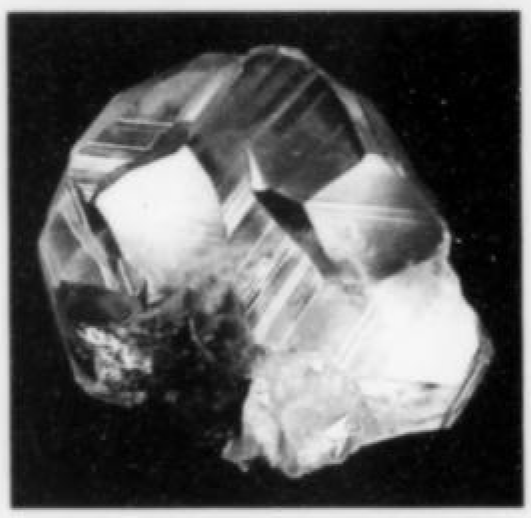
THE CONKLIN FAMILY

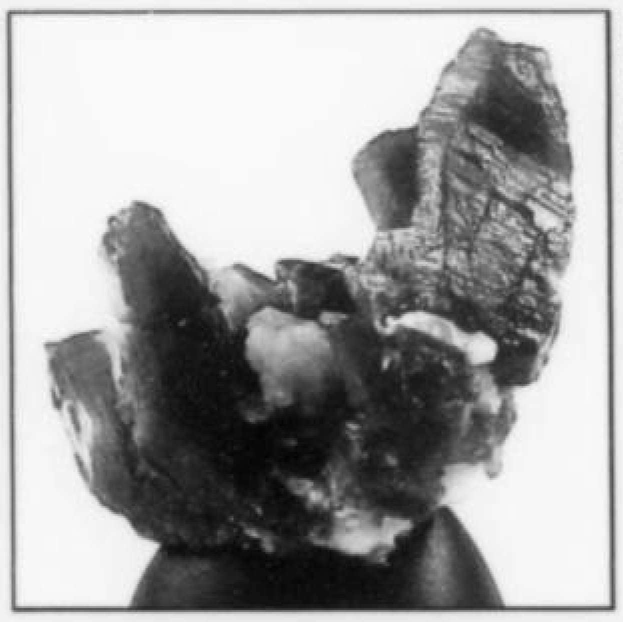
Mineral Collection

Selections from the Conklin family mineral specimen collection are available for sale.
There is no list, but inquiries for individual species are invited.
It was begun in the 1970s by the late Halina A. Conklin, and continued by her children
Sarah and Charles, under the supervision and guidance of Lawrence H. Conklin.

**Dioptase
2.5 inches,
Tsumeb,
Namibia**



**(Center) Calcite,
3.9 inches,
Verchniy mine,
Dalnegorsk,
Russia**



**Ruby Corundum
2.5 inches,
Luc Yen dist.,
Yen Bai prov.,
Viet Nam**

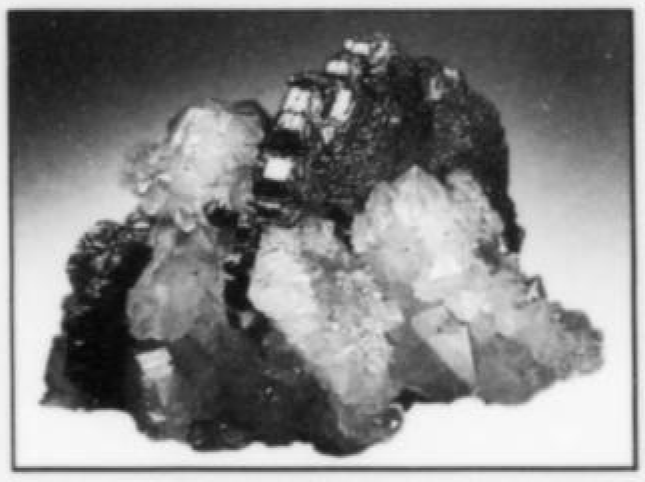
**Pyrargyrite,
3 inches,
Fresnillo,
Zacatecas,
Mexico**

**(Center)
Elbaite on Quartz
3.5 inches,
Morro Redondo mine,
Minas Gerais,
Brazil**

**Benitoite, 2 inches,
Benitoite Gem mine,
San Benito Co.,
California**

**Apatite-(CaF)
3.5 inches,
Paprock,
Nuristan,
Afghanistan**

**(Center)
Cerussite,
4 inches,
Tsumeb,
Namibia**



**Bournonite
on Quartz,
2.3 inches,
Herodsfoot m.,
Cornwall,
England**

Some mini-collections within this collection are from Brazil; Franklin-Sterling Hill, New Jersey; Tsumeb, Namibia; Långban, Sweden; Michigan; Pakistan-Afghanistan; Canada; New York State; Bisbee, Arizona; also, illustrated specimens from John Barlow's book- *The F. John Barlow Mineral Collection*; Old-time European classics are well represented, as is Cornwall, England, and others. Laguna agates and bull's-eye agates.
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The Arkenstone
Crystal Classics
Andreas Weerth
Lehigh Minerals
Superb Minerals
Wendy's Minerals
Majestic Minerals
Awake Aesthetics
Miner's Lunchbox

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Graeber and Himes
Wright's Rock Shop
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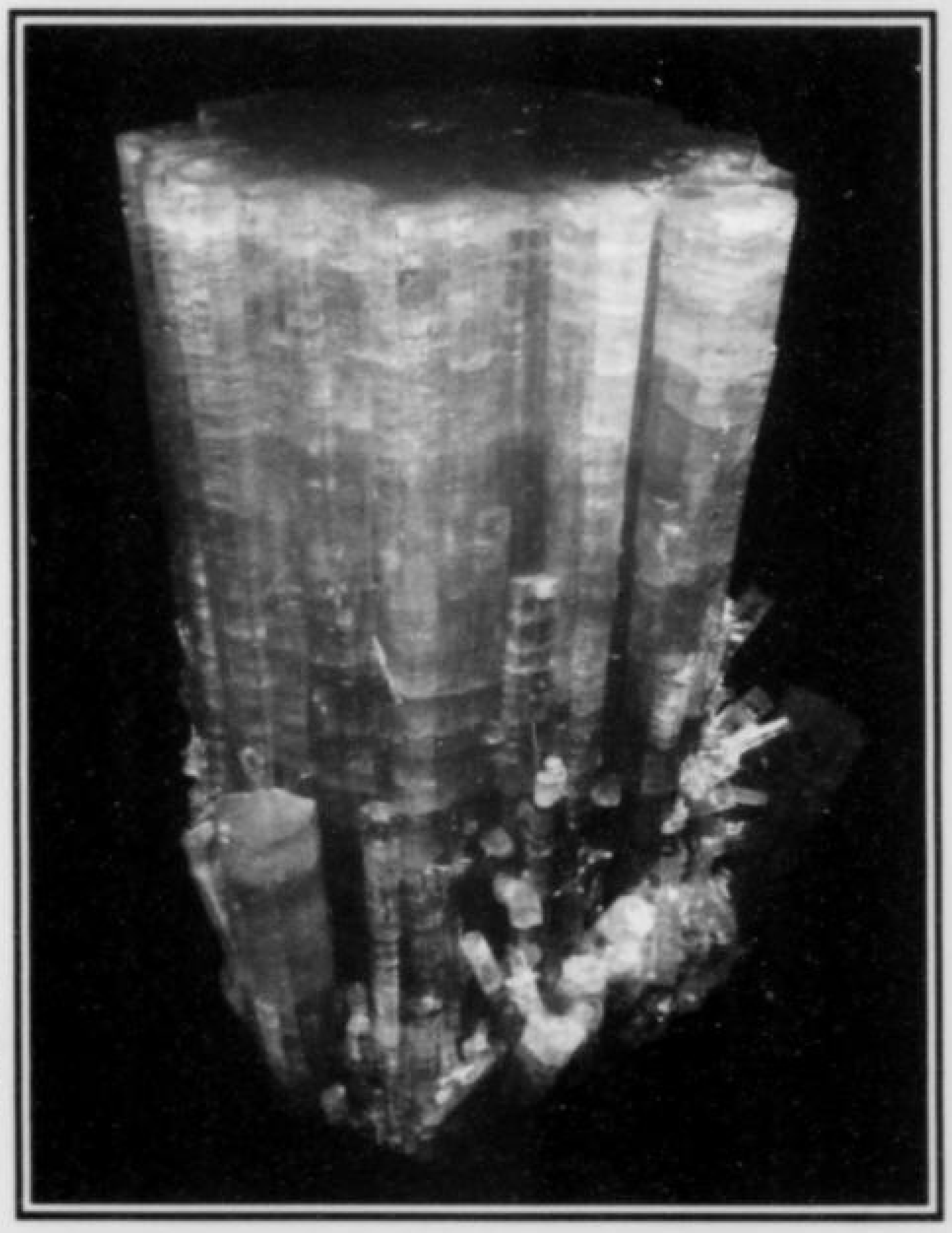


DOLOMITE (twinned)
Eugui
Navarra, Spain

HERITAGE

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Saber-toothed Cat, South Dakota
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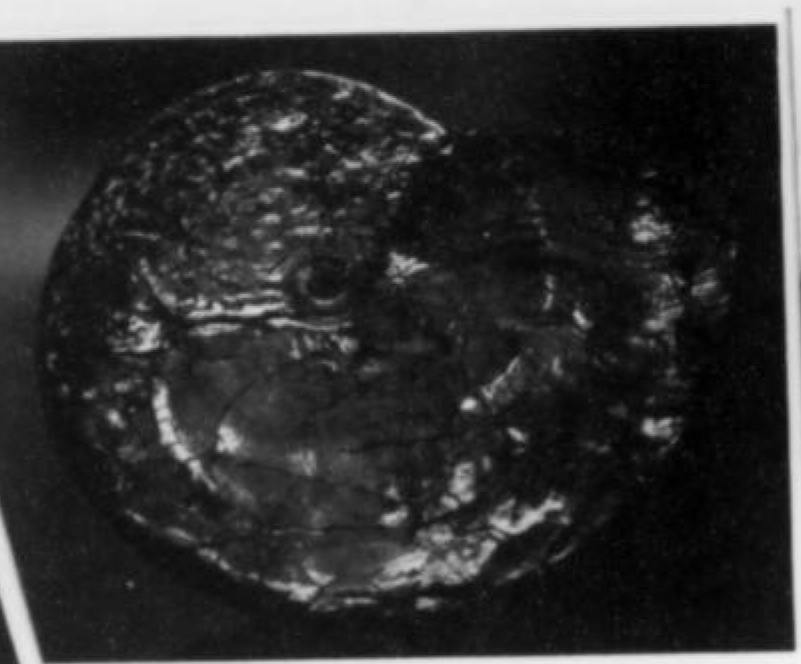

Gem Ammolite, Canada
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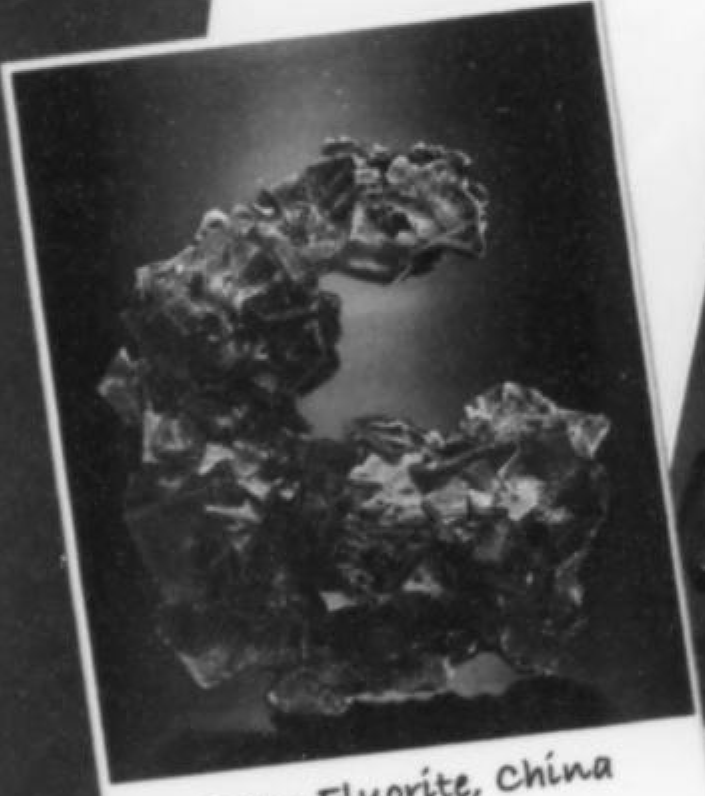

Green Fluorite, China
HA.com/6008-6177

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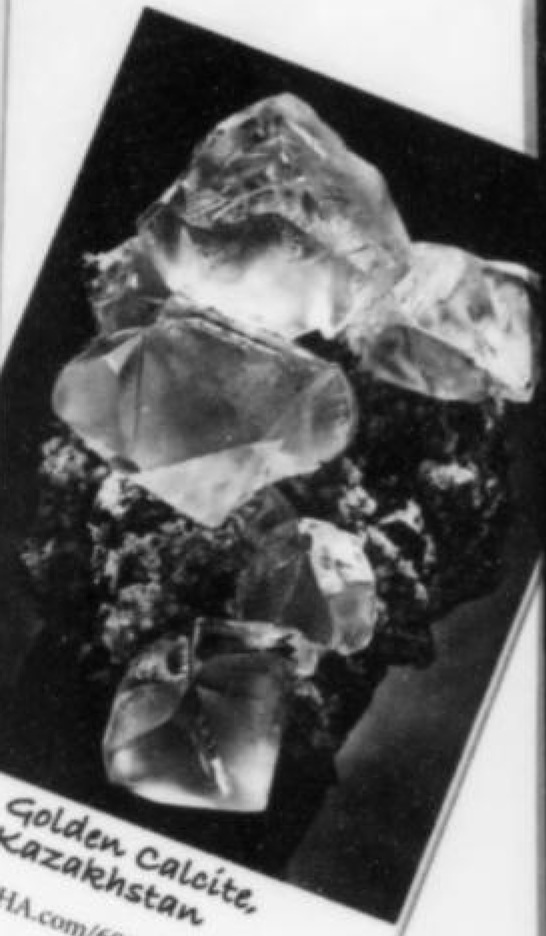

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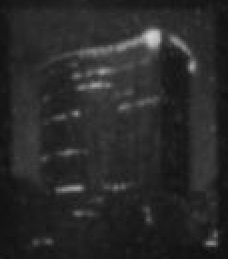

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16469

"SKUNK" CALCITE

MINERAL PARAGENESIS IN AN AMETHYST GEODE FROM AMETISTA, RIO GRANDE DO SUL, BRAZIL

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The famous amethyst geodes of Brazil and Uruguay rarely contain crystals of "skunk" calcite, wherein microcrystals of goethite form sharp, narrow black bands on rhombohedral calcite faces. Close study reveals the probable paragenetic relationships among goethite, lepidocrocite, calcite and two generations of amethystine quartz in a "skunk" calcite specimen; important uncertainties, however, remain.

INTRODUCTION

Amethyst-lined geodes occur in great numbers at certain horizons in Lower Cretaceous basalts in the Parana Basin. Such geodes, which reach weights of several hundred kilograms, are mined at numerous localities in Brazil's southernmost state, Rio Grande do Sul (Juchem, 1999; Mossman and Juchem, 2000), and in neighboring Uruguay. These geodes occasionally are found to contain crystals of what has been called "skunk calcite," so named because of the striped appearance. The geode discussed here, recovered near Ametista do Sul, weighs 23 kg. It is distinguished from the vast majority of other geodes in that it contains seven large (to 5 × 10 cm), distinctly terminated, honey-colored calcite crystals set amid numerous amethyst crystals (Fig. 1). Two generations of amethyst crystals are present, the earlier crystals—"quartz (I)"—reaching more than 1 cm, the later and slightly smaller crystals—"quartz (II)"—never exceeding that size. The geode also contains black goethite crystals confined within narrow stripes on the calcite crystals. Between the rhombohedral faces of the calcite crystals, paired scalenohedral faces occur, making a total of nine pyramidal faces on each of the calcite crystals: this combination of trigonal scalenohedral and rhombohedral forms is not uncommon (Gunter, 2003). It is, however, the presence of quartz (II) crystals and minute bundles of goethite crystals that lend interest to this rare and distinctive habit of calcite from Ametista (Fig. 2).

Occurrences of such specimens are apparently confined to southeastern Uruguay and the Brazilian border region of Rio Grande do Sul. Currier (1997) described skunk calcite from the Jaketti mine in Uruguay as scalenohedral crystals which show broad or narrow stripes of black goethite. This banding apparently ". . . extends

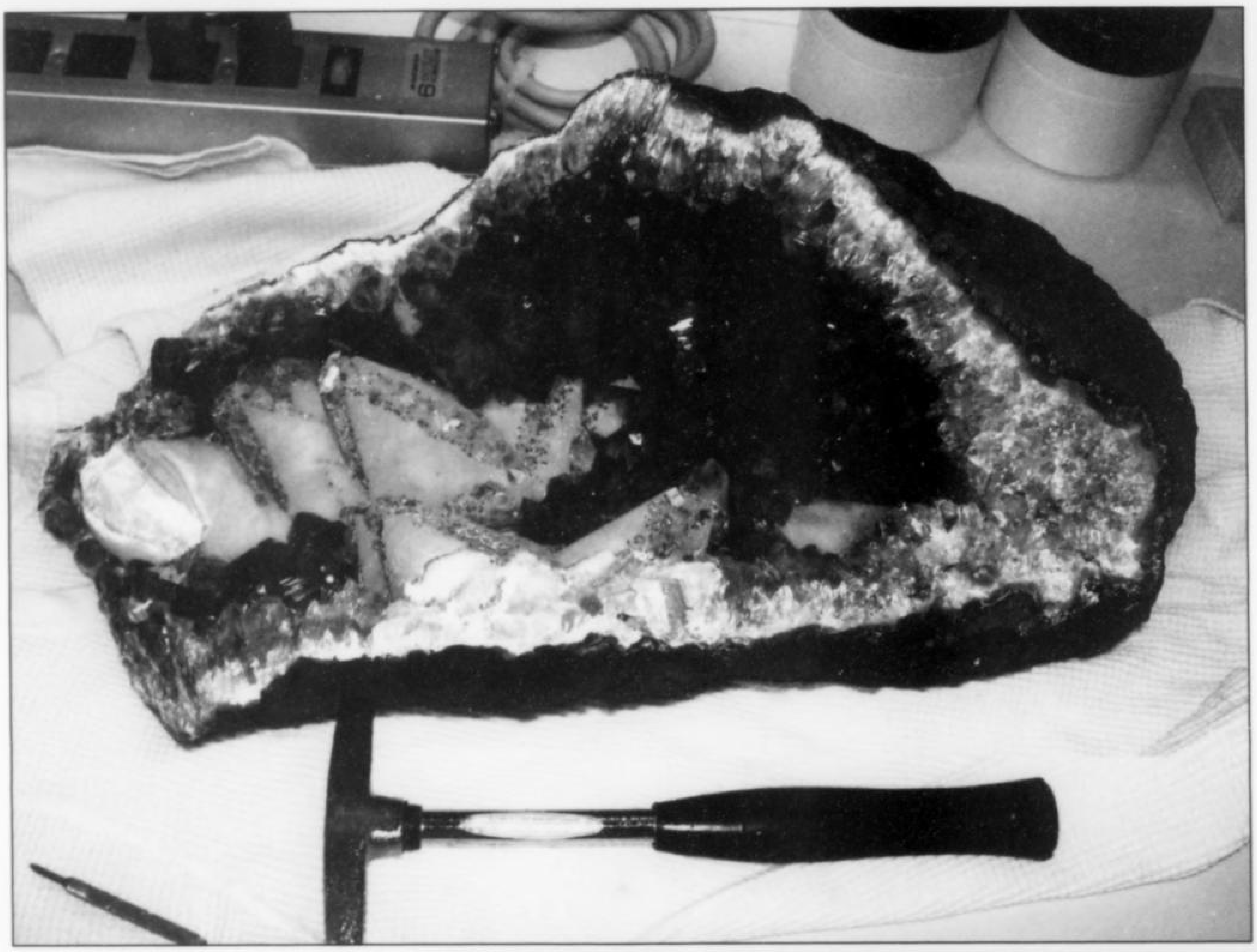


Figure 1. **View of a portion of an amethyst geode from region near Ametista do Sul, Rio Grande do Sul, Brazil. The hammer is 30 cm long.**

Figure 2. **Close-up oblique view of the interior of the amethyst geode shown in Figure 1, showing several calcite crystals with small quartz crystals present as narrow stripes on rhombohedron faces of the calcite; dark spots are millimeter-long sprays of radiating acicular goethite crystals. Note that the edge of the stripes is parallel to but not coincident with the edge (shown by faint white line on either side of the stripe on the large crystal in the center of photo) bounding the rhombohedron and scalenohedron faces. The largest calcite crystal is 5 cm in diameter at the base. Field of view is about 10 cm wide.**

up the center of the three sides of the crystal and converges at its termination. In addition, little amethyst crystals sometimes occur in the center of the goethite stripes" (Currier, 1997). This description generally fits the Ametista specimen, except that goethite is only weakly disseminated in the latter's "skunk-like" stripes (Fig. 2). Here we document the mineralogical relationships and paragenesis associated with this specimen of skunk calcite, and we briefly examine the possibility of quartz-calcite epitaxy.

INITIAL EVALUATION; METHODOLOGY

Damage to the geode during shipment to Canada revealed that at some time one of the calcite crystals had been fractured, then rather carelessly mended with a transparent glue. Whereas the glue fluoresces brightly, the calcite fluoresces weakly dark red in longwave ultraviolet light. An attractive yellow patina on the calcite crystals was initially suspected to be an artifact meant to enhance the specimen's value, but later was shown to be natural. Small, scattered

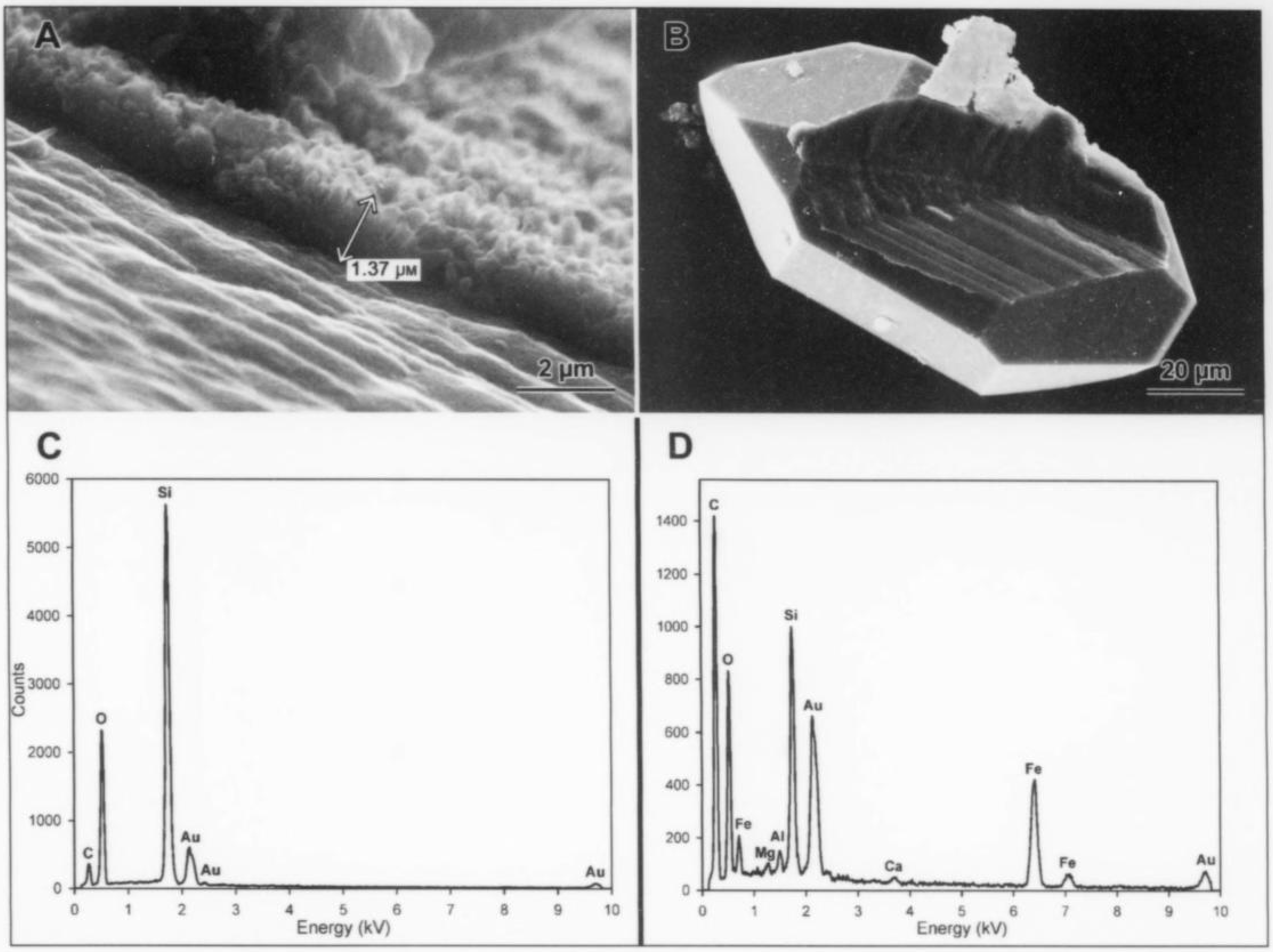


***Figure 3. (a)* Thickness of the coating of iron oxide crystals can be estimated from a tilted view of the edge of the coating. Assuming a 60° tilt, the thickness measured at 1.37 µm would be 1.58 µm. Bar shows scale. *(b)* SEM photomicrograph shows the underside of a quartz grain ripped up by double-sided tape from the calcite rhombohedral face. The depression in the center of the crystal is a perfect replica of the surface expressions of growth faces observed in numerous examples on the calcite surface. Lighter material at top of photo is iron oxide, deposited preferentially on calcite *after* the quartz grains had formed. Bar shows scale. *(c)* EDS spectrum collected from the depression in the center of the quartz crystal shown in Figure 3b, confirming the composition as SiO_2. *(d)* EDS spectrum collected from the pale material (top of image shown in Figure 3a) confirms identity as iron oxide. The topography of the crystal and the thinness of the iron oxide patina allow excitation of the quartz beneath.**

whitish patches appear on several of the small quartz crystals and on some acicular black goethite crystals composing the stripes; the calcite crystals do not show similar patches. This feature is believed to be the result of the Brazilian practice of cleaning many amethyst specimens with an industrial cleaner known as *chispas,* a minor component of which is hydrofluoric acid (Currier, 1997).

Goniometric measurements indicate that the rhombohedral faces are $\{02\bar{2}1\}$. Subsequent investigation of the skunk calcites relied primarily on SEM with an EDX system to analyze the calcite and to image and elucidate contact relationships between the various phases. A Debye-Scherrer X-ray powder camera was used to identify crushed samples of the smaller crystals. Computer models were developed which would allow the dimensions of crystal lattices of quartz and calcite to be superimposed, and percentage differences in fit to be measured.

MINERALOGICAL RELATIONSHIPS

Judging from the edge of the broken geode (see Fig. 1), it is apparent that the quartz (I) and calcite crystals grew upon the outermost 3 to 4-mm-thick layer of banded agate which lines the cavity. Evidently the quartz (I) and calcite crystals grew simultaneously. However, understanding the textural and paragenetic relationships between calcite and several other phases poses a somewhat greater challenge.

The small sheaves of acicular black crystals were identified as goethite by X-ray diffraction. The yellow patina (already mentioned) is lepidocrocite, chemically identical with goethite, its trimorph. As measured by SEM imaging, the patina consists of a uniform, 1.6-µm-thick layer of lepidocrocite (very unlikely to have been applied artificially) upon calcite (Fig. 3a). The composition of the carbonate is virtually pure $CaCO_3$.

In order to ascertain the true relationship between the calcite substrate, the quartz (II) crystals, the acicular goethite crystals, and the yellow patina, double-sided tape was used to peel off some of the small quartz crystals from the patina. In this way it proved possible to pluck off the quartz (II) grains, whose undersides then revealed the nature of the surface of contact between quartz and calcite. The underside view (Fig. 3b) demonstrates that this quartz grew directly on the calcite surface, for the depression in the center of an otherwise perfect crystal replicates the striations characteristic of the

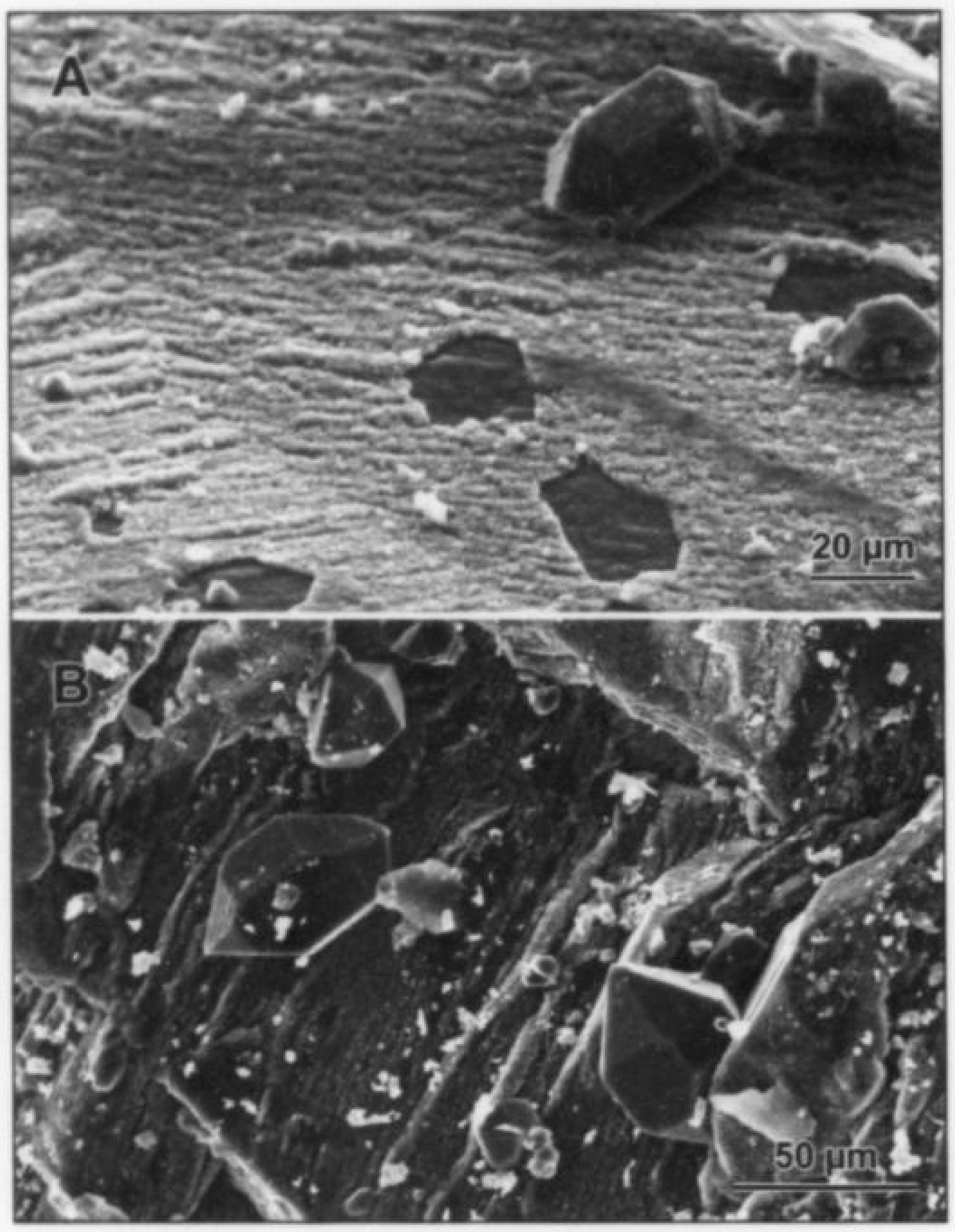


Figure 4. (a) **Oblique SEM photomicrograph shows a (carbon-coated) calcite fragment with a thin patina of lepidocrocite crystals arranged in groups parallel to the calcite cleavage. Several quartz crystals occur on the surface; small bare (black) patches may represent locations from which tiny quartz crystals have been lost. Bar shows scale. *(b)* High-angle SEM photomicrograph shows quartz crystals with their prism faces apparently parallel with the calcite (rhombohedron) face. Bar shows scale.**

calcite surface. The lighter material abutted against the depression at the top of the image is iron oxide, deposited preferentially on the calcite after the quartz grains were formed. EDS spectra (Fig. 3c, 3d) confirm the identities of the quartz and the iron oxide.

The quartz (II) crystals which help highlight the "skunk" stripes on the rhombohedral calcite faces range from 3 mm to about 1 cm long, the longest crystals being crowded near the apex of each calcite crystal. These quartz crystals rest, in no apparent preferred orientation, upon the calcite rhombohedra (Fig. 4a, 4b). They occupy a band up to 1 cm wide which extends from the base of each of the three rhombohedral faces (Fig. 2b) to the apex of the crystal.

Accompanying these small quartz crystals in the stripes, and less commonly enclosed within them, are 1-mm-long, radiating sheaves of black goethite crystals. Each sheaf is about 0.5 mm in diameter and slightly greater in length. Goethite crystals do not occur in or on the large amethyst crystals within the main portion of the geode. Microscopic euhedral quartz (II) crystals also occur scattered about the surface of the calcite scalenohedrons, and tiny quartz (II) crystals commonly cluster around the sheaf-like bundles of goethite (Fig. 5c). In no observed case, however, do goethite crystals occur on the scalenohedral faces.

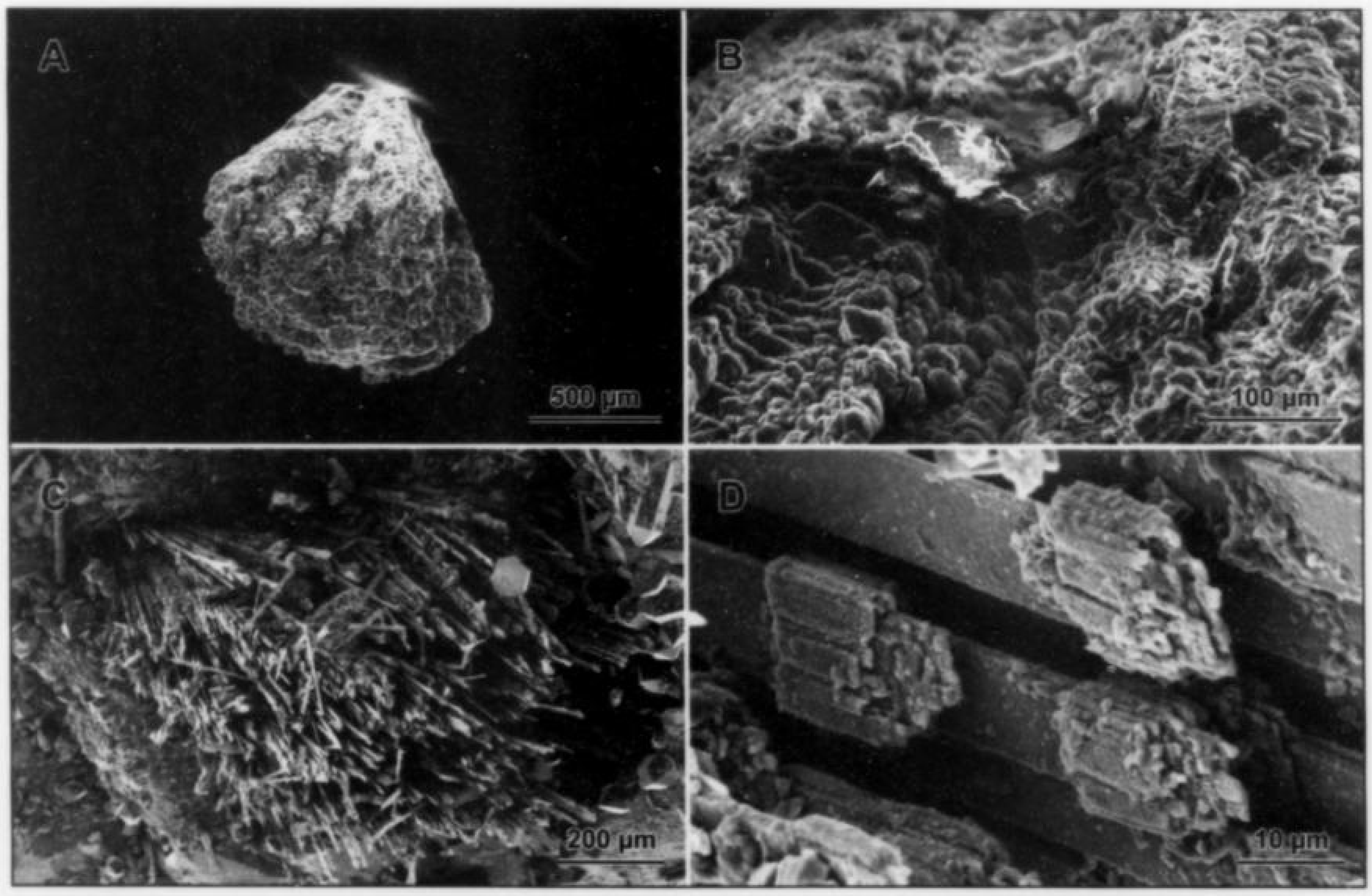
The surfaces of unbroken sheaves of goethite are encrusted with minute lepidocrocite crystals (Fig. 5a, 5b), nearly masking the underlying lath-like subparallel sprays of elongated (orthorhombic) goethite crystals; some of these lath-like crystals show scepter-like terminations. No iron oxide crystals occur upon quartz although some quartz (II) crystals enclose goethite sheaves.

A NOTE ON EPITAXY

According to the IMA definition and general recommendation: "*Epitaxy* is the phenomenon of mutual orientation of two crystals of different species, with two-dimensional lattice control (mesh in common), usually, though not necessarily, resulting in an overgrowth" (Bailey *et al.*,1978).

Although there is no epitactic relationship evident between quartz and calcite in the Ametista specimen, one wonders how common such a relationship may be in nature. The common occurrence together of quartz and calcite, and the tremendous richness of forms and habits, particularly in calcite (Kostov and Kostov, 1999), suggest that such epitaxy, if it is possible, could be widespread. Curiously, however, there is but one reported occurrence. In the relevant

Figure 5. (a) **The surface of this unbroken sheaf of goethite crystals is incrusted with minute lepidocrocite crystals. Bar shows scale. *(b)* Close-up showing surface of goethite crystals coated with lepidocrocite. Bar shows scale. *(c)* Clusters of tiny quartz II crystals surround broken sheaf-like bundle of goethite crystals. Both minerals are rooted in calcite. Bar shows scale. *(d)* Close-up showing scepter-like parallel growth upon lath-like goethite crystals. Bar shows scale.**



specimens, from the Madan region of Bulgaria, crystallographic *c*-axes and (001) (a base normally absent in quartz) are coincident in quartz and calcite (Bonev, 1983).

We tested the possibility of epitactic relations between (low) quartz and calcite, using an in-house computer program to generate crystal models. The results yielded fits along various lattice parameters, including {001}, that fall well within the generous allowance (10–15%) accorded by the Royer-Friedel rule (Turnbull and Vonnegut, 1952; Royer, 1928).

PARAGENESIS

Following its formation near the bottom of a solidifying lava flow, the amethyst geode became lined with banded agate. This provided a base for subsequent deposition of the geode's crystalline contents. From the results of fluid inclusion studies, Juchem (1999) determined that the temperature ranged from 500°C during formation of the agate to about 100°C or less during late stage (epithermal) crystallization of amethyst in the geodes of Rio Grande do Sul. According to Kostov (1968) and Moroshkin and Frishman (2001), the temperature of crystallization of various calcite forms proceeds from the $\{10\bar{1}1\}$ rhombohedron at high temperature to the $\{\bar{1}\bar{1}20\}$ prism, $\{21\bar{3}1\}$ scalenohedron, and lastly the $\{02\bar{1}1\}$ steep rhombohedron at low temperature.

The perceived paragenetic sequence in the Ametista geode is:

(1) Formation of a thin inner wall of banded agate.

(2) Crystallization of large amethyst crystals—quartz (I)—and calcite crystals upon the agate lining of the geode.

(3) Formation of tiny sheaf-like sprays of black goethite together with small amethyst crystals—quartz (II)—in "skunk" stripes upon the calcite rhombohedrons.

(4) Continuing formation of quartz (II) so as to enclose some goethite sprays; during this interval sparse microscopic quartz (II) also grew upon the calcite scalenohedron $\{21\bar{3}1\}$. There is no evidence to indicate that any quartz (II) grew upon quartz (I) at this time.

(5) Deposition of a patina of yellow lepidocrocite upon all exposed surfaces of calcite and upon the goethite sheaves (but evidently the surfaces of the amethyst did not accept lepidocrocite).

DISCUSSION AND CONCLUSION

The formation of skunk calcite was initiated with the earliest precipitation of iron oxides as goethite. It has been shown that quartz (II) crystals formed, contemporaneously with the goethite sheaves and in some cases enclosing them, along the "skunk" stripes. To account for the origin of the "skunk" pattern it is necessary to explain the confinement of goethite and the concentration of quartz (II) crystals along the stripes on calcite rhombohedron faces. Provided that the formation of the rhombohedron faces did indeed succeed the formation (at lower temperature) of scalenohedrons, the later conditions must have favored precipitation of quartz (II) and goethite. Unfortunately, proof for this most simple of all scenarios is lacking, as is an explanation for the relatively orderly arrangement of goethite and quartz (II) into stripes.

Clarke *et al.* (1985) studied experimentally the precipitation of iron oxides on calcite (Iceland spar) surfaces, at room temperature and in a solution containing Fe^{2+}. Precipitation rates were controlled chiefly by the rate of oxidation of Fe^{2+}, by pH, by concentration of Fe^{2+}, and by rate of aeration. Results showed that a slow growth of well-crystallized lepidocrocite (γ-$Fe^{3+}O(OH)$) as 1 × 4-μm platelets, and of smaller, less well-formed crystals of goethite (α-$Fe^{3+}O(OH)$), occurred on the calcite. Some of the grains of lepidocrocite, the dominant phase, also showed subspherical morphology (Clarke *et al.*,1985; comparc also Welton, 1984), a morphology closely resembling the patina on Ametista calcites (see Fig. 3a). At the higher temperatures prevalent in the Brazilian geode, still other, unnamed factors doubtless enter the picture. Among them are probably some thus far elusive aspects of the surface chemistry of certain crystal faces which permit the remarkable stripes on skunk calcites to form.

ACKNOWLEDGMENTS

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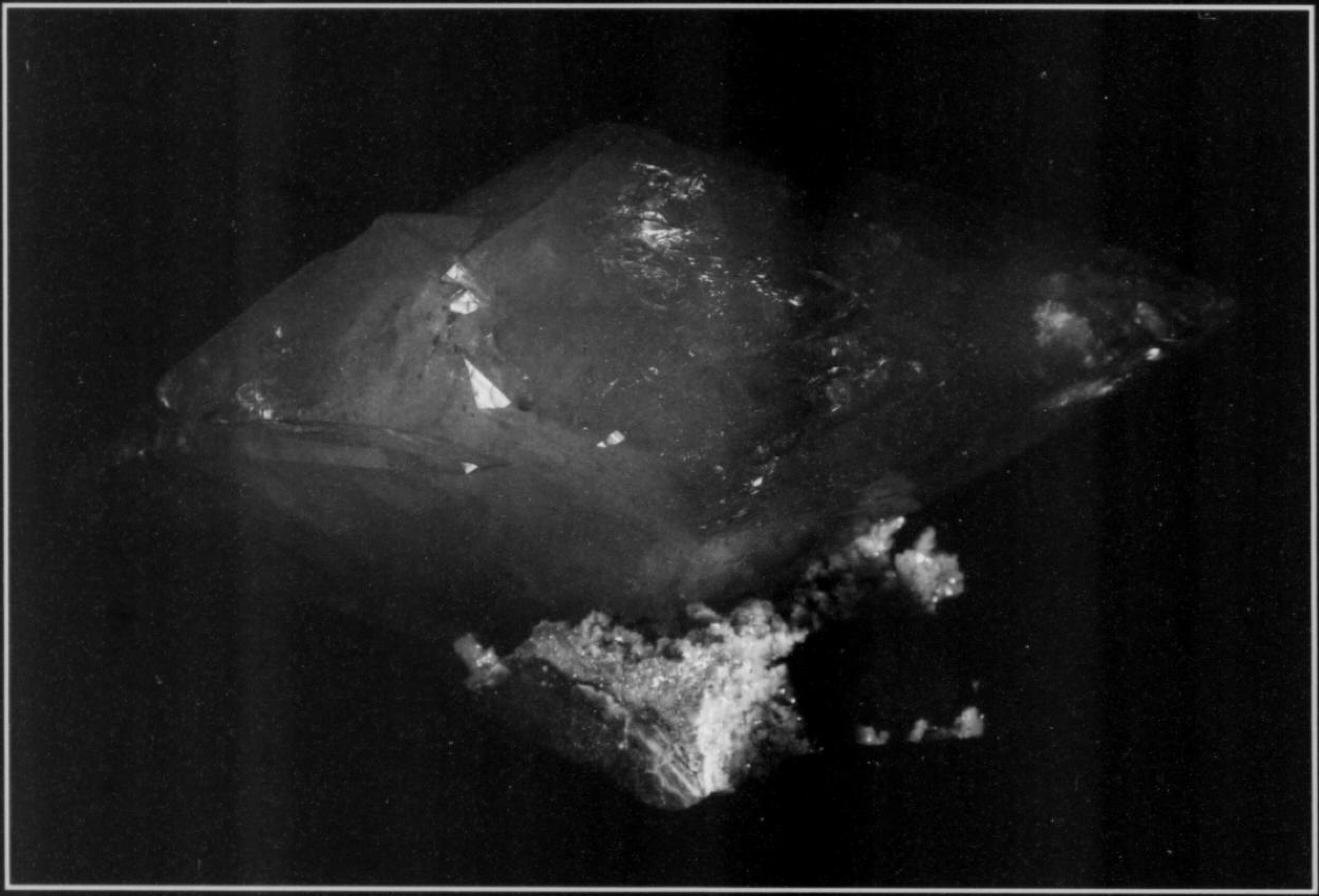
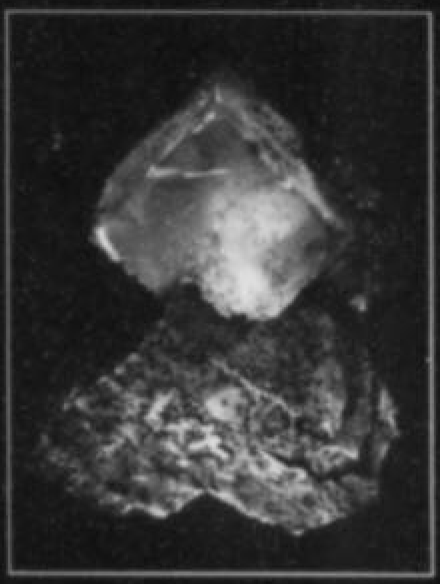
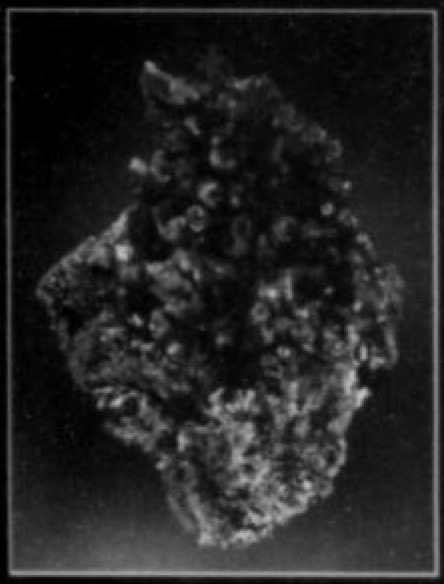


CALCITE, 38 cm (15 inches), Elmwood mine, Smith County, Tennessee





from the Collection of

STEVE NEELY

TWINNED DATOLITE *from* DALNEGORSK, PRIMORSKIY KRAY, RUSSIA

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INTRODUCTION

Datolite ($CaBSiO_4$) is structurally classified as an orthosilicate and is a member of the Gadolinite Group of minerals. It crystallizes in the monoclinic system and is isostructural with herderite. While the standard mineralogical references indicate that datolite does not form twinned crystals, twinning is very commonly observed in herderite crystals. Why twinning is common in herderite and not in the structurally similar datolite is not known. In 2001, an outstanding example of twinned datolite was discovered from the Bor pit near Dalnegorsk, Primorskiy Kray, Russia.

PREVIOUS WORK

As far as is known, only one report of crystal twinning in datolite is found in the literature. In his article "Datolite from Westfield, Mass," Whitlock (1905) describes a single 8-cm crystal from Lane's Quarry that he believed to represent penetration twinning on the (100) crystallographic plane. Shannon (1922) cites Whitlock's work but indicates that twinning has not been unambiguously established to occur in datolite.

GEOLOGIC SETTING

Moroshkin and Frishman (2001) report that the Borosilikatnoye deposit of the Dalnegorsk ore district was discovered in 1946 and was first mined by the Bor Enterprise in 1959. The deposit resulted from a series of skarn events sequentially superimposed one upon another. It is hosted in Upper Triassic limestone associated with Tertiary diabase dikes and granitic intrusives. The major ore minerals are datolite and danburite with the later datolite at least partially derived from alteration of the earlier danburite. Associated species of note include quartz, calcite, wollastonite, hedenbergite, "garnet" (andradite-grossular), fluorapophyllite and manganaxinite. Most of the finest datolite crystal specimens known originate from this deposit.

Datolite mineralization completely replaces the limestone matrix in the central portions of the deposit with well-formed crystals occurring both in pockets and in large open fissures. Three distinct generations of datolite crystallization, each with subtle crystallographic and associated mineral characteristics, have been identified by Moroshkin and Frishman (2001): early, late and latest. Crystal habits are reported as generally most complex in the early and simplest in the latest genera-

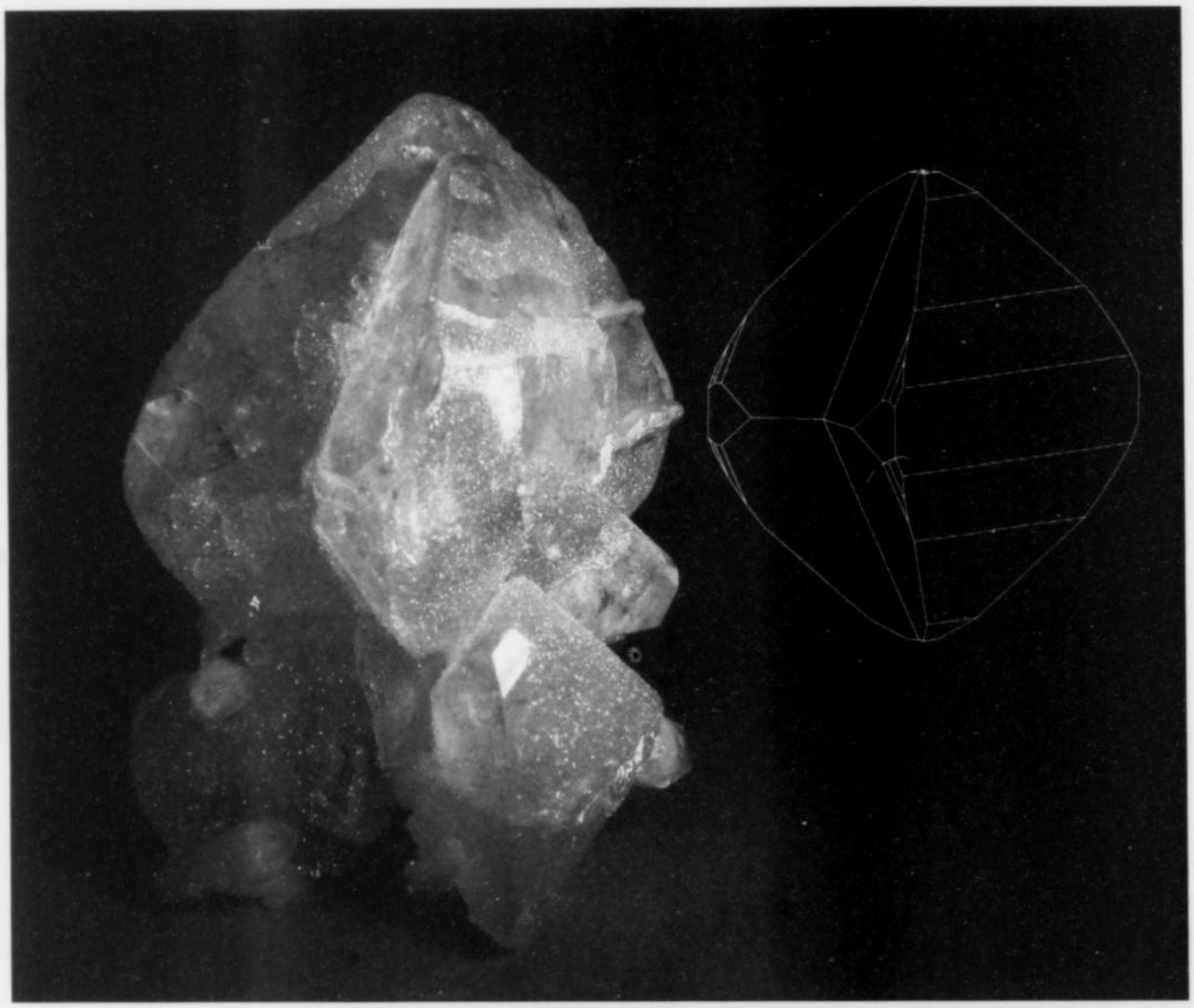

Figure 1. (*above*) **Datolite specimen CM27862 from Dalnegorsk with corresponding SHAPE-generated line drawing of the twinned datolite crystal. Prismatic and microcrystalline drusy quartz and calcite crystals are present as associated species. Carnegie Museum of Natural History specimen. R. Peter Richards photograph.**

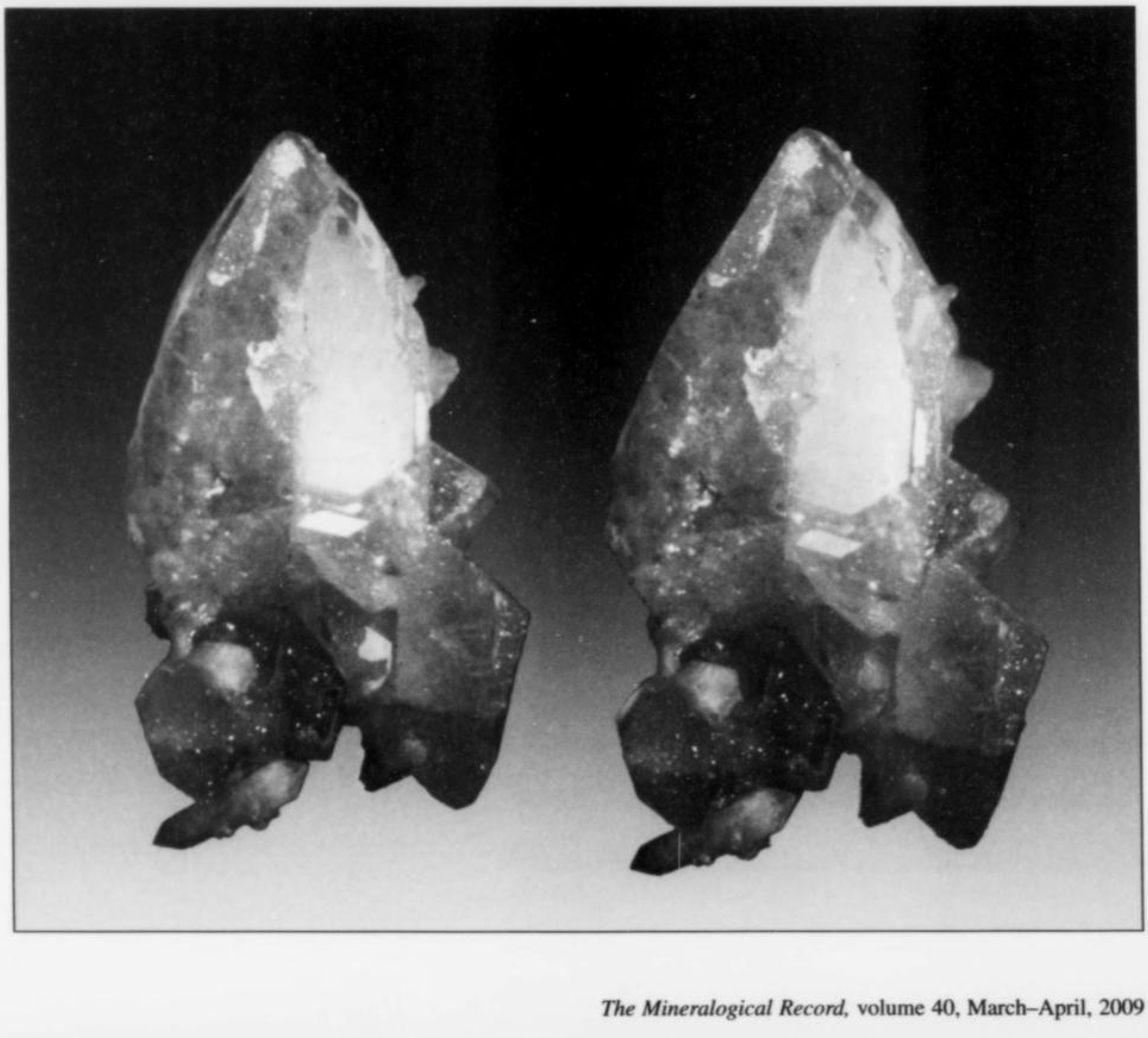

Figure 2. (*right*) **Stereo pair photographs of CM27862 showing re-entrant angles resulting from contact of the interpenetrating twin individuals. Carnegie Museum of Natural History specimen. Debra L. Wilson photographs.**

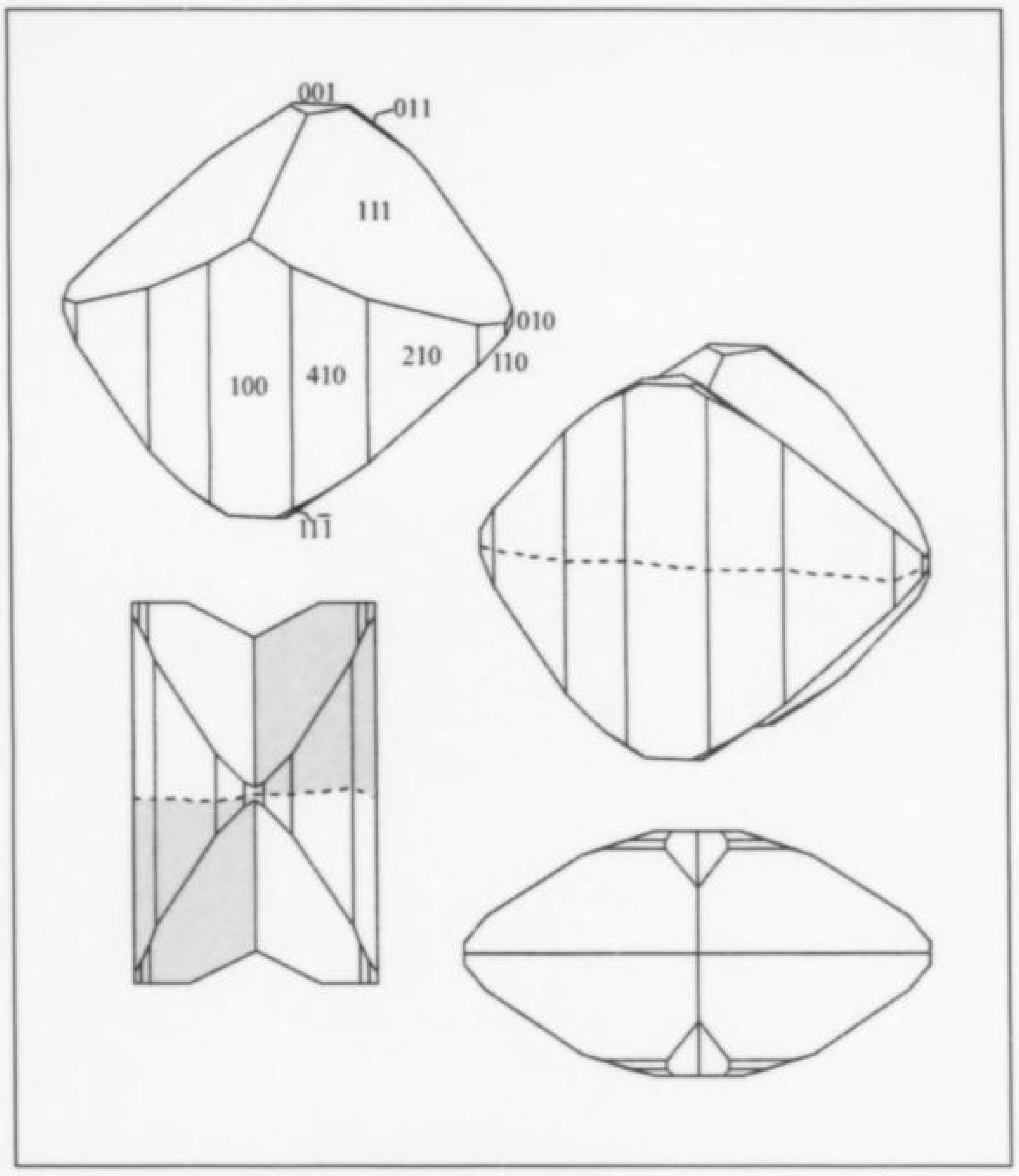

***Figure 3.* Top left: Untwinned crystal showing identified forms. Top right, twinned crystal in standard clinograpic orientaion. The dashed line indicates schematically the boundary between individuals of the penetration twin, which also meet along {100}. Bottom left: View along the *b*-axis. Bottom right: Top view, sub-parallel to the *c*-axes of the two individuals, which form an angle of about 1.5° with each other. Line drawings generated by SHAPE.**

tions. The twinned crystal currently under discussion is believed to be of the middle, or "late," generation of datolite crystallization.

DISCUSSION

The present study centers on Carnegie Museum of Natural History specimen CM27862, a 6.5 × 4.7 × 3.7 cm specimen from the Bor pit of the Borosilikatnoye deposit at Dalnegorsk. The specimen consists of a single penetration twinned crystal, 5.2 cm in height, with minor quartz, calcite and subsidiary datolite crystals. It was obtained at the Detroit Gem & Mineral Show in October of 2001 from Mr. Chris Wright of Wright's Rock Shop. This specimen is reportedly one of four or five similarly twinned crystals that were found together, but efforts to locate the additional twinned crystals for further study were unsuccessful.

The twinned crystal is well-formed and evenly developed. The individuals that make up the twin have obvious monoclinic symmetry (unlike some datolite crystals that mimic orthorhombic symmetry). As a consequence, the twinning is clearly shown by re-entrant angles formed by equivalent faces of the two crystals where they meet.

The twin law is penetration by reflection across (100) as confirmed by X-Ray diffraction analysis. The penetration nature of the twin is not obvious, but is indicated in Figure 3 by the irregular surface shown schematically in two of the drawings using a dashed line. Comparison of the twinned and untwinned crystals in these drawings demonstrates that the faces forming a prismatic zone parallel to the c axis must belong partly to one individual of the twin and partly to the other.

We conclude that this specimen unambiguously establishes twinning in datolite.

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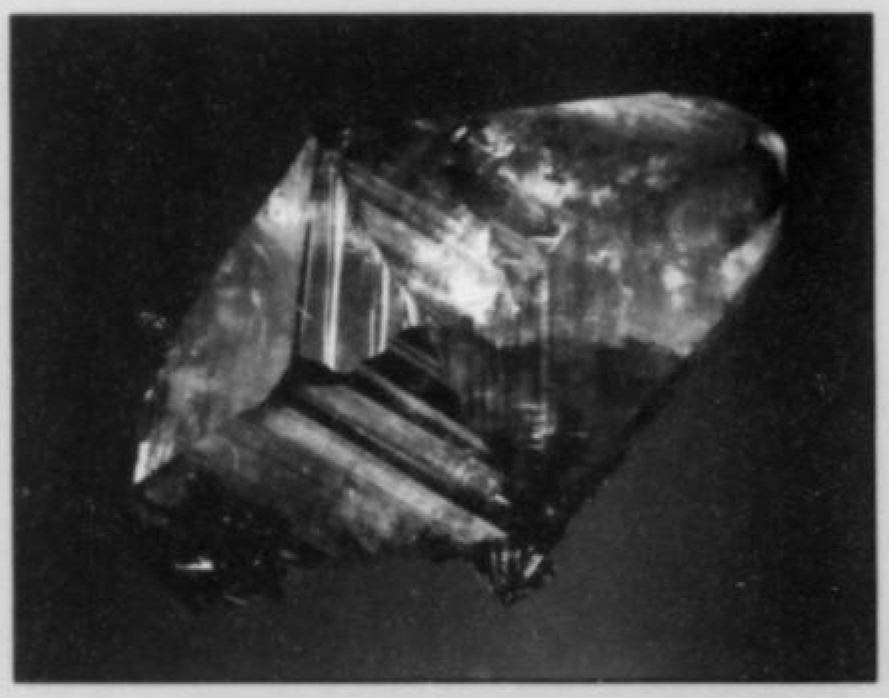

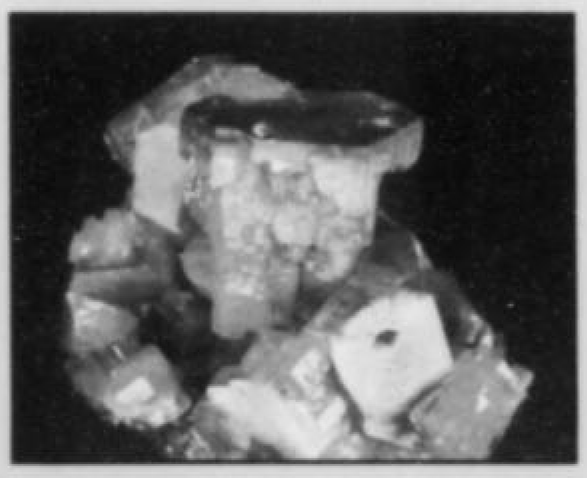

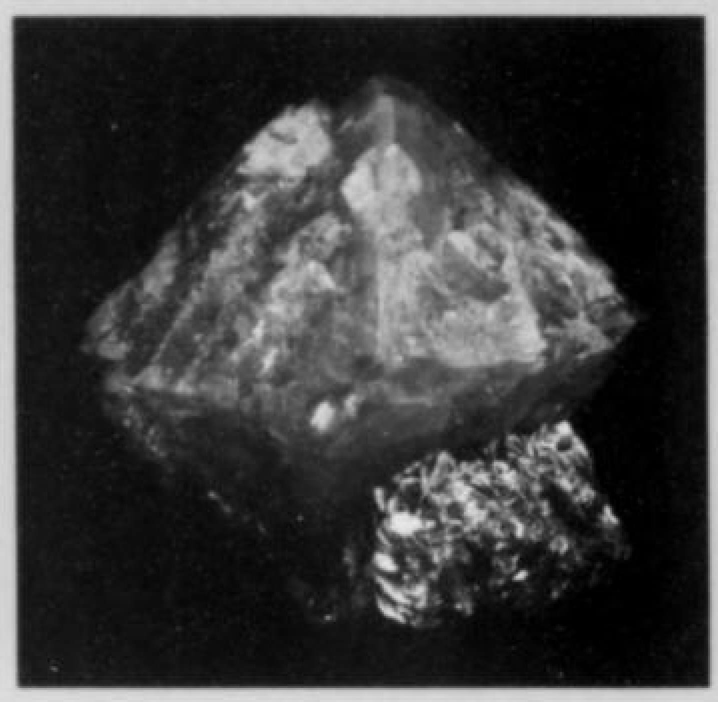

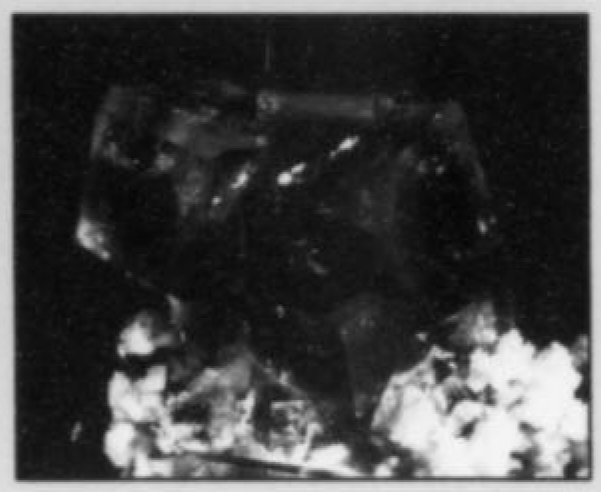

JEFF SCOVIL PHOTO

TOURMALINE with Stilbite and Lepidolite. Himalaya mine, California. From Stuart Wilensky, May 2002; Ex Gene Meieran and Irv Brown Collections. Published in January 2000 *Le Règne Minéral*

Clara & Steve Smale

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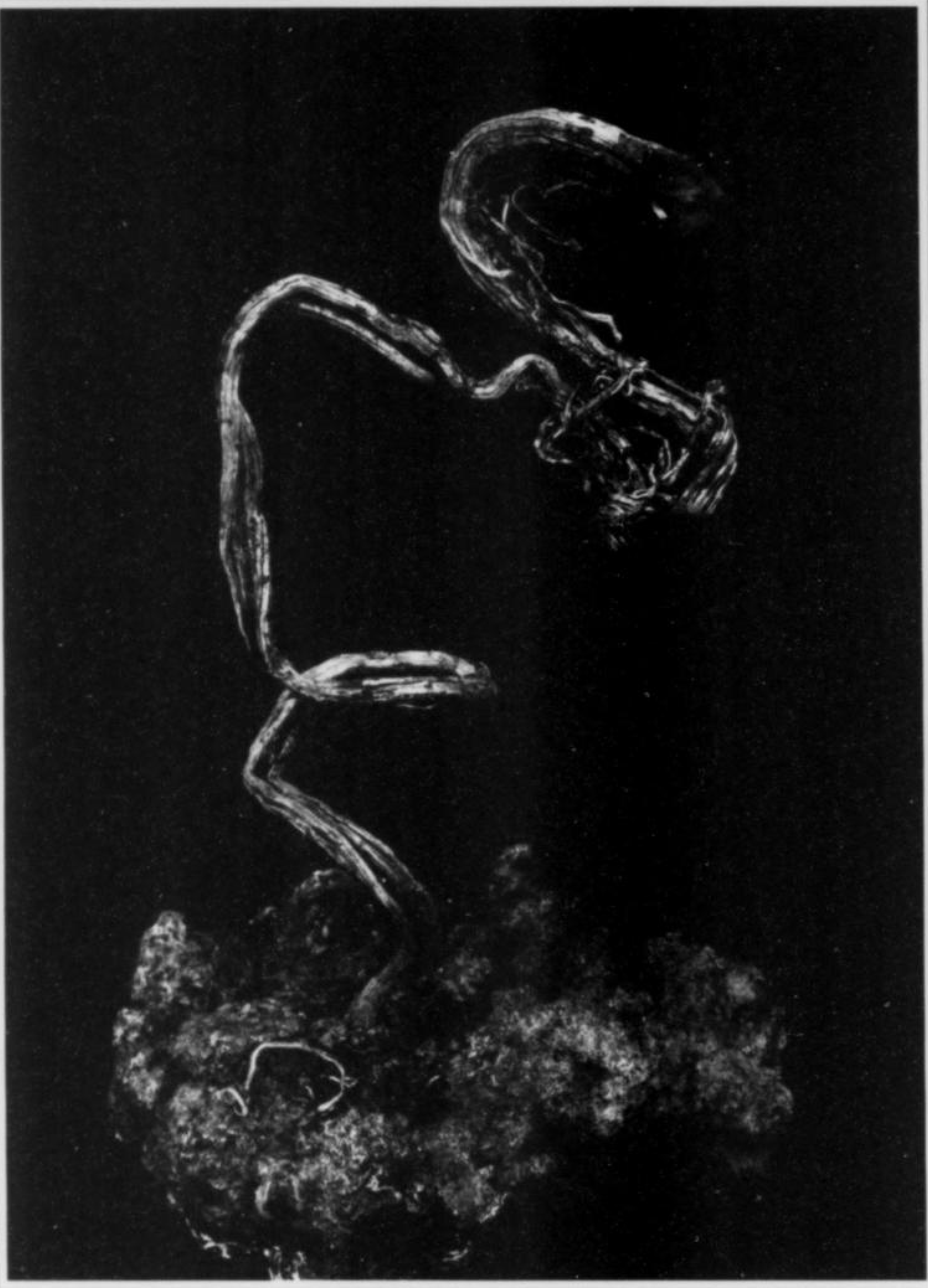

THE REFRACTOMETER

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The index of refraction is a fundamental property of a substance, and its determination may provide valuable diagnostic information about minerals and crystals. Over a period of four centuries, widely varying devices and experimental arrangements for measuring indices of refraction have been developed. These instruments are generally called refractometers, or—if the physical phenomenon of total reflection is used—also total reflectometers. These range from the precursor of Kepler's refractometer (1611) to the primitive but ingenious instrument of Wollaston (1802) to modern, ultra-precise total reflectometers.

INTRODUCTION

Light is an electromagnetic radiation which is generated by a source and travels at a constant speed. The speed of light in vacuum was first determined in 1676 by the Dane Olaf Römer (1644–1710), from astronomical observations of the moons of Jupiter. It has the unimaginably high value of approximately 300,000 kilometers per second (186,000 miles per second): a light ray from the Sun takes only 8 minutes to reach the Earth. The speed of light is retarded to varying degrees in all media except a vacuum. The ratio of the speed of light while passing through a material to the speed of light in a vacuum is given as the refractive index (n) for the material; the simple relationship is:

$$n = \frac{c_0}{c_1}$$

n = refractive index
c_0 = speed of light in a vacuum (300,000 km/sec)
c_1 = speed of light in the material

From this formula it is clear that the index of refraction is a pure number with a value greater than 1.

The index of refraction is an important physical constant. It is distinctive for any given substance and can therefore be employed diagnostically. It is considerably influenced by physical and chemical variations; thus its value will alter with changes in temperature, pressure or composition. For example, it is possible, by measuring the index of refraction, to ascertain the purity of solutions, the chemical composition of mixed crystals, and even the water content of butter or the Brix degree of wine.

The measurement of indices of refraction is generally of great importance, and is employed in—aside from mineralogy—routine optical procedures, petrochemistry, analytical testing of foodstuffs and beverages, and medicine. Devices used to measure indices of refraction are called refractometers.

The index of refraction may be thought of as "optical density," since it depends directly on the kinds of atoms in the medium, as well as on their stacking and arrangement. For each chemical element there is an empirically determined constant which describes the influence of the element on the refractive index of the whole substance: if one knows the chemical composition of a compound, it is possible to calculate what the compound's theoretical index of refraction should be. The comparison of this with the value actually measured furnishes a criterion for the quality of the data, called the "compatibility index"; as an empirical formula it is called the Gladstone-Dale Relation (Mandarino, 1976, 1981). When a new mineral species is described, the international IMA CNMMN (**I**nternational **M**ineralogical **A**ssociation; **C**ommission of **N**ew **M**inerals and **M**ineral **N**ames) requires a determination of its compatibility index—indicating the importance given to this value.

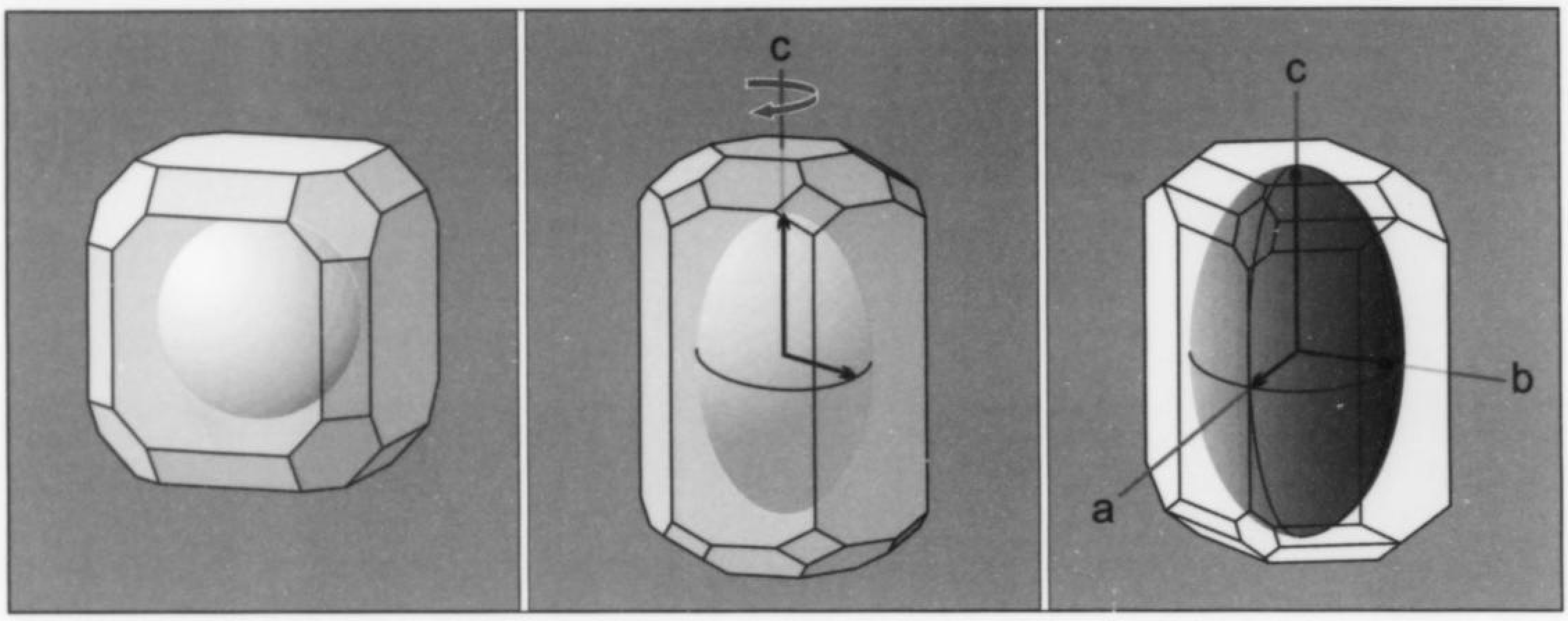


Figure 1. **Schematic drawing of the three principal shapes of the optical indicatrix and corresponding crystal forms. All illustrations by Olaf Medenbach unless otherwise noted.**

In mineralogy, the determination of refractive index is very important, but also somewhat problematical. That is because (except in the case of isometric crystals) the propagation of light is anisotropic, i.e., the speed of light within the crystal varies in different directions. Light propagating from an imaginary source in the center of a crystal does not travel uniformly in all directions, so as to make the shape of a hollow sphere, but rather it forms more complex three-dimensional figures.

To better imagine optical relationships, the model of the *indicatrix* has proven very useful. Described by Fletcher in 1892, this is an imaginary three-dimensional surface in which all axial lengths represent the value of the refractive index in a given direction.

The indicatrix for an isometric crystal is a sphere (see Fig. 1); the refractive index, which is the same in all directions, corresponds to the radius of the sphere. In tetragonal, trigonal and hexagonal crystals, the indicatrix is an ellipsoid (elongated, somewhat like a lemon, or in some cases flattened, like a tangerine). This indicatrix has two "principal" refractive indices, one parallel to the rotational (c) axis, the other perpendicular to it. In orthorhombic, monoclinic and triclinic crystals the indicatrix is an ellipsoid with three axes, the indicatrix being extended from the three mutually perpendicular "principal" indices of refraction: this shape is somewhat like that of a potato or a kiwi fruit. Depending on the symmetry of the crystal, either one, two, or three principal indices of refraction have to be measured, and in order to do that, the crystal must correspondingly be oriented.

Methods for the Determination of Refractive Indices

There are two basic methods for determining refractive indices: by measuring the speed of the light, and by determining the angle formed by light rays at the boundary between two substances (refraction).

Direct measurement of the speed of light in a medium which retards the speed by a relatively small amount runs up against nearly insurmountable technical difficulties. In practice, therefore, one measures the speed of light by measuring the difference between the time a light beam takes to pass through a sample and the time a parallel beam takes to go through a medium with known refractive index. The difference between the two beams is rendered both visible and measurable through interference, i.e. superpositioning of the light. Since these methods are practically insignificant for mineralogy, they will not be elaborated upon here.

In contrast, all methods which are important for mineralogy depend on the phenomenon of light refraction. The fact that a beam of light is bent at an angle when passing from one medium into another was grasped intuitively by early humans, who, when fishing, knew that the prey was not where it seemed to be, but instead was nearer to the hunter. The physical explanation for this phenomenon is given by Snell's Law, named after the Dutch mathematician Willebrord van Roijen Snell (1580–1629) of Leiden, who formulated the law in 1618. This discovery remained unknown until its posthumous publication in the famous book *Dioptrica* (1703) of his countryman Christiaan Huygens (1629–1695).

Snell's Law implies that a beam of light, when passing from an optically less dense (faster) medium into an optically denser (slower) medium, is deflected towards the perpendicular of incidence (Fig. 2).

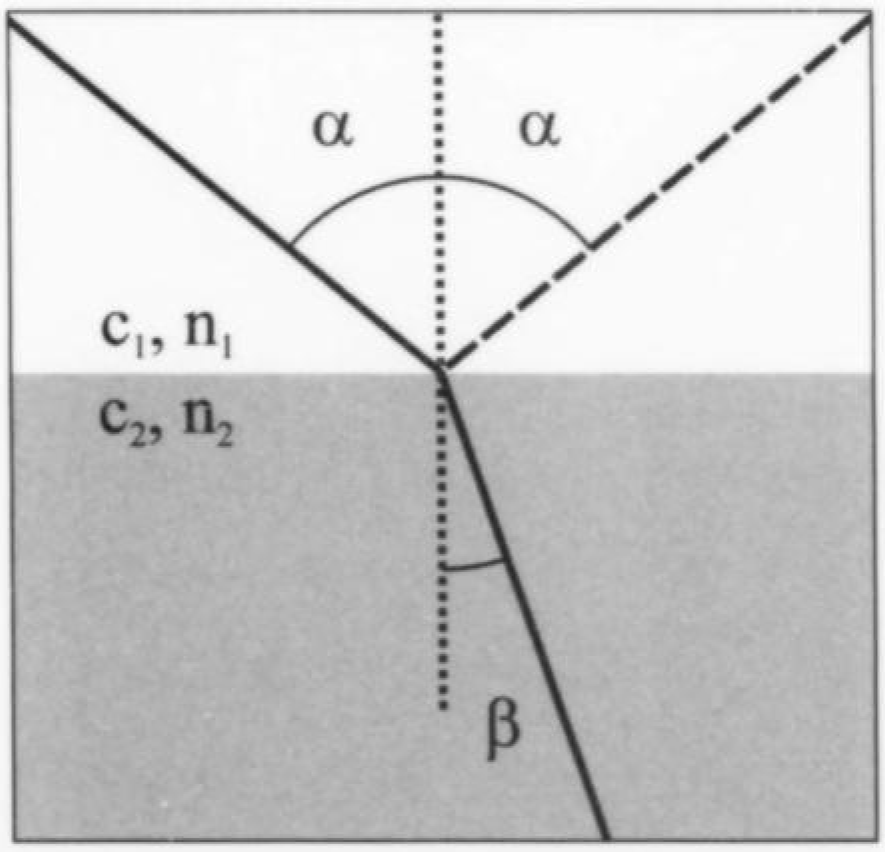


Figure 2. **A beam of light deviates according to Snell's law on a boundary between two transparent media of different optical properties. One part is reflected upward at the same angle as the incident beam (dashed line), the other part is bent at the boundary and deviated into the second medium. The speeds of light are c_1 and c_2 and the indices of refraction n_1 and n_2 for both media, respectively.**

The formula is:

$$\frac{c_1}{c_2} = \frac{n_2}{n_1} = \frac{\sin\alpha}{\sin\beta}$$

Snell's Law is exemplified clearly when a light beam passes through a prism. In this case, refraction takes place at both boundaries between glass and air, i.e., the beam is bent twice. Another important phenomenon is also observed. The original beam of white light is differentiated into spectral colors, and the blue light (of shorter wavelength) is bent more strongly than the red light (of longer wavelength). This signifies that the speed of the blue light through the glass is less than the speed of the red light, i.e. the refractive index for the blue light is accordingly greater. This relationship between refractive index and wavelength is termed **dispersion** (see Fig. 3).

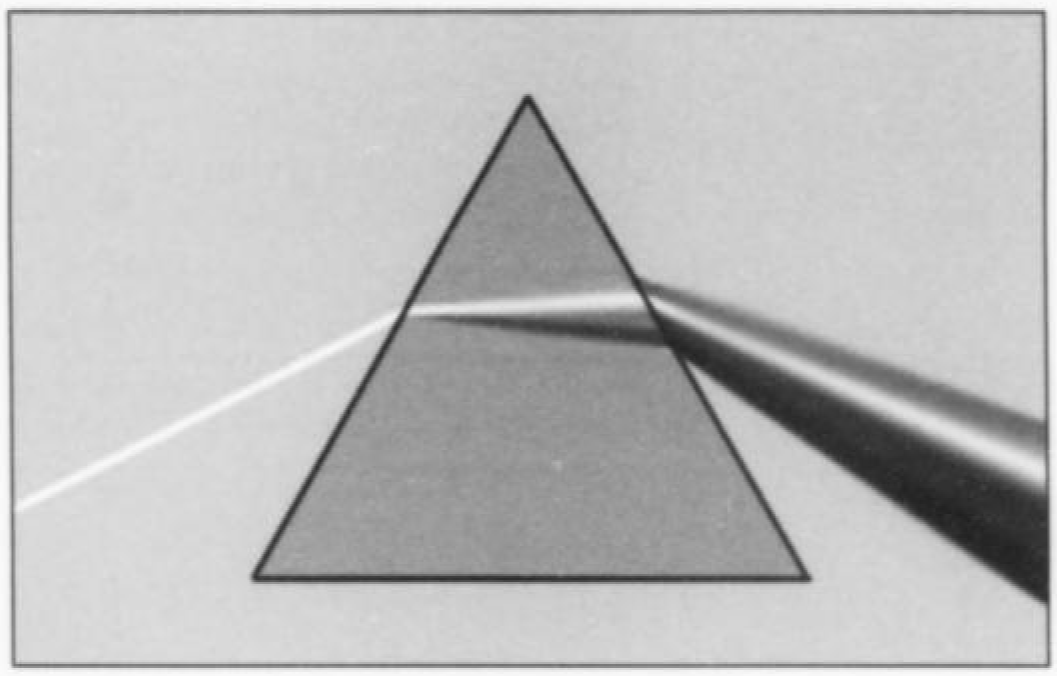


***Figure 3.* Beam of light propagating through a prism: The beam is bent on both glass-air boundaries and radiated into its spectral colors. This is called "dispersion." Source: Wikipedia.**

The magnitude of the dispersion is yet another physical constant for any substance. It is determined by measurement of refractive indices for different wavelengths, and it can be of major diagnostic and technical significance. In the optics industry, for example, a precise knowledge of the dispersion of different glasses is indispensable for the production of high-grade systems of lenses. Dispersion is also the cause of the glittering color-play in faceted gems, especially diamonds.

The dispersion curve of a substance is shown in Fig. 4. Usually the values given in determination tables are for the n_D-spectral line, which is the bright-yellow line for sodium vapor, with a wavelength of 589.3 nm (5893Å). There are historical reasons for this, since this particular "monochromatic" light (light of a single wavelength) can be generated very easily when kitchen salt (NaCl, halite) is scattered into the flame of a Bunsen burner. There have been unsuccessful attempts to generally replace this value by the one for the green mercury line at 546 nm (n_e), since the human eye is more sensitive to this light, and its wavelength lies in about the middle of the visible spectrum.

A straightforward method of measuring refractive indices by utilizing Snell's Law was described in 1611 by the famous "natural philosopher" and astronomer Johannes Kepler (1571–1630), in his *Dioptrik*. It is simple as it is intelligent, being based on the differences between shadows thrown in oblique sunlight through bodies with different refractive indices. The principle is illustrated in Fig. 5. In an opaque trough lies a small block of glass with height equal to that of the wall of the trough. In the empty area inside the trough, the projected shadow corresponds to the surface BCHK, but inside the glass block it corresponds to the surface BDGI.

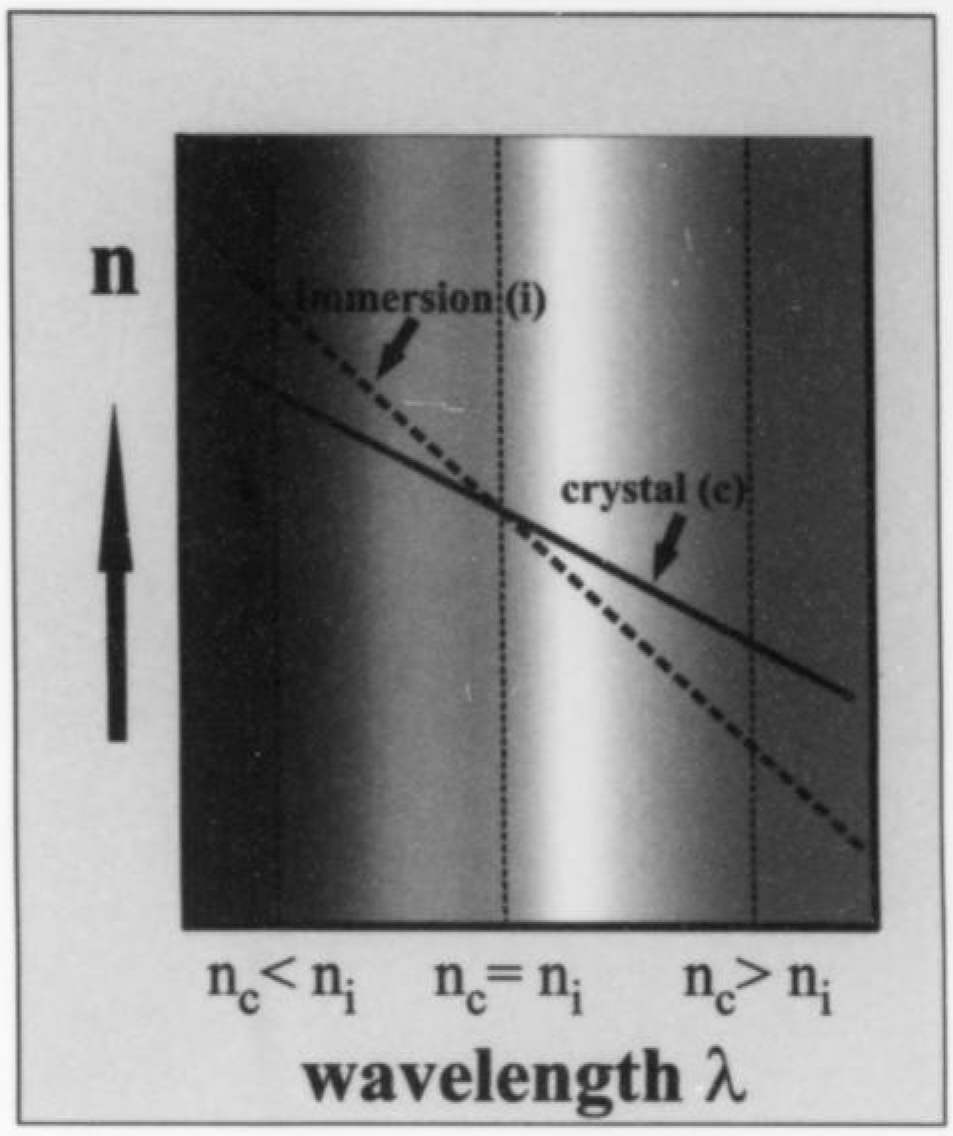


***Figure 4.* "Dispersion curves"—graph of wavelength versus index of refraction. Note that refractive indices are greater for blue light than for red light. Shown is a curve for a crystal (solid), and for a liquid (dashed), and their intersection in green light.**

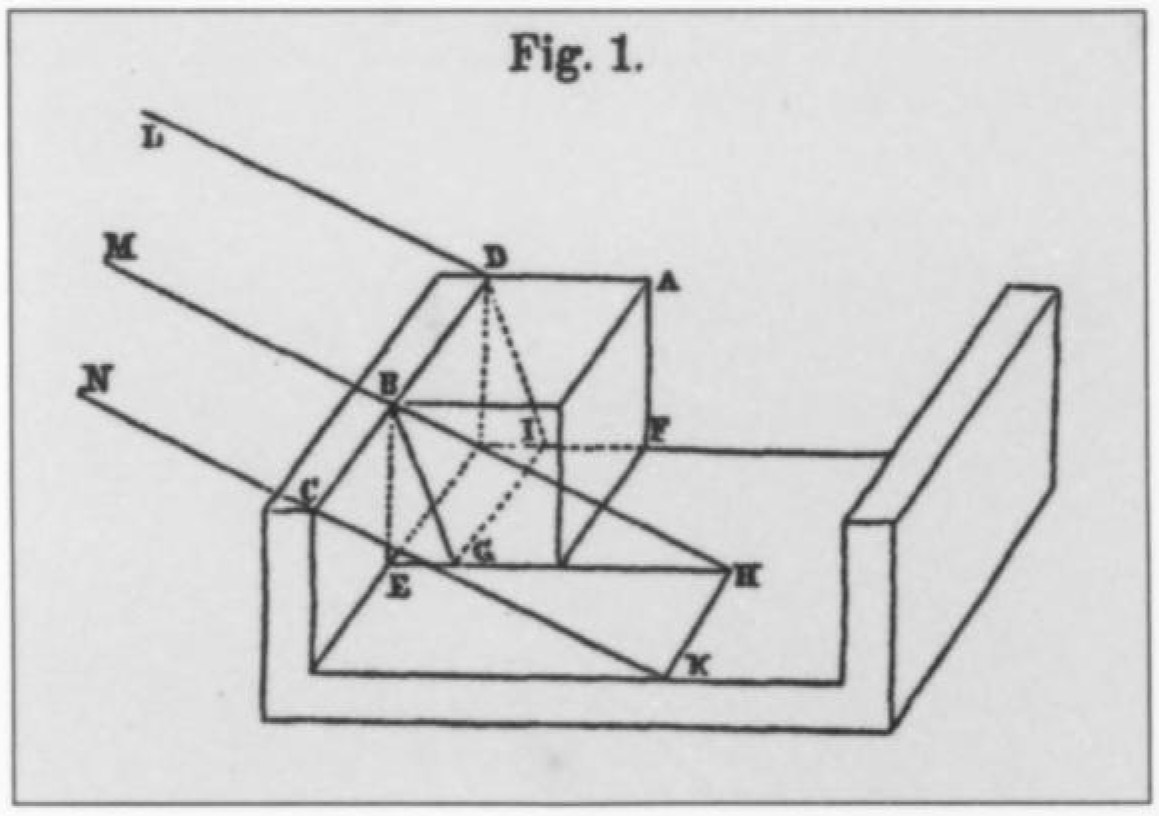


***Figure 5.* Drawing of a simple method to determine the index of refraction of a transparent solid. For details see text. From Kepler (1611).**

Today the measurement with a prism is carried out with the aid of goniometers or spectrometers. This principle will be described in greater detail under the heading "The Prism Method."

A further important phenomenon follows as a consequence of Snell's Law: as the angle β increases from the ray path given by the green line in Figure 6, angle α also increases proportionately until it finally reaches 90°. A ray of light (red line in Fig. 6) originating from an optically denser medium (n_2) then travels exactly along the boundary plane. When angle β increases further, past that of β_{crit}, no more light can pass out of the denser medium into the less dense one, and all light will be reflected from the boundary surface back into the denser medium (yellow line). The angle β_{crit} for the grazing light (red line) is also called the "critical angle of total reflection,"

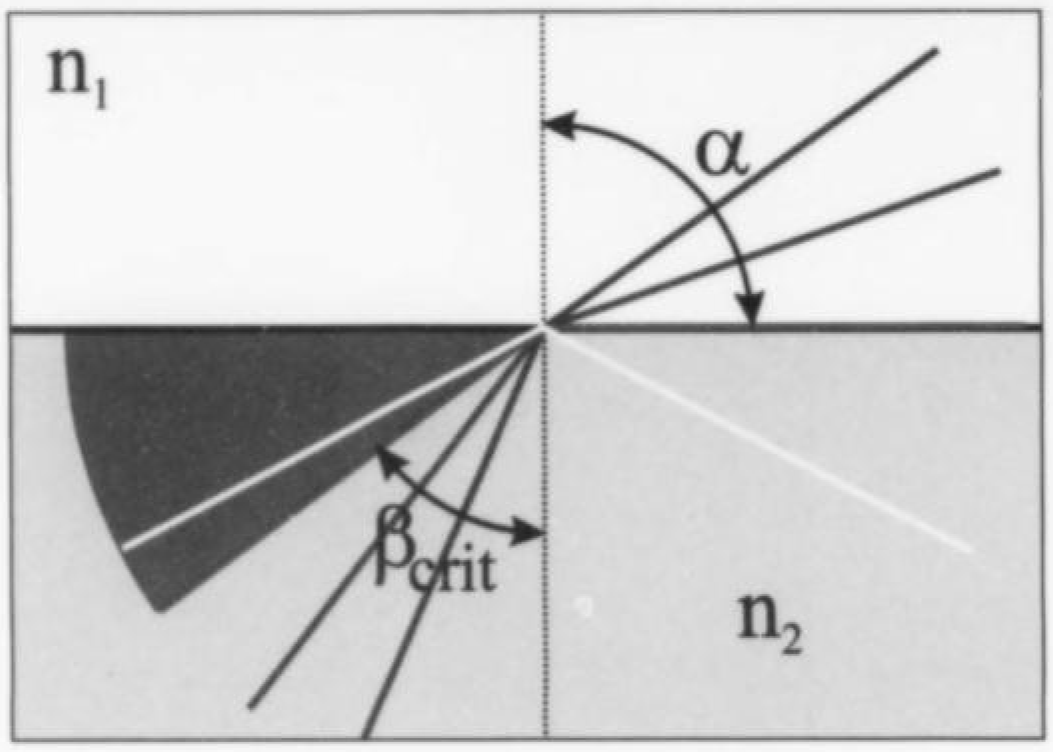


Figure 6. **Total reflection on a plane surface between optically less dense (n_1) and optically denser (n_2) media. The green and blue light beams pass the interface and are deviated according to Snell's law. The red light beam proceeds to the boundary of both media, but does not travel beyond this interface (into n_1) on account of its refractive index. The angle between this beam and the perpendicular on the interface is called the critical angle ($\beta_{crit.}$). All beams with an angle greater than $\beta_{crit.}$ are totally reflected (e.g. the yellow beam). From the angle $\beta_{crit.}$ the index of refraction can easily be calculated. This physical phenomenon is the basic principle of all total-reflectometers, the most important instrument for measuring refractive indices.**

and from it, the difference between the indices of refraction of the two media can be calculated conveniently and accurately. The critical angle is determined with a refractometer, by adjusting the light/shadow demarcation using a telescope with crosshairs. The generation of this light/shadow boundary is easily understandable when one allows light to impinge from the right (Fig. 6) at a nearly flat angle (α close to 90°) onto the boundary surface from the optically thinner medium. Light can then attain the critical angle of total reflection in the range $\beta \leq \beta_{crit}$, but never in the dark gray area. By far the majority of refractometers are based on this physical phenomenon; they may be also called **total reflectometers**.

In 1611 the phenomenon of total reflection was also described by Johannes Kepler, and in 1802 it was first used by Wollaston for the determination of refractive indices. In principle, all total reflectometers derive from the instrument of Wollaston, which was both ingenious and simple; it will be described below.

Practicing mineralogists often face the problem of determining refractive indices of very small samples. In these cases the methods described above are not practicable, and the investigator must revert to microscopic examination by the so-called "immersion method." The principle underlying this method is very simple. There will be no refraction or diffraction phenomena along the surfaces of a colorless substance provided the refractive index of the sample exactly matches its surrounding fluid. The sample will be invisible.

In practice, the test sample is surrounded by an immersion liquid, whose composition and temperature (hence its refractive index) are manipulated so that the sample becomes invisible. Then the refractive index of the liquid is measured with a refractometer. Because the dispersion curve for a liquid is always much steeper than for a solid body (see Fig. 4, dotted line), the refractive index is identical only for one given wavelength (i.e. color of light): in Fig. 7 the immersion is matched for green light (Fig. 4, $n_c = n_i$), whereas in the blue (Fig. 4, $n_c < n_i$) and red regions (Fig. 4, $n_c > n_i$) of the spectrum the grain is clearly visible.

Precision of Measurement of Refractive Indices

Whatever the method employed, measurements of refractive index can be carried out with a high degree of precision with some care. Accuracy to the third decimal place can be attained mostly without difficulties—it was even arrived at by Wollaston (1802) with his simple set-up. Routine measurements to identify a mineral species are carried out with a margin of error around ±0.002. With somewhat more care and appropriate apparatus, measurements to an error margin of ±0.0001 may be attained. For precision measurements in optics and food-quality control, etc., however, an accuracy better than ±0.00001 is necessary. This requires considerable expenditure and very closely controlled conditions. One of the essential factors is constancy of temperature. Usually, the refractive indices of liquids vary by about 0.0005 per degree Celsius; for solid bodies this value is clearly smaller, but still can easily reach 0.00005/°C.

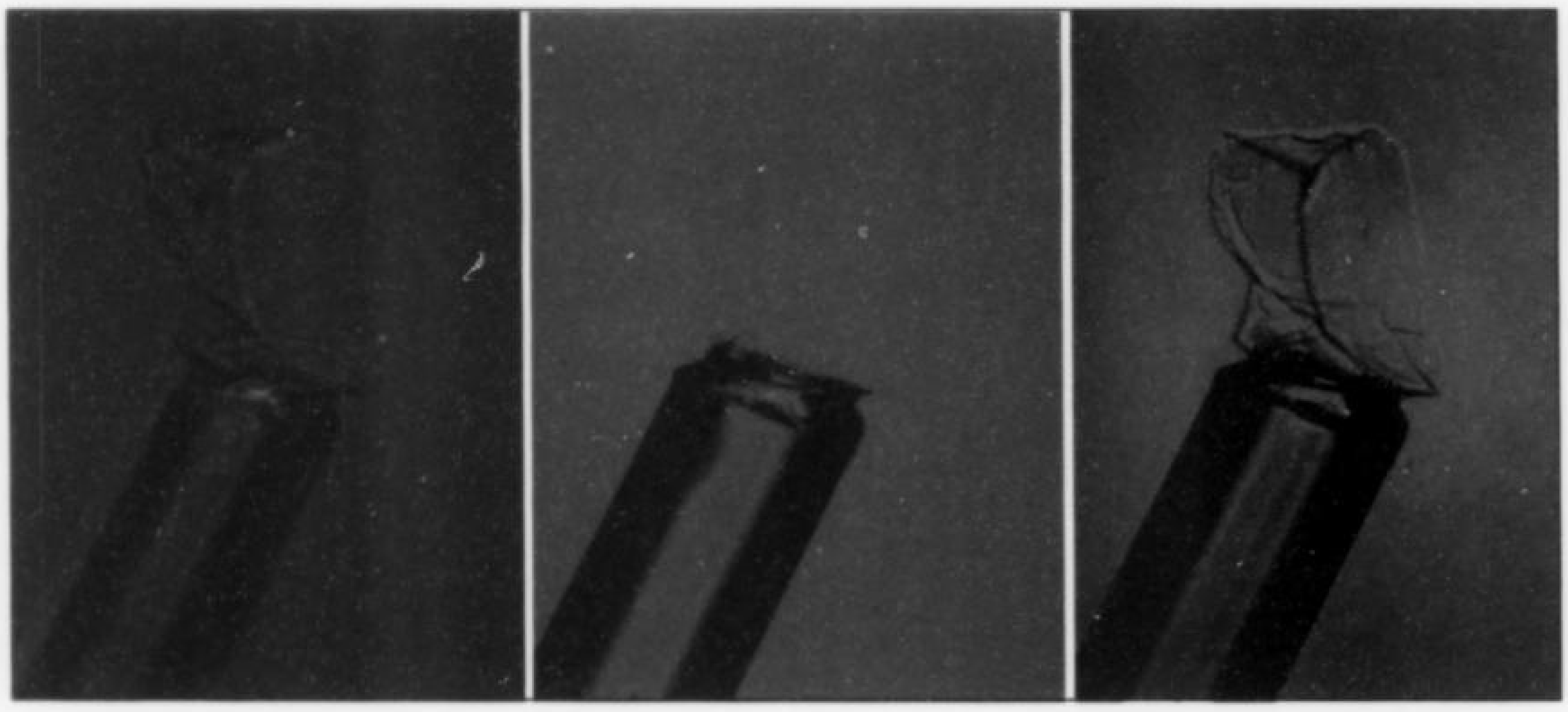


Figure 7. **A mineral grain mounted on a glass fiber and immersed in a liquid with comparable index of refraction shown in monochromatic light at three different wavelengths (compare also to Fig. 4). In this case, the match between the dispersion curves of crystal and immersion liquid is for green light (center), where the crystal becomes invisible. For all other wavelengths it is faintly visible. Size of crystal is 50 microns.**

I. THE PRISM METHOD

With the prism method, any optical goniometer (Burchard, 1998) or spectrometer may be employed as a refractometer, simply because the refraction angle of the prism edge (ω) and that between the incident and the deviated light rays (δ) is to be measured. The one-circle goniometer is the most sensible choice, since the complex construction of the two-circle goniometer unnecessarily increases possible sources of error. The prism of the substance to be measured is located on the goniometer head or the adjustable central disc of

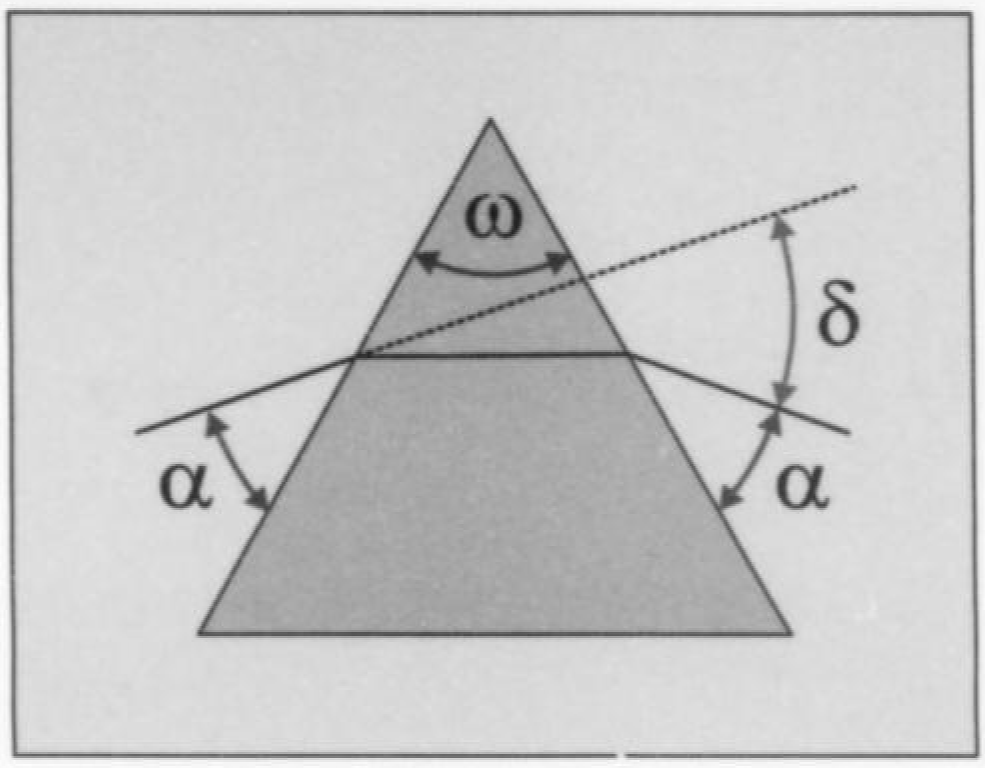


Figure 8. **For a light beam that is passing symmetrically through a prism, the angle of deviation, δ, is at its minimum. This is the principle of the "minimum deviation method" for the determination of the index of refraction.**

the spectrometer, its edge aligned exactly parallel to the instrument's axis of rotation, and the prism angle ω is measured by standard goniometer methods. Subsequently δ is determined for a beam penetrating the prism. The light path for such a beam, which is exactly symmetrical with respect to the prism edge, is shown for green light in Fig. 8. For this beam δ becomes a minimum, and the formula for calculation, following Snell's Law, is especially simple.

This method thus is designated as **minimum deviation method**. It is characterized by high accuracy, assuming that the prism has been prepared perfectly. In the case of anisotropic crystals, principal indices of refraction to be measured must be parallel to the edge or in the symmetry plane of the prism. In addition, the faces of the prism have to be perfectly polished and exactly plane. In order to meet this requirement, elaborate crystal grinding apparatus such as "grinding tripods," shown in Figure 9, have been developed.

To determine the three principal refractive indices of a biaxial crystal one needs at a minimum two prisms in different orientations. In especially favorable cases one can use natural crystal faces, of course, if their quality and orientation are appropriate (for example, the prism faces of a hexagonal or orthorhombic crystal).

If, instead of a crystal, a hollow prism with plane and parallel glass walls is used, an easy and precise measurement of fluids will be possible. A few micro-refractometers for the determination of small volumes of fluids, which are usually employed in connection with the microscopic immersion method, are based on this hollow prism technique (e.g. the Jelley-Refractometer by Leitz/Wetzlar, the Microscope Refractometer by Zeiss/Oberkochen, and the Wilke-Refractometer by Hofmann/Clausthal). The detailed description of these devices is beyond the scope of this publication.

For a thorough description of the prism method, see Groth (1905) and Tutton (1911).

II. METHOD OF TOTAL REFLECTION

As shown above, total reflection can occur only when a light beam passes from an optically denser medium to an optically less

Figure 9. **The preparation of prisms for the minimum deviation method requires great skill, as they have to be perfectly oriented with respect to the optical indicatrix. To facilitate this, special grinding apparatus in the form of a tripod have been designed. The crystal is fixed on one of the legs (left in the picture), and can be transferred to an optical goniometer for control. Variations from the desired orientation can be corrected by means of the angular movements and the threads on the two other legs. The instruments shown here were manufactured by the Dr. Steeg & Reuter Company, Bad Homburg/Germany, ca. 1900.**

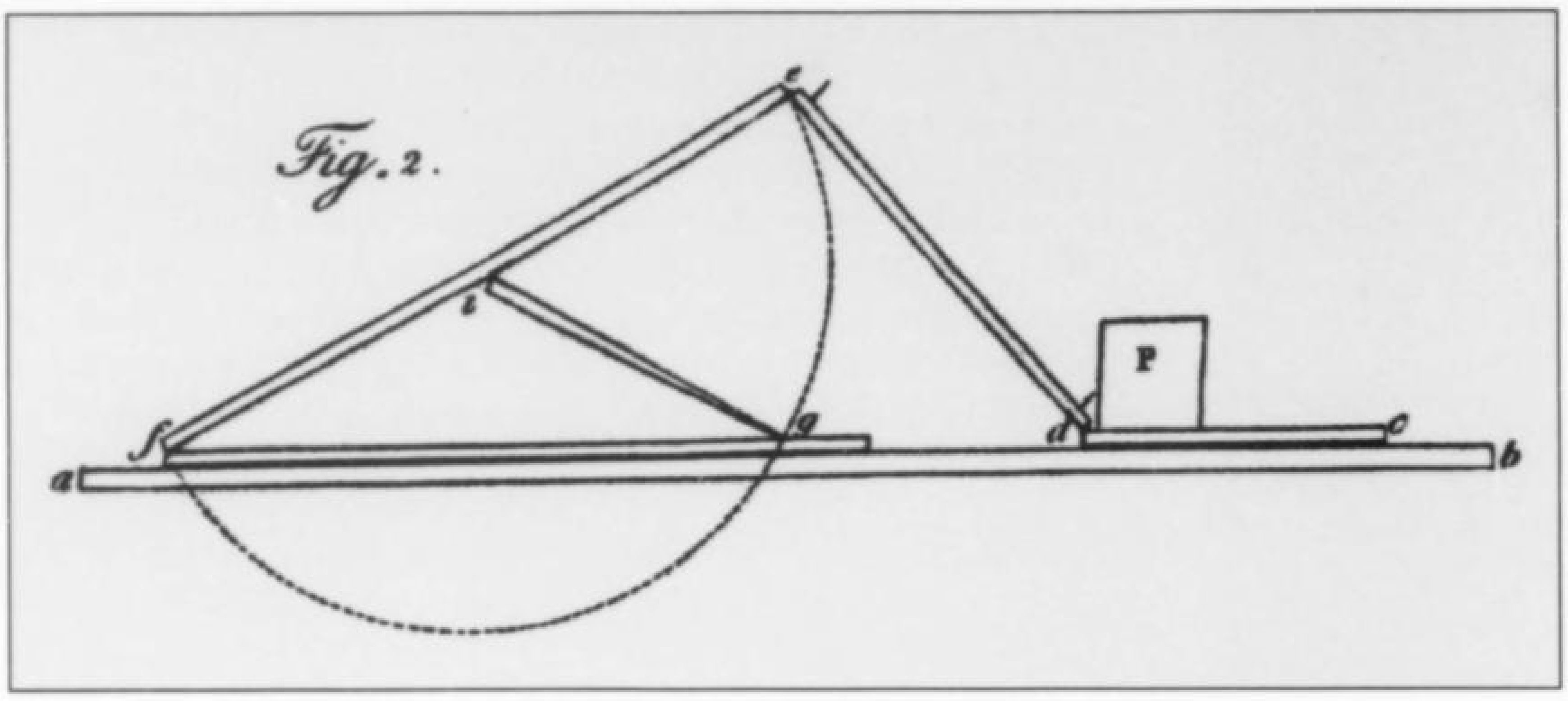


Figure 10. **Wollaston's ingenious total reflectometer, the precursor of all total reflectometers. For details see text. From Wollaston, 1802.**

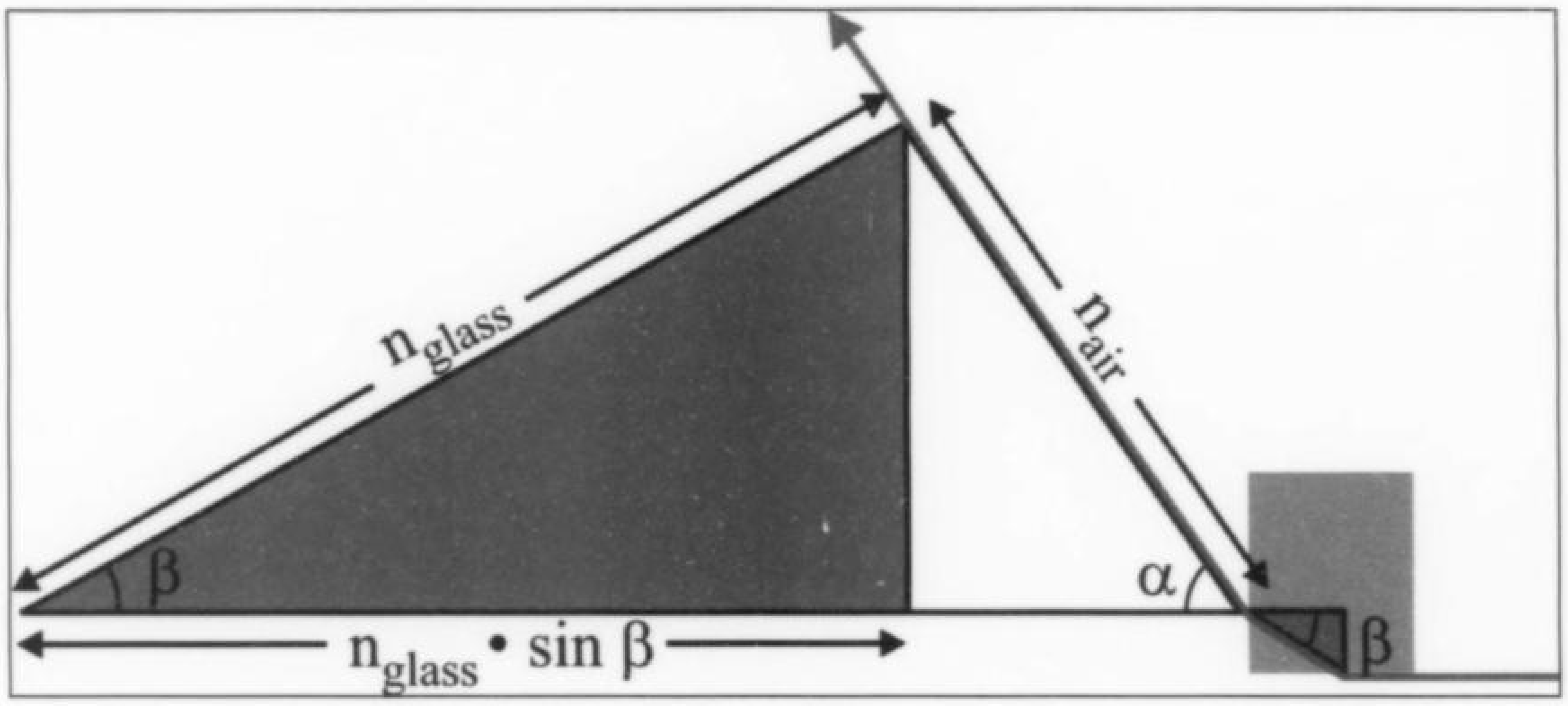


Figure 11. **Principle of Wollaston's total reflectometer.**

dense one. With most total reflectometers, the sample is aligned with a plane face against a body of highly light-refracting glass, which may be in the form of a hemisphere, half-cylinder, or prism. In this case, the space necessarily present between the sample and the glass body must be filled with a liquid of high refraction—higher than the one of the sample, otherwise one will only be measuring the boundary angle for the interstitial air. To calculate the index of refraction of the unknown sample, one needs a very exact knowledge of the index of the glass body.

In principle, of course, only samples with indices smaller than those of the glass body and the contact liquid can be measured, which limits the range of measurement to $n \leq 1.9$. Particularly for gemstone refractometers, there have been attempts to increase this range by using materials with a higher refractive index (such as zirconia, with $n = 2.26$), but the attempts have been problematic, as almost no contact liquids with comparably high indices are available.

Until the middle of the 20th century, the total reflectometer was the instrument that mineralogists chiefly used to measure the indices of refraction. Besides the capacity of the instrument for high accuracy, this was more importantly due to the fact that only a single, arbitrarily oriented, polished face suffices for the measurement of all three of the principal refractive indices of an anisotropic crystal. In these birefringent substances, two bright/dark demarcations are visible rather than one, and the locus (and thus the critical angle) for both lines changes with rotation about an axis perpendicular to the plane of contact between crystal and glass body. The maximum and minimum values of these lines define the principal refractive indices n_x and n_z, and one of the two inflection points of them defines n_y (for further details see Hurlbut, 1984). An axis of rotation with a divided circle for either the crystal alone (e.g., the Liebisch refractometer) or both crystal and glass body combined (e.g. the Pulfrich and the Abbe hemisphere-refractometers) is therefore an essential feature of such instruments for mineralogical use.

Today, total reflectometers are still used primarily in gemology. Hurlbut (1984) describes very clearly the principles, the methods of measurement, and the applications of this instrument.

The nomenclature of total reflectometers is not consistent throughout the literature. The same instrument may be called a refractometer or total reflectometer by different authors or even by the same author in different descriptions. Refractometer is the more general term since the critical angle of total reflection is a peculiar aspect of reflection, thus all total reflectometers are also refractometers. In this publication the term total reflectometer is consistently used for all refractometers which are based on the measurement of the critical angle of total reflection for the determination of the index of refraction.

A. Total Reflectometers with Glass Bodies

Wollaston's Apparatus

Wollaston's method relies on the congruency of triangles (see Fig. 11); it is elucidated by Danker (1885).

In principle, all total reflectometers derive from a simple but ingenious apparatus described in 1802 by William Hyde Wollaston (1766–1828). Wollaston's experimental setup was almost primitive; it can be duplicated by any competent handyman. It consists simply of a board, a number of thin wooden planks connected with hinges, and a glass cube of known refractive index with at least two polished faces. The glass cube (P) (see Fig. 10) rests on the board *cd*, in which there is a small depression that holds the substance to be measured. This substance has to be in close contact with the bottom face of the cube, and even at this early date Wollaston realized that an immersion liquid had to be applied when a

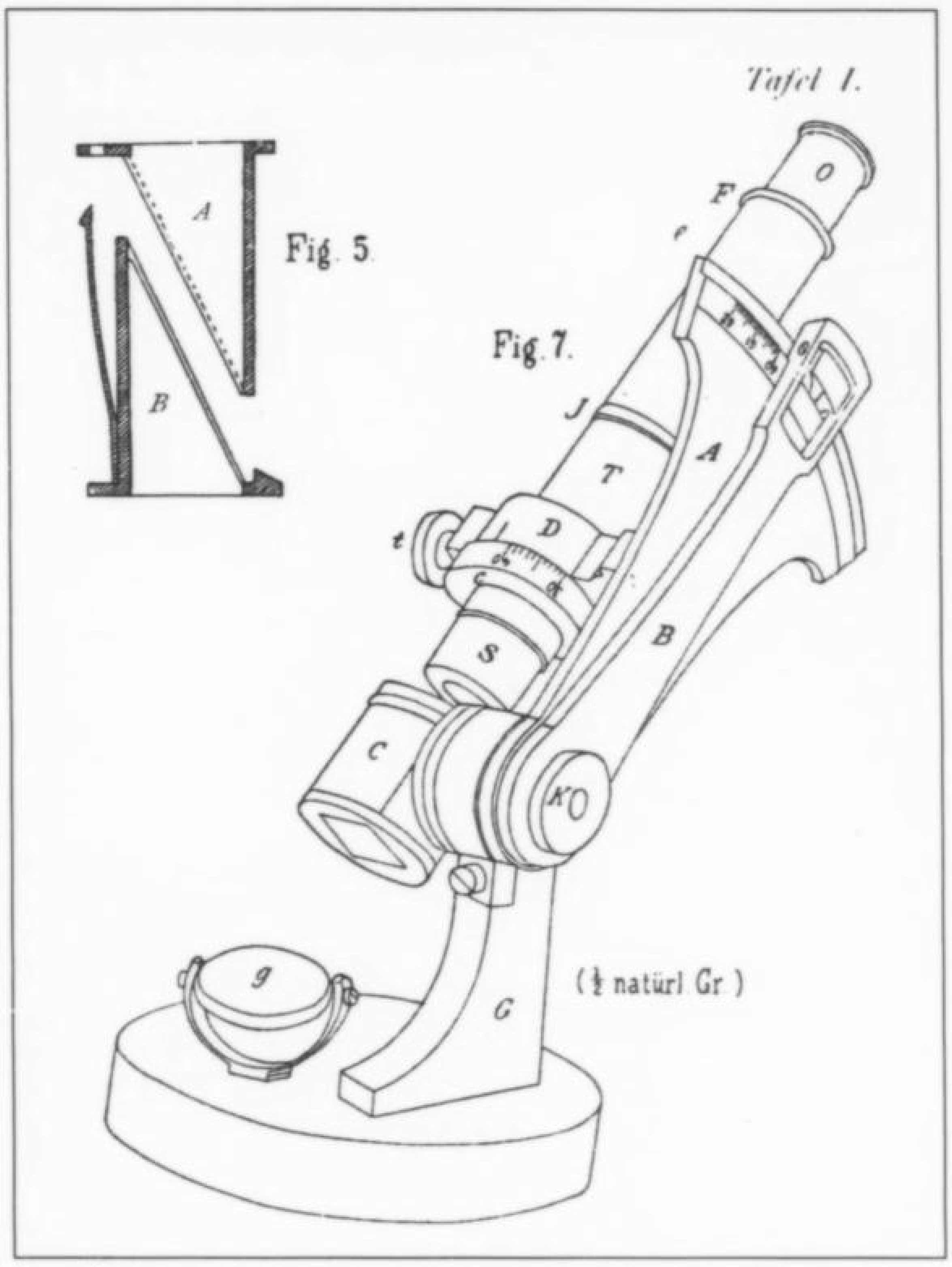


Figure 12. **Schematic drawing of the Abbe double prism total reflectometer. A cross section of the prism arrangement is shown in the upper left corner (Abbe, 1874).**

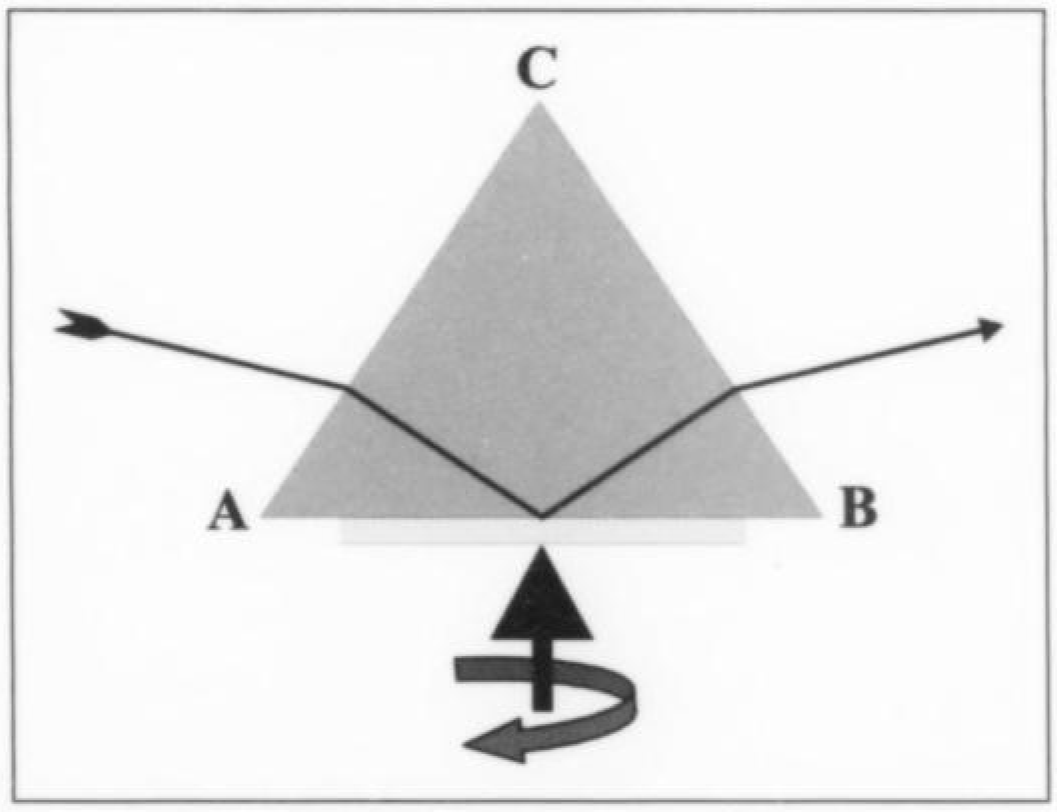


Figure 13. **Optical path in a Liebisch total reflectometer. Total reflection occurs at the boundary between the prism (blue), and the sample (yellow). For birefringent crystals, the sample can be rotated about an axis perpendicular to the boundary between prism and crystal.**

solid is measured—for this he used oil of the sassafras laurel tree. The light is incident from the right. The board *de* has a randomly determined length; in Wollaston's case it is 10 inches, and the board *ef* has a length which agrees exactly with the product of the refractive index of the glass cube and the length *de*—in Wollaston's case this is 15.83 inches, since the glass cube had a refractive index of n = 1.583. The board *ig* is a pointer of half the length of *ef*, thus is also the radius of a circle with the diameter *ef*. Thanks to gravity its pointed end always lies perpendicularly underneath *e*, and the sine of angle β is directly readable on a graduated scale along *fg*. With this measurement the critical angle of total reflection is determined with a sighting arrangement (small marks along *de*). Since, when the experiment is performed in daylight, dispersion effects cause colors to fan out on the boundary surface, Wollaston focused on the yellow part of the spectrum.

The Abbe Double Prism Total Reflectometer

In his fundamental book of 1874 "neue Apparate zur Bestimmung des Brechungs- und Zerstreuungsvermögens fester und flüssiger Körper" (*New Devices for the Determination of the Refractive and Dispersive Capabilities of Solid and Fluid Bodies*), Ernst Abbe presented design drawings of a total reflectometer (see Fig. 12) that is primarily useful for measuring fluids.

On a round metal base a tiltable mirror is mounted, microscope-style, for better illumination of the viewing field. A vertical L-shaped column holds the sector of a graduated circle along with a vernier that is rotatable about a horizontal axis. Firmly attached to the graduated circle is a telescope by means of which the critical angle of total reflection may be observed.

Also firmly attached with the horizontal swivel pin is a right-angled, 60-degree glass prism such that its edge is perpendicular to both the plane of the divided circle and the axis of the telescope. By means of a guiding groove and a spring-tensioned locking screw, a second prism of the same form and size is brought adjacent to the hypotenuse face of the first prism, creating an N-shaped cross-section (see Fig. 12 top left). The fluid to be measured is introduced as a thin film between the hypotenuse faces of the two prisms. Ideally the testing is carried out in monochromatic light. The reading of the position of the critical angle appears directly on the scale (using a small magnifying lens) and is accurate to the fourth decimal place.

In 1898, Pulfrich altered Abbe's double-prism total reflectometer to make it usable also for solid substances. For this purpose the second prism was removed and a small triangular auxiliary prism was mounted on the remaining prism. This made it possible to illuminate the solid substance in reflected light, whose plane face is in contact with the prism.

In order to eliminate the influence of temperature, later models of the Abbe double-prism total reflectometer were fitted with a system of internal passages and external tubes for circulating water. For convenience the second prism was hinged. This type of total reflectometer was manufactured in quantity by Carl Zeiss of Jena, Bausch & Lomb of the USA, and Adam Hilger of London. It should again be pointed out here that this device is of merely minor importance in mineralogical research except for the fact that it was often used for calibrating index liquids.

The Liebisch Total Reflectometer

In 1884 Liebisch described two "Neuere Apparate für die Wollaston'sche Methode zur Bestimmung von Lichtbrechungsverhältnissen" (New devices for applying the Wollaston method for determining the relations between indices of refraction). The principle of the method is shown in Figure 13 and an engraving in Figure 14. The equal sided glass prism ABC with a high index of refraction has two polished faces (AB and BC); AC can either be polished or frosted. The crystal (shown in yellow) is placed with its polished surface onto the prism face AB, of course again with a high index immersion liquid for optical contact in-between. It is held in place by gentle pressure of a special spring-loaded device

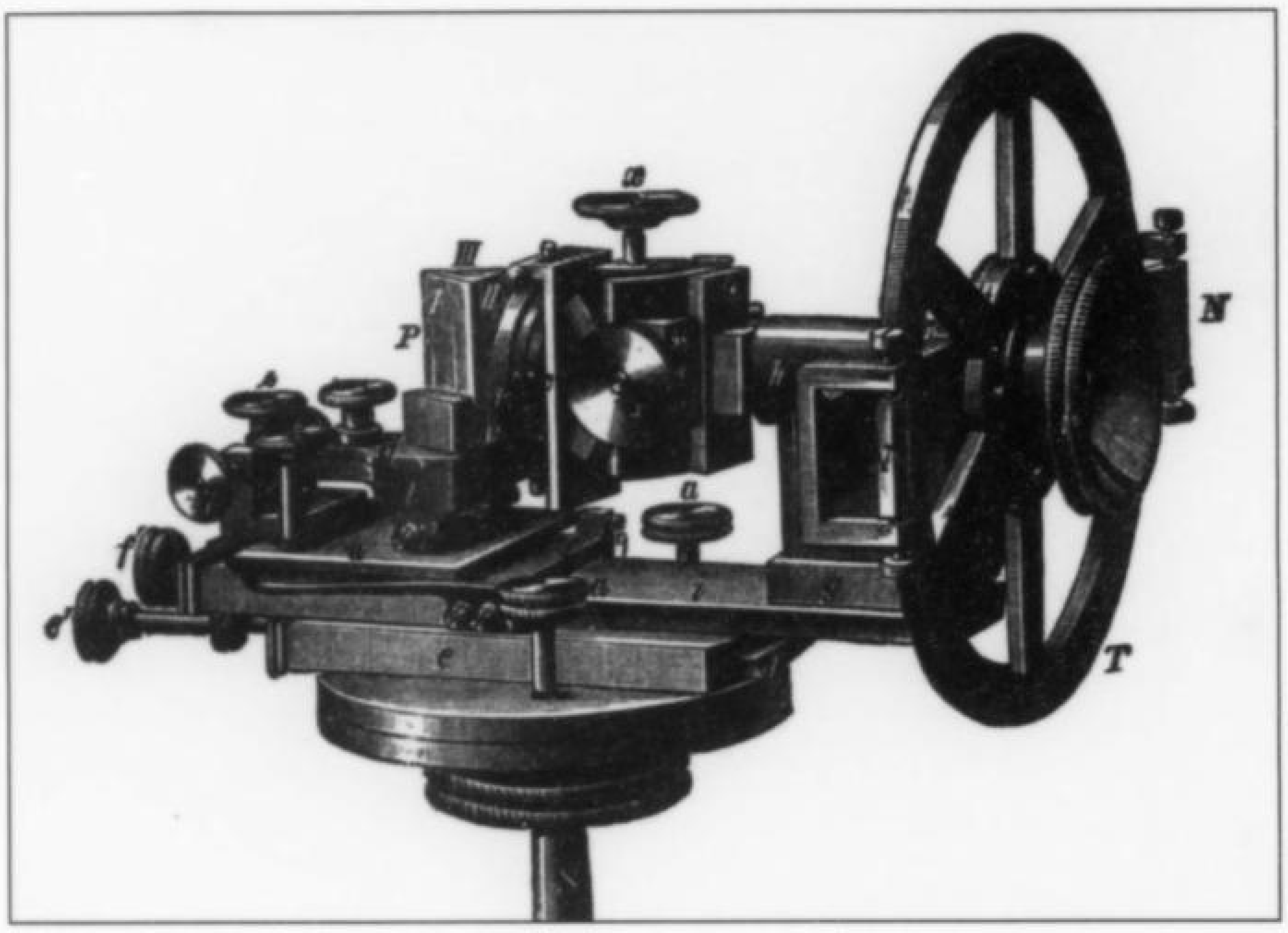
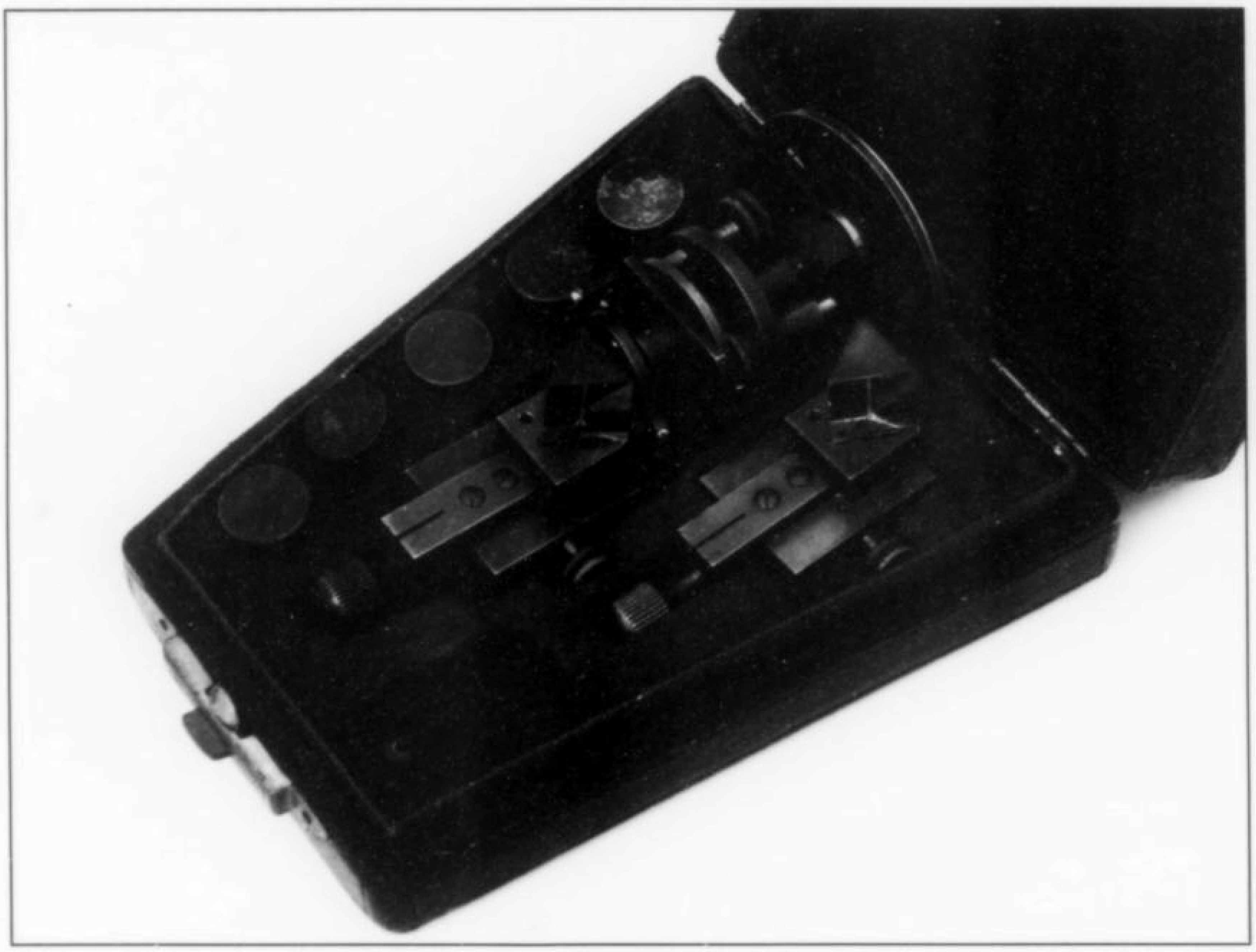


Figure 14. **Contemporary steel engraving of a Liebisch total reflectometer, Liebisch (1896).**

Figure 15. **The Liebisch total reflectometer in its fitted case. Note the presence of two interchangeable prisms, one with a medium index of refraction for standard measurements, and a second one with a high-index glass for the measurements of highly refractive samples. Manufactured by Fuess, Berlin/Germany, ca. 1900.**



described in more detail later. A diffuse light enters the prism via the face AC, is reflected on the crystal's polished face, and leaves the prism through BC. Observation of the reflected light is facilitated by a telescope (e.g. the telescope of a goniometer), and the critical angle is visible by a sharp demarcation between a bright and a feebly illuminated portion of the image. For measuring anisotropic crystals, the sample must be rotated about an axis perpendicular to the reflecting face, and both the angle of rotation about this axis and the corresponding value of the critical angle have to be monitored. It is essential that the crystal's polished face lies always exactly parallel to the prism face AB. Therefore, Liebisch designed a special delicate device: the crystal is mounted with beeswax onto a small disc which is suspended within a pair of gimbaled rings similar to the attachment of a gyrocompass. This arrangement assures a gentle and proper contact between crystal and prism for all settings. The amount of rotation of the crystal can be read out by a divided circle and a vernier to 5 minutes.

Theodor Liebisch (1852–1922) distinguished himself by his experimental inquiries into the properties of minerals and rocks. From 1908 to 1921 he was the director of the Humboldt University in Berlin, noteworthy for its famous mineral collection.

Liebisch's total reflectometer was produced by the Fuess Company in Berlin/Steglitz. In the 1909 price list, Fuess offered several different designs: Model I (for 115 Marks), a small instrument to be used as an accessory to all goniometers (e.g. No. II as shown in Fig. 16), a larger device with important improvements for the adjustment and a larger divided circle for higher precision (Model II for 230 Marks) exclusively for the No. I goniometer, and a so-called "Selbstständiges Totalrefraktometer"—an autonomous instrument for 250 Marks.

The range of measurements is limited by the index of the glass prism, but high refractive glasses have two major drawbacks: 1) they are very soft and will be scratched during intensive use, and 2) they show a yellow tint which reduces the transparency in blue light and thus make measurements in this portion of light more difficult. Therefore all instruments were delivered with a second

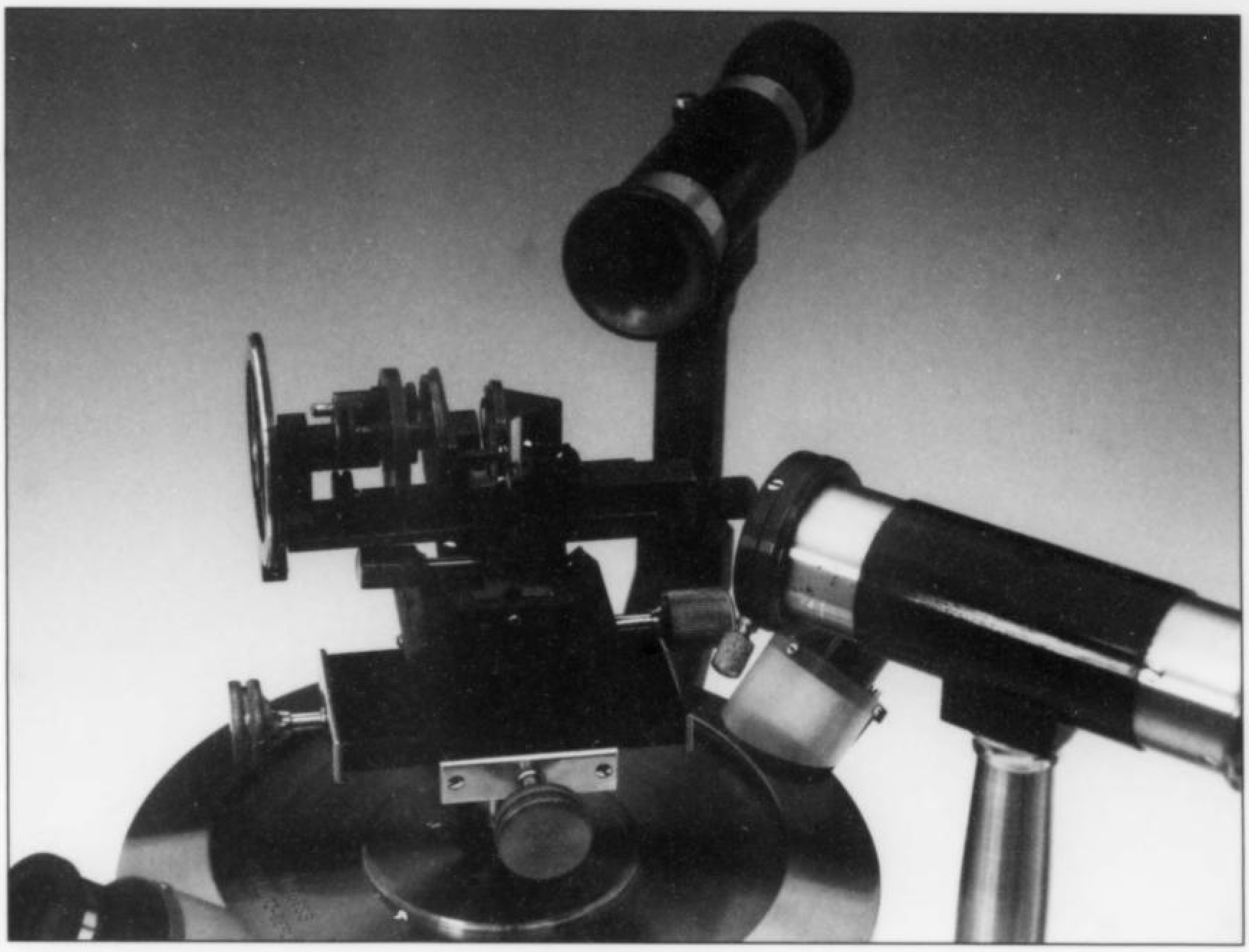


Figure 16. **Same accessory shown when mounted on a Fuess No. II goniometer, ca. 1920.**

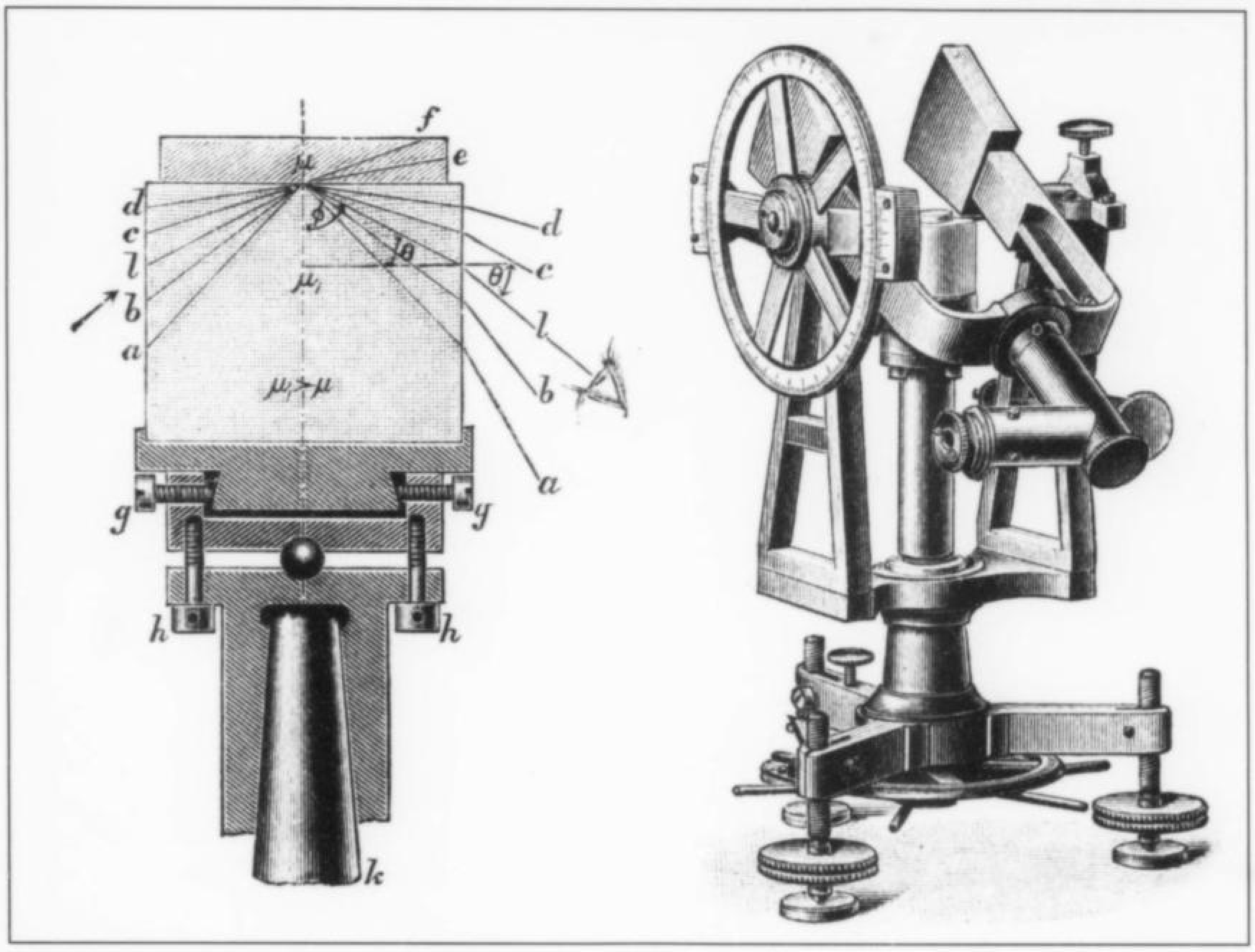


Figure 17. **Contemporary steel engraving of a Pulfrich total reflectometer, and the path of rays within the glass cylinder and the sample. Screws *g* and *h* are for the fine adjustment of the cylinder. Tutton, 1911.**

interchangeable prism of lower index for routine measurements in a lower range. Figure 15 shows the device and both prisms in a fitted case, and also illustrates the complexity and delicacy of the mechanical parts of this accessory.

The Pulfrich (Wolz) Total Reflectometer

Carl Pulfrich (1858–1927) was employed after 1883 as an assistant professor at the University of Bonn. He experimented with the refractive indices of crystals, glasses and liquids. At this time he came into contact with the firm of Max Wolz, a resident in Bonn. In 1890 Ernst Abbe called Pulfrich to Jena to be the first head of the "optical measuring instruments" department of the Carl Zeiss Company. Above all, Pulfrich became famous for his success in optimizing refractometers; less well known are his pioneering achievements in the field of stereo-photogrammetry—all the more amazing since he was blind in one eye.

In 1887 and 1888, still in Bonn, Pulfrich introduced his "new total reflectometer," as well as "a new refractometer." The instruments resemble each other, but the first is more technically elaborate (see Fig. 17). The central part of his total reflectometer consisted of a glass cylinder with a height of 31 mm and a diameter of 38 mm on a vertical, rotatable axis, with a small horizontal circle on which the degree of rotation may be monitored. A centering device enables exact adjustment of the glass cylinder. The flat upper face of

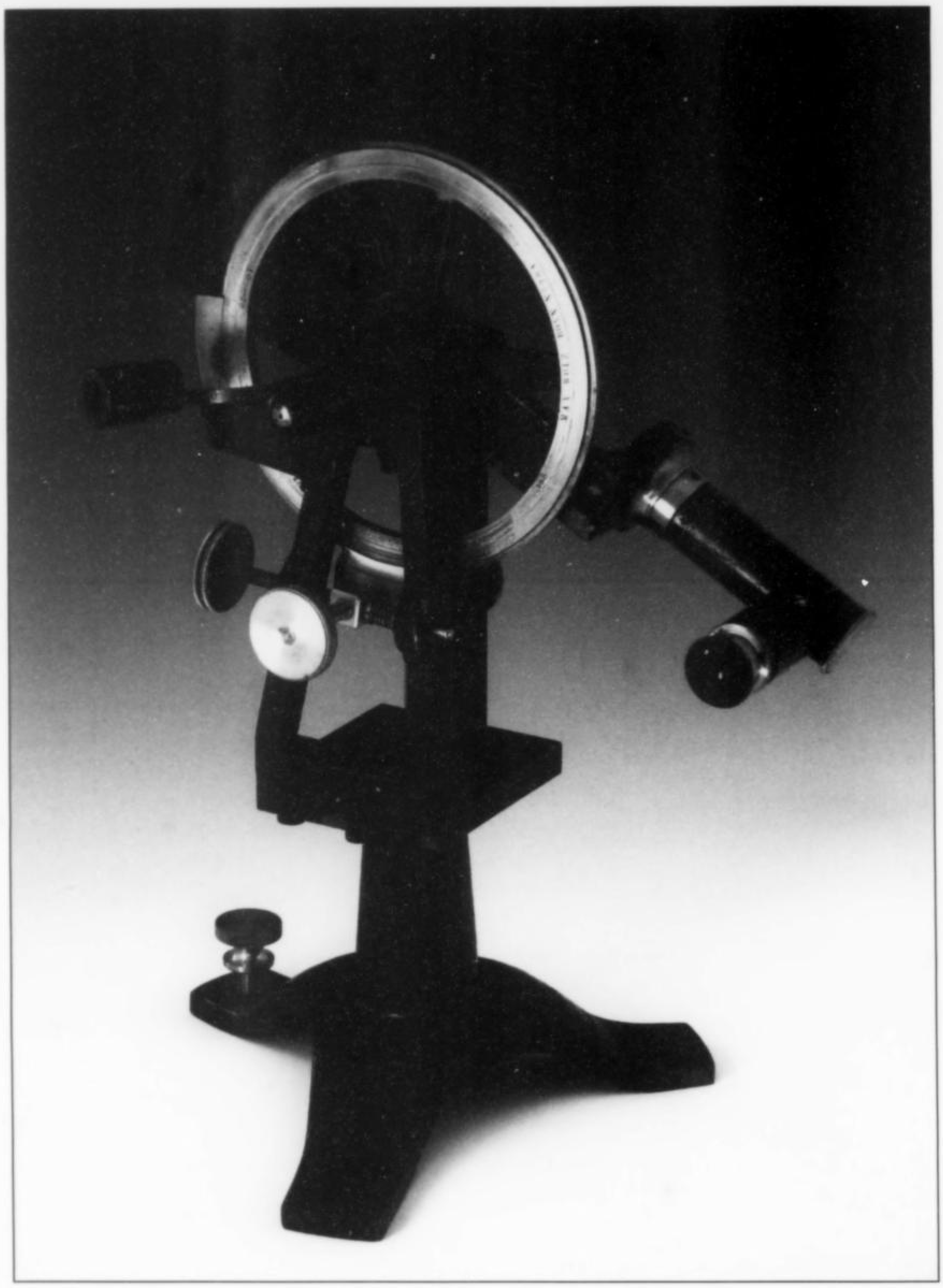


***Figure 18*. Pulfrich total reflectometer for chemists—the simplified model with a fixed glass prism rather than a rotatable cylinder. Manufactured by Wolz, Bonn/Germany, ca. 1890.**

this cylinder has a frosted bevel on its circumference and a plane-polished center. The refractive index of the glass was 1.7151, and thus sufficient for the measurement of most mineral species.

Fig. 17 shows a cross section of the cylinder on its centering device, and the ray paths from a light source on the left to the observer's eye. μ_1 is the glass cylinder of the total reflectometer, μ is the sample (ideally also a cylinder with its polished face in contact with μ_1, but any other shape of the sample would do as well as long as a polished face is present).

The critical angle of total reflection is observed, through a telescope with crosshairs, as a sharp bright/dark boundary, and its value is read out on a large divided circle. Because of the elbow-type design of the telescope, all settings and readings can be made from the front side of the instrument.

As already mentioned above, this type of total reflectometer is useful to measure all three principal refractive indices of anisotropic crystals on just one polished face. In the advanced Pulfrich total reflectometer, the whole unit of glass cylinder and crystal can be rotated about a vertical axis by means of a large spoked wheel on the lower end of the instrument.

The "new refractometer equipped particularly for use by chemists" (1888) is—in comparison to the elaborate total reflectometer—a simplified model without a vertical rotation axis and was widely distributed in the laboratories of its day to measure the refractive index of fluids (Fig. 18). Its most important distinguishing feature is a 90° prism as a glass body onto whose horizontal face a trough for holding liquids is cemented, rather than the vertical glass cylinder of the large total reflectometer. The delicate prism is protected on both sides by glass plates, and only two polished faces—the vertical face for the exiting light beam, and the horizontal face which holds the trough—are visible. The dark cement which was used for assembling these parts makes any false reflection impossible. A mechanical axis of rotation is missing; therefore this apparatus is only of limited use for mineralogical measurements.

The first such Pulfrich instruments were fabricated by the mechanical workshop of Max Wolz of Bonn. This company was founded in 1883, and exhibited these devices as late as the World Exhibition in Paris in 1900. Wolz instruments may be recognized by their dark green lacquer, which clearly distinguishes them from the products of other manufacturers.

With Zeiss in Jena, Pulfrich further developed the "refractometer for use in chemistry" after 1890. In 1895 he described his "universal device for refractometric and spectroscopic examination." The most important new features were a Geissler tube as a monochromatic light source and an ingenious heating system; the latter enabled the testing of liquids at differing temperatures.

The Abbe Hemispherical Total Reflectometer

Ernst Abbe (1840–1905) was a mathematician, physicist, optician, entrepreneur and social reformer. He investigated the theoretical fundamentals for improving microscopes. For example, he solved the problem of distortions of color in microscope objectives and developed achromatic systems of lenses. Abbe invented many new optical instruments. From 1866 he was a friend of Carl Zeiss (1816–1888) of Jena; he joined the Zeiss firm (founded in 1846), and in 1889 he took over its proprietorship and leadership. Ernst Abbe was also well known as a socio-political reformer; he introduced many groundbreaking and exemplary reforms of welfare for the factory workers. In 1891 he signed over all his assets to a foundation that still exists today.

After 1885, when Bertrand had first devised a small reference-scale total reflectometer with a glass hemisphere (cf. Fig. 27), Abbe and his associates picked up the idea. At Zeiss's establishment in Jena a perfect instrument was developed which lent itself especially to precise measurement of indices of refraction of solids.

Siegfried Czapski (1861–1907) became Abbe's assistant in 1885; his hemisphere total reflectometer was first introduced on September 20, 1889, at the Natural Science Convention in Heidelberg. In principle its mechanical construction was the same as that of the Pulfrich-Wolz total reflectometers. However, instead of a glass cylinder, a hemisphere ($n = 1.8904$) with a diameter of 4 cm and a plane face on top was utilized. This change offered a technical and economic advantage, as a perfect hemisphere is easier to manufacture than a cylinder. By applying an optical trick, Abbe was able to decisively improve on the sharpness of the demarcation curve of total reflection. The front lens of the objective of the observation telescope is a concave lens of the same glass and of the same radius of curvature as was used for the hemisphere (Fig. 19): this compensates for inaccuracies in the image which otherwise would occur when the light rays leave through the curved surface of the hemisphere.

The mechanical construction of the Zeiss total reflectometer resembles that of the Pulfrich-Wolz instruments. The hemisphere is mounted with bearings on a complicated adjustable support resting on a small horizontal graduated circle. The larger vertical circle, with a diameter of 13.5 cm, is furnished with a locking and tangential fine-movement device. The exact value of the angle may be read with a micrometer screw. To facilitate observation, the light beam enters the telescope at an angle and, in the original model, is directed through a tube within the axis of the vertical circle. The light is reflected from a mirror and proceeds either across the plane face, or through the hemisphere from below. The telescope is arranged in the form of an elbow, and rotated by an arm about the axis of the main graduated circle; it may be positioned on either side of the hemisphere. The axes of rotation of both graduated circles intersect each other at right angles in the center of the sphere of which the hemisphere is half.

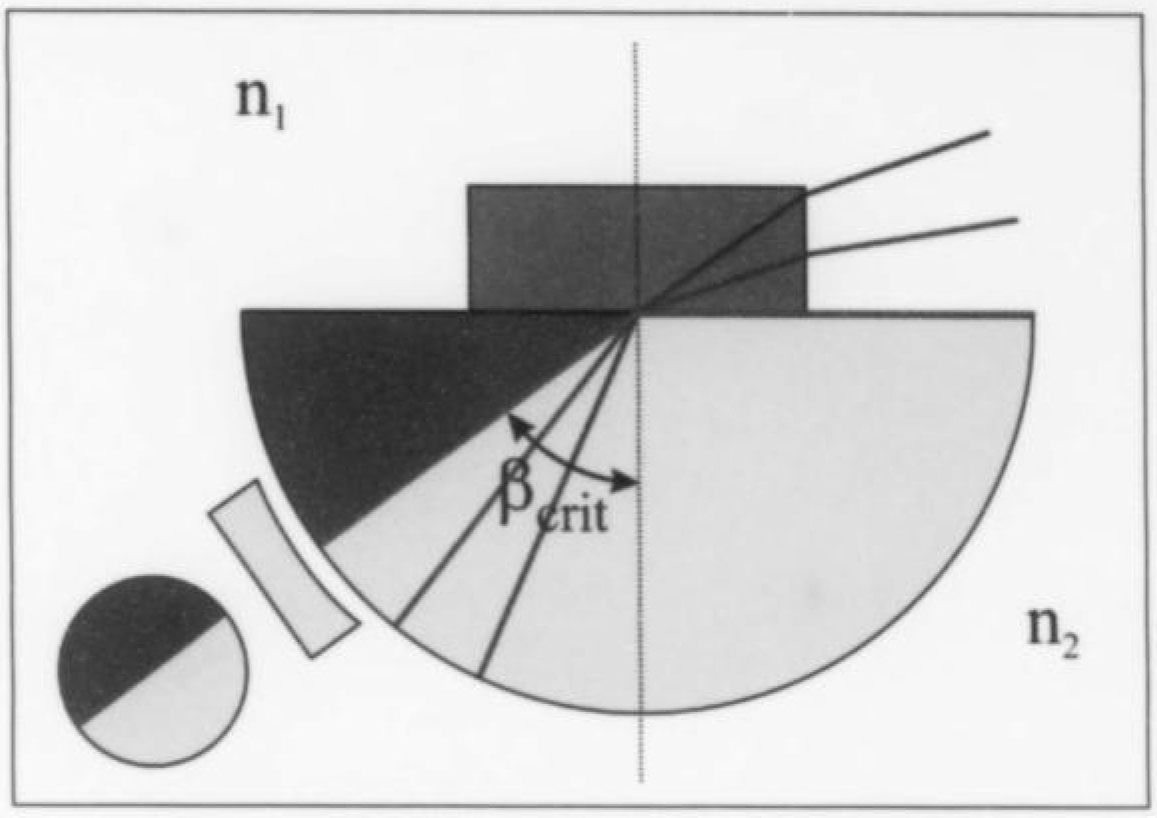


***Figure 19*. Principle of an Abbe hemispherical total reflectometer (compare Fig. 6). Note the planoconvex lens of the telescope, which considerably improved the quality of the image.**

From 1895, at the Zeiss workshop, Pulfrich perfected the Abbe hemispherical total reflectometer. He gave full consideration to making the instrument employable for the smallest crystal faces. He introduced the instrument—which in this highly developed form would find wide application—on September 22, 1897, at the Natural Science Convention in Braunschweig, and in 1899 he published a paper about it. The most important improvement was the introduction of a darkening mechanism in order to limit the illumination to the crystal face being measured. Pulfrich chose a rotatable metal plate with apertures of different diameters; alternatively, an iris-like diaphragm mounted on a carriage with perpendicular sliders would have the same effect. Additionally Pulfrich attached an additional lens in front of the eyepiece of the telescope to convert this into a low-powered microscope in which the crystal could be viewed for orientation and adjusting. Thanks to this optical trick it was now possible to measure small polished faces down to 1.33 mm.

Later Zeiss models are characterized by the fact that the axis of the telescope no longer coincides with the axis of the main vertical circle but lies on its outer edge. Most of the other mechanical and optical components were retained unchanged (see Fig. 20).

The Zeiss instrument came with a separate box for accessories; in it were two telescope oculars, providing respectively 2× and 3× magnifications, and a third objective which, in combination with one of the oculars, comprised a low-powered microscope.

While sodium light was used to illuminate small crystal plates, sunlight also could be used for larger crystals, and the refractive index for different colors of the spectrum (based on the position of well-known Fraunhofer lines), and thus the dispersion of the crystals, could be measured. Employed for this purpose was a direct vision ocular spectroscope, which also came in the accessories box.

Also made available was a small box with 10 standard reference samples (see Fig. 20) of isosceles glass prisms with different refractive indices. Viola (1899) described his "differential method" as follows: "if the refracting capacity of a mineral is measured with complete accuracy, one can choose for comparison, from among the available glass samples, one whose refractive capacity is near that of the mineral. For example, if one wants to measure the refractive capacity of albite, one chooses a glass sample whose refractive index approaches 1.52157. This sample is placed on the hemisphere of the Abbe instrument, and the telescope is adjusted to the demarcation line as produced through the glass sample. The position of the telescope is then locked to the graduated circle. Thereupon the glass

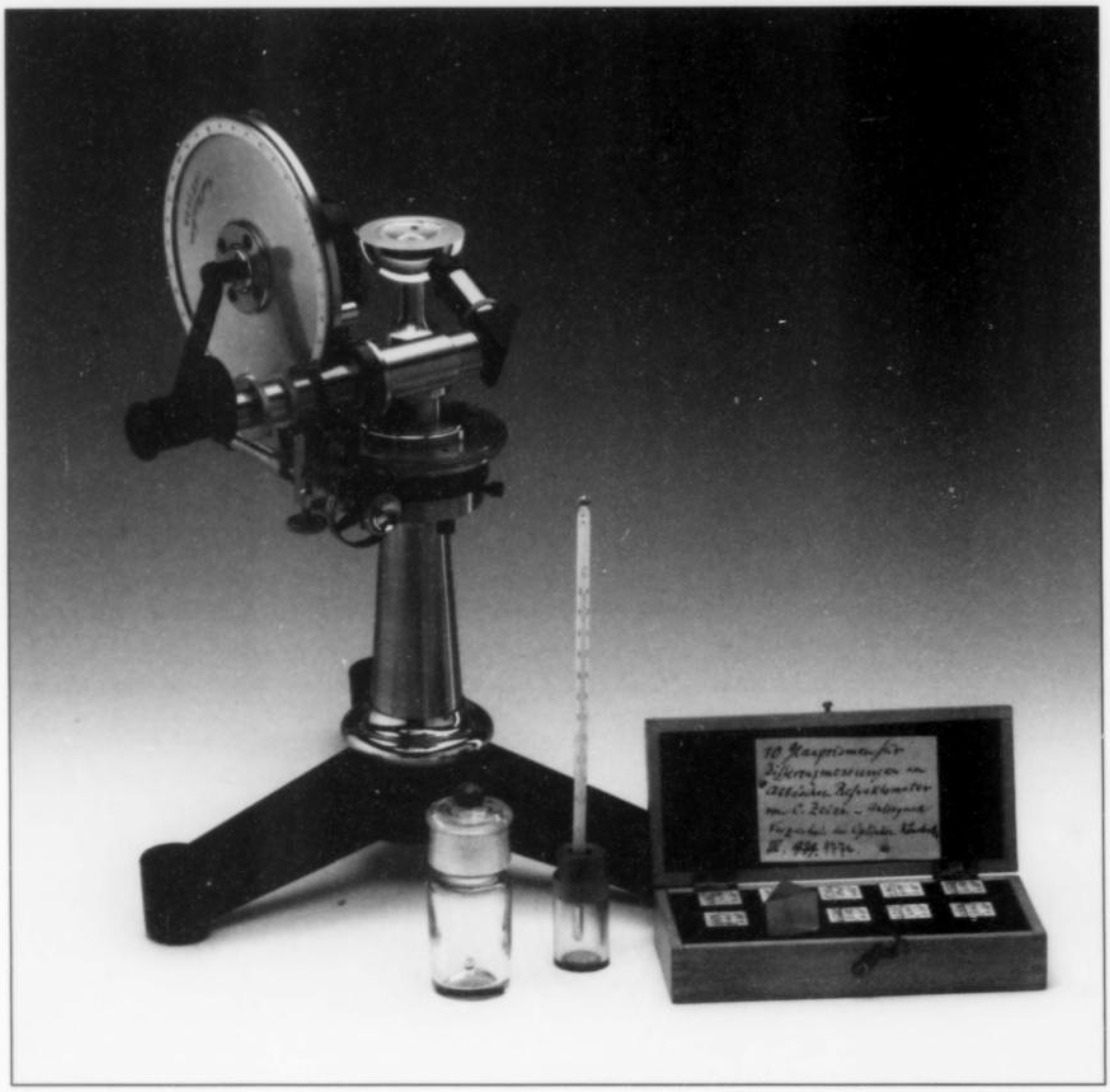


***Figure 20.* The Abbe total reflectometer, dated ca. 1900, with characteristic elbow shaped telescope with different interchangeable oculars, a rotatable hemisphere for the measurement of birefringent crystals, and a fine motion mechanism via a micrometer screw. Accessories shown are (from left) a glass container for high index contact liquid, a glass vessel with a perfectly flat bottom, a thermometer to control the temperature of fluids during measurement, and a set of standard prisms with a perfectly known index of refraction. Manufactured by Zeiss, Jena/Germany, ca. 1900. Photo Peter Kubath and Olaf Medenbach.**

sample is removed without changing anything in the apparatus, and the albite sample is put in its place. Since the telescope has not been moved, the demarcation line as produced by the albite is adjusted with the aid of the fine movement micrometer screw. In this way the angular difference (between the glass and the albite) may be read off, or rather calculated, with great precision." The main graduated circle is rendered dispensable using this method.

In 1905 the Abbe hemisphere total reflectometer, with the features described above, cost 550 Marks, including the glass samples and the carrying case. All of the instruments were signed and numbered.

The design and improvements which originated with Abbe, Czapski and Pulfrich of the Zeiss workshop were adopted by C. Leiss, the head of the contemporary firm of R. Fuess, Berlin Steglitz. After 1900 the firm of Fuess also offered a variety of hemisphere total reflectometers built almost exactly like that of Zeiss.

Total reflectometer Model I (see Fig. 21) was introduced in 1902 by C. Leiss and by C. Klein. It was mounted on a horseshoe-shaped base. One major feature distinguishing it from the Zeiss instruments is the fact that instead of interchangeable tubes for objective lenses, a hinged magnifying lens in front of the eyepiece was used, affording rapid crossover between telescopic enlargement (1.25×) and microscopic enlargement (10×).

The trailblazing innovation of the Fuess hemisphere total reflectometer lies in the fact that, if the observing tube is put into a vertical position (see Fig. 22), the instrument can be transformed into a weakly magnifying polarization microscope. To enable this the support of the hemisphere has a central bore through it. Underneath there is installed a polarizing unit and an illuminating mirror. The analyzing unit may be inserted by a slider directly into the ocular. By this means, the index of refraction of single grains in polished thin sections without cover slips may be measured: the thin section is laid on the hemisphere with its polished side downwards, a grain is selected in the "microscope position," the telescope tube is loosened, and in a "total reflectometer position" (see Fig. 21) the demarcation curve of total reflection is determined. Thus the Fuess Model 1, at a price of 500 Marks, was the perfect instrument for mineralogists!

The Fuess Model II (Fig. 38), mounted on a solid tripod base, was developed well before 1900 and was of about the same overall size as Model I. The number of optical fittings for the telescope was reduced as compared to Model I. A device to reduce light intensity, in the form of a sleeve with adjustable slits, was also a new feature. This could be inverted above the hemisphere, and its use permitted examinations of samples without the need to darken the room. The Model II cost 340 Marks.

Model III (see Fig. 23), priced at 170 Marks, was described by C. Leiss in 1908. The dimensions of the instrument, the hemisphere and the graduated circle are smaller than for the models already mentioned. The optical system is mounted on a round base plate that could be adjusted for height. This model was developed above all for demonstrational uses; refractive index can be determined only to the second decimal place.

The Wallerant Microscope Total Reflectometer

Around the turn of the 20th century, Frédéric Wallerant (1859–1936) modified the instrumental set up. The observation telescope remained in a fixed position and was no longer rotated simultaneously with the graduated circle it could be locked with. In this new arrangement the glass prism and the sample attached could be rotated around the sector of a vertical divided circle.

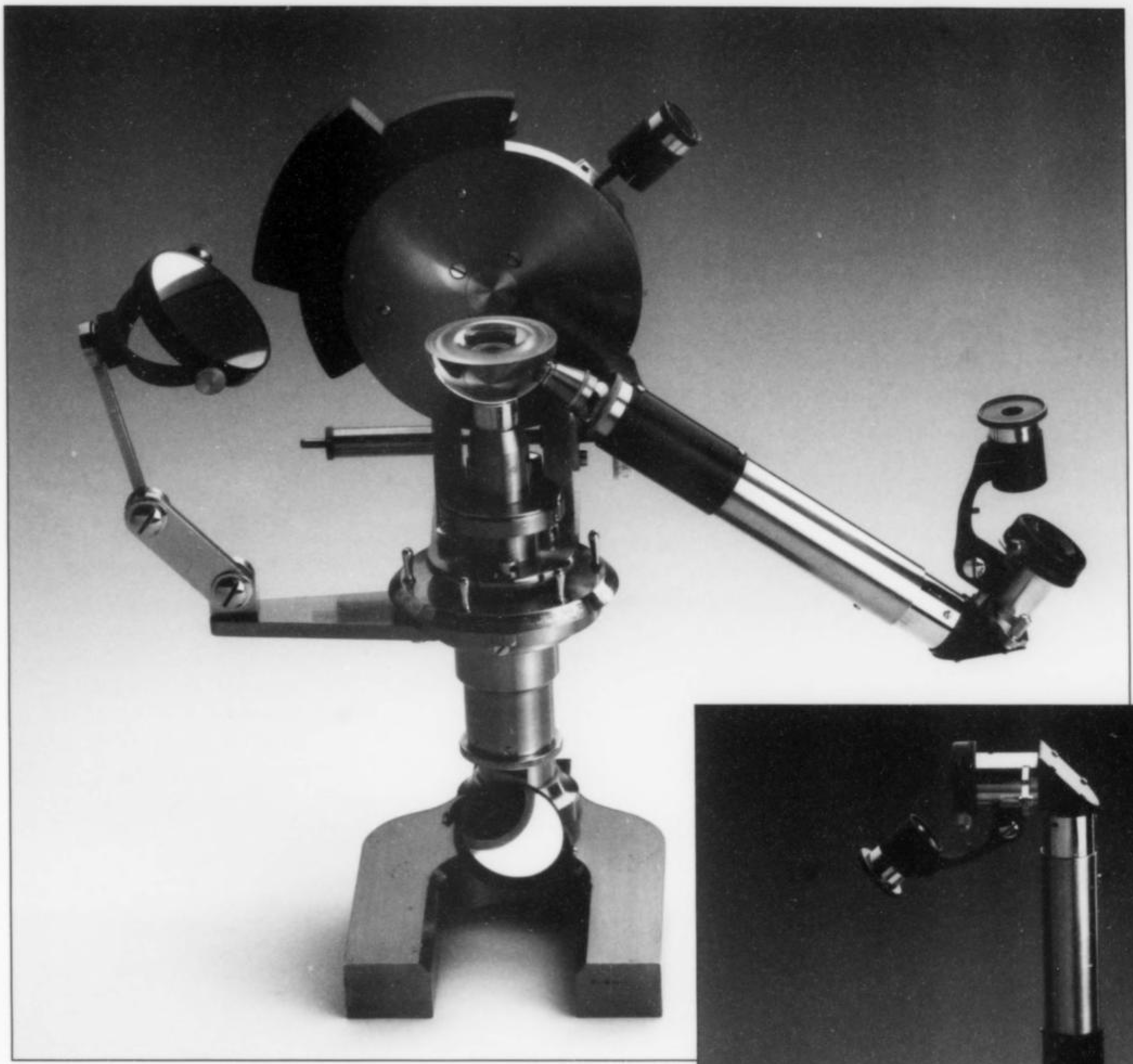
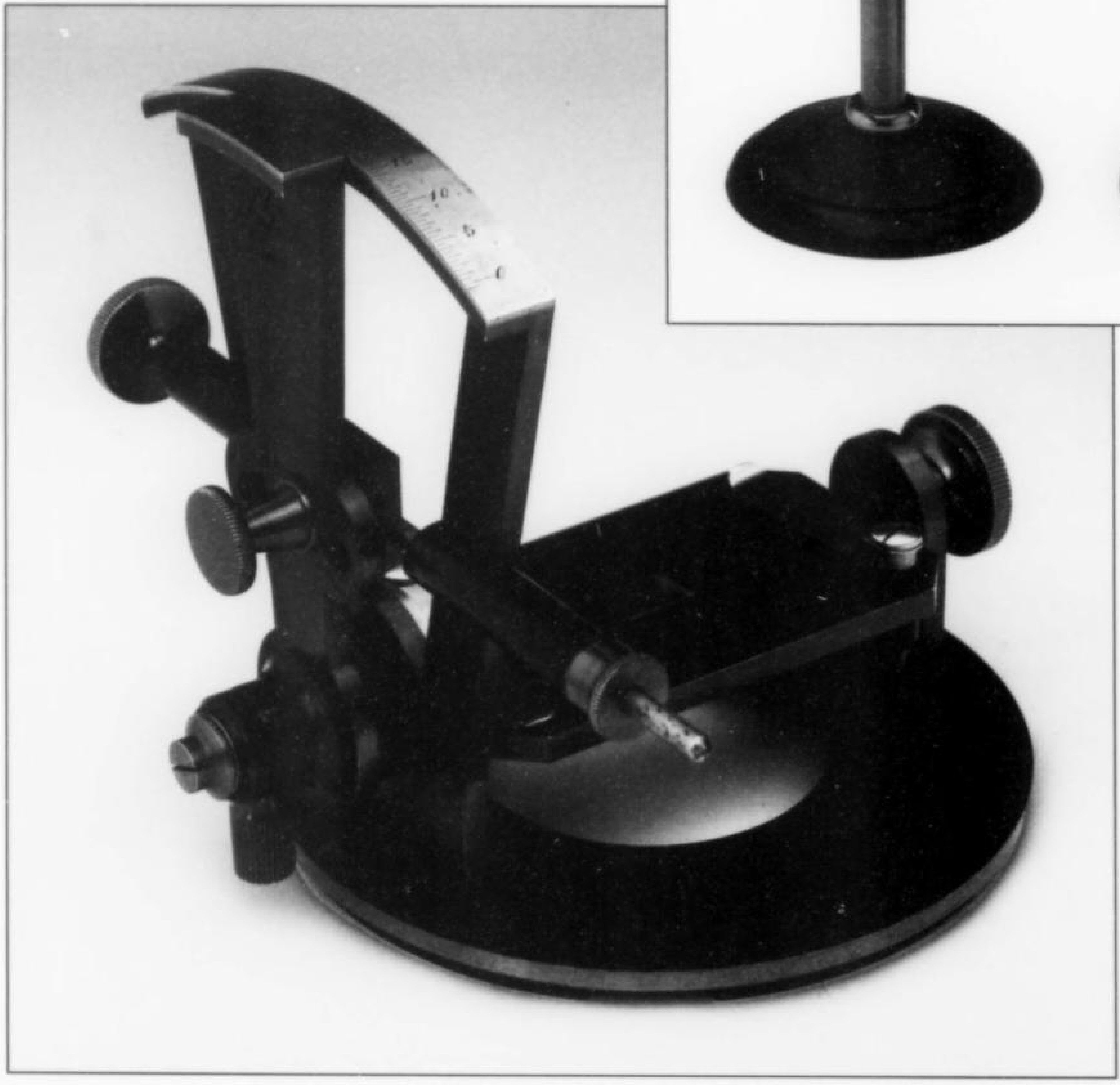


Figure 21. **The No. I total reflectometer for mineralogical use made by Fuess, Berlin/Germany, ca. 1905. In contrast to the Abbe/Zeiss design, the column of the hemisphere has a central hole for illumination from the bottom; the lower end of this tube bears a nicol polarizer. The elbow-shaped telescope houses a slider with a nicol analyzer, and a hinged lens to transform it to a low-power microscope. Photo Peter Kubath and Olaf Medenbach.**

Figure 22. **Same instrument with the telescope in a vertical position for the microscopic selection of suitable samples from polished thin sections. After these have been brought into the center of the field and isolated from the neighboring crystal using china ink, the grain could be measured when the telescope had been rotated back into the position shown in Fig. 21. Photo Peter Kubath and Olaf Medenbach.**

Figure 23. **The two downsized Fuess total reflectometers No. III (right) and IV (left), both about 1900. For details of No IV, see the section on "Hand-held total reflectometers." Manufactured by Fuess, Berlin/Germany, ca. 1900. Photo Peter Kubath and Olaf Medenbach.**

Figure 24. **Wallerant microscope total reflectometer made by Pellin in Paris, about 1890. Like the Fuess No. I total reflectometer, this instrument also allowed measurements of small crystals in polished thin sections.**



Wallerant was professor for mineralogy at the Sorbonne in Paris. His main field of research was polymorphism and liquid crystals. In 1897 Wallerant suggested a method to determine the refractive indices of minerals in thin sections by means of total reflection. He commissioned the Paris firm of Phillipe Pellin to build a microscope accessory to be fitted on the stage of a Zeiss petrographic microscope. This attachment, firmly screwed onto the stage, has a ring-shaped base plate to allow light to pass from the optical system below the stage (see Fig. 24). It could be rotated horizontally with the stage. A thin section (without coverslip but with a perfectly polished surface) is placed on the slightly truncated edge of an equilateral glass prism of high refractive index (n = 1.89). This setup could be tilted by a graduated vertical circle with a sector of 50 degrees until the critical angle appears, manifested by the boundary between a bright and a dark field. Klein in 1902 augmented the Wallerant device by improving the optical system of the microscope, mainly the centerable iris diaphragm which was essential to focus on a small area of the thin section.

Figure 25. **Wallerant-type total reflectometer with glass hemisphere. Please compare with Bertrand's hand held total reflectometer in figures 26 and 27. French, ca. 1890.**

In 1902 Wallerant published details concerning another new total reflectometer, probably built by Pellin in Paris. Its turning apparatus was very similar to the one above. However, it was an autonomous instrument by itself with an observation telescope fixed rigidly at an inclination of 45 degrees. Its glass prism had a very peculiar shape—on the outside it was bounded by eight isosceles triangles with an acute angle of 45 degrees. All of these are inclined towards the ninth face—the base—at 60 degrees, thus forming an eight-cornered pyramid. The prism is attached to a vertical graduated sector. It also could be rotated horizontally analogous to the movement of the stage in the model described above. The advantage of this oddly shaped prism is the fact that the refractive indices of the crystal could be determined successively through two opposing prism faces. This minimized errors resulting from non-parallelism of crystal and basal prism planes. It would appear that these microscope total reflectometers were not widely distributed. A comparable instrument incorporating a glass hemisphere (see Fig. 25) originates from the same period.

All these ideas and proposals of Wallerant and Klein influenced the construction of the Model I hemispherical total reflectometer of Fuess. The optical system suggested by both authors was fully maintained.

Hand-held Reference Scale Total Reflectometers

The small reference scale total reflectometer lends itself chiefly for quick approximate determinations of refractive indices in various fields of application. The hand-held instruments are very compact. There are no mechanical rotational parts, as a graduated reference scale within the field of vision permits direct read-off to the second decimal. This type of instrument is frequently used in the gemstone trade and for instructional purposes. The invention is owed to Emile Bertrand (1844–1909) who published an article in 1885, unfortunately without a diagram or any mention of the maker. Bertrand, who described a great number of new mineral species, was called in an obituary by Wyroubuff (1910) "un veritable genie de l'appraeil" (a true genius of apparatus). Bertrand became immortalized by his invention of the lens inserted between the ocular and the objective into the tube of a petrographic microscope for the conoscopic investigation of interference figures of crystals.

The Bertrand total reflectometer (Fig. 26) consists of a brass tube R, 5 cm in length and 2.5 cm in diameter. Within, there were two additional short sliding tubes for focussing. The innermost one was fitted with a magnifying lens L on its outer side. The central tube had at its inner end a scale S divided into tenths of a millimeter. The main outer tube is slanted at an angle of 30 degrees at the side opposite the lens. There it is covered by a metal plate holding a glass hemisphere H of high refractive index of about 1.8 with a diameter of 1 cm. The plane of the cover plate coincides with that of the hemisphere. Light is admitted by a small section of frosted glass G arranged on top of the hemisphere, thus illuminating its plane surface and any test sample placed on it. The reference scale has to be calibrated with substances of known refractive indices before the instrument can be used. The only instrument of this type known to the authors was built by Wehrlein of Paris (Fig. 27).

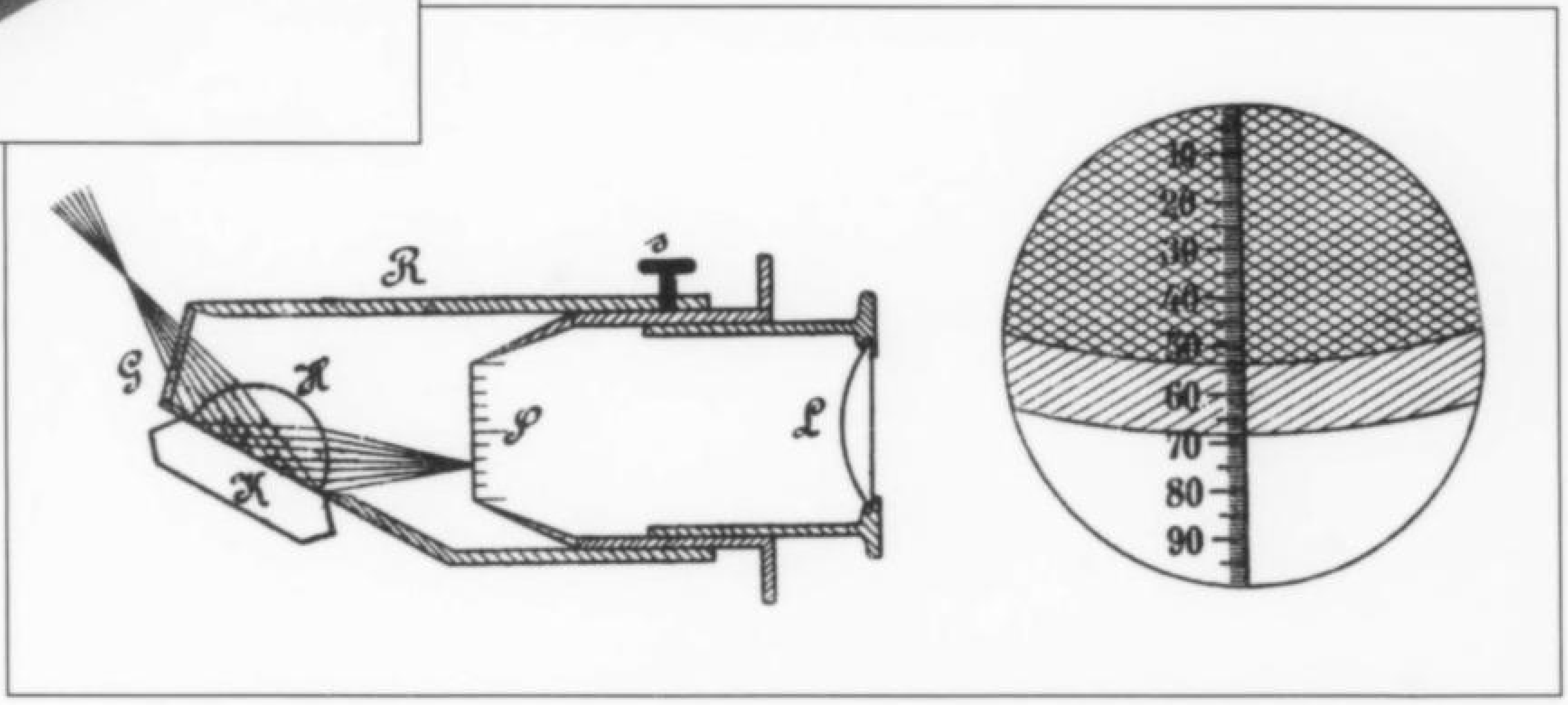


Figure 26. **Schematic drawing of the small hand-held Bertrand total reflectometer. These instruments are equipped with a fixed scale that was divided either in millimeters (which requires calibration with standard crystals), or directly in units of index of refraction. On the right side, the critical angles for a birefringent crystal are shown. From Rosenbusch and Wülfing, 1921.**

It is interesting to note that these small total reflectometers, equipped with a prism rather than a hemisphere, are manufactured

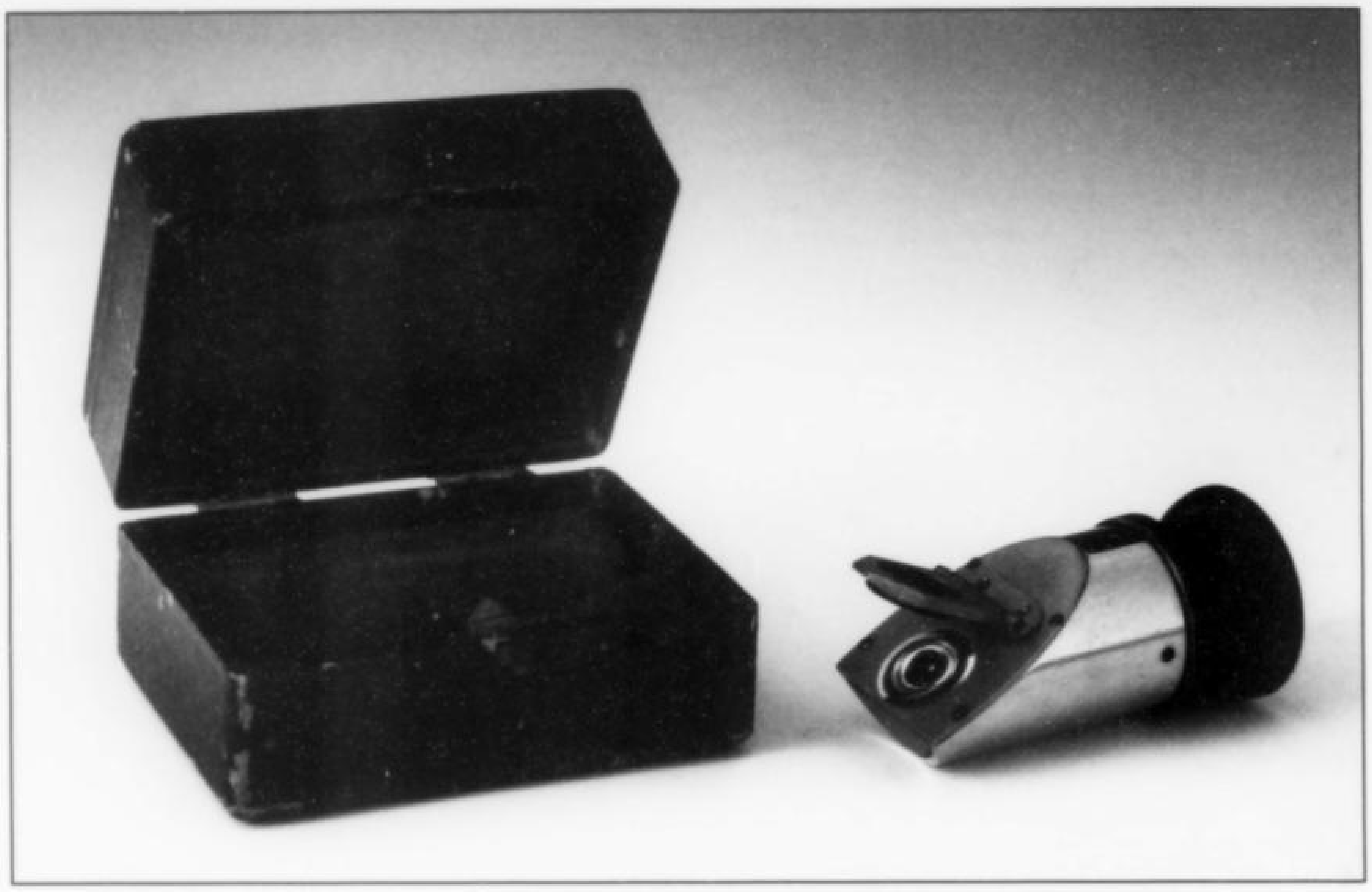


Figure 27. **Bertrand hand-held total reflectometer made by Wehrlein in Paris, about 1900.**

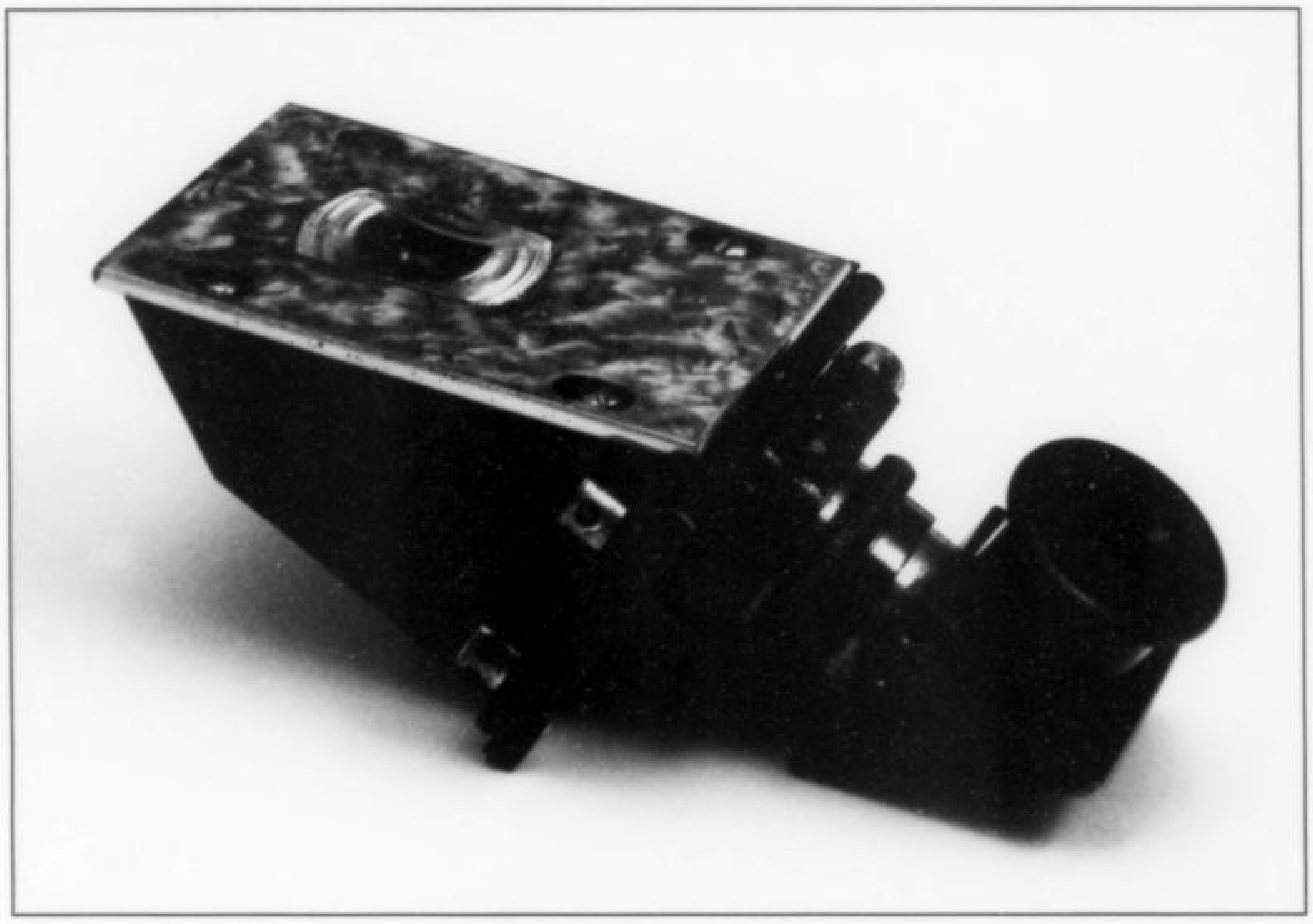


Figure 28. **The Herbert Smith total reflectometer for the determination of gemstones. The elbow-shaped telescope, designed for convenient use, is distinctive. This total reflectometer is the precursor of the modern small gemstone total reflectometers and other total reflectometers that are frequently used for technical measurements. Made by Steward, London, ca. 1900.**

today in quantity. These low-priced instruments with specially calibrated scales are employed in a great variety of applications. For instance, the concentration of sugar in wine grapes, anti-freeze detergent in automobile radiators or in solar panels or of serum protein in urine may be determined quickly and conveniently.

The gemstone expert of the British Museum of Natural History in London, G. F. Herbert Smith (1872–1953), improved and amended the Bertrand instrument maintaining its dominating features. A corrective convex glass lens was arranged in proximity to the hemisphere compensating for the spherical curvature of the focal plane and effecting a sharp demarcation line between the bright and dark field. For convenient viewing the setting of the read out lens was bent at a 90-degree angle (see Fig. 28). The firm of J. H. Steward produced two similar models of the Herbert Smith pocket total reflectometer. The larger one, in its wooden case and a printed reference card listing the refractive indices of the major gemstones, was priced at 9 Pounds 10 Shillings, or 130 Marks.

In 1904 C. Leiss introduced the Model IV total reflectometer of the Fuess, Berlin firm (see Fig. 23). The hemisphere (n = 1.7938) was rotatable around its vertical axis for the examination of doubly refractive crystals. It was in a metal casing for protection. For testing in reflected light, the casing was furnished with a narrow slit that could be shut for experiments with "grazing" light. The Model IV, priced at 90 Marks, was detachable and came with both a wooden handle and a base plate and column.

B. Total Reflectometers with Liquids

The principle of all immersion total reflectometers is identical with that of total reflectometers with glass prisms or hemispheres in that total reflection appears on the boundary between different optical media. In the immersion total reflectometers, the crystal with a polished face or a perfect natural growth face is immersed in a fluid with higher index of refraction, and the critical angle is likewise defined as a line of demarcation between a brightly and a feebly illuminated field. In order to increase accuracy of the measurement, these instruments allow the determination of this line twice, once by tilting the telescope to the right and once by tilting it to the left. Half the angle between the two settings equals the required angle and the refractive index may be calculated accordingly. Also, in case of doubly refractive crystals, there are two demarcations to be distinguished as fields of differing grades of shadings.

Kohlrausch Total Reflectometer

The renowned experimental physicist Friedrich Kohlrausch (1840–1910) conducted research in electrical conductivity, among other fields. In 1878 he published the results obtained with his new instrument, which he called a total reflectometer. The original instrument was built in the university town of Göttingen by the mechanic Wilhelm Apel (?–1898). It was suitable only for observations in a darkened room.

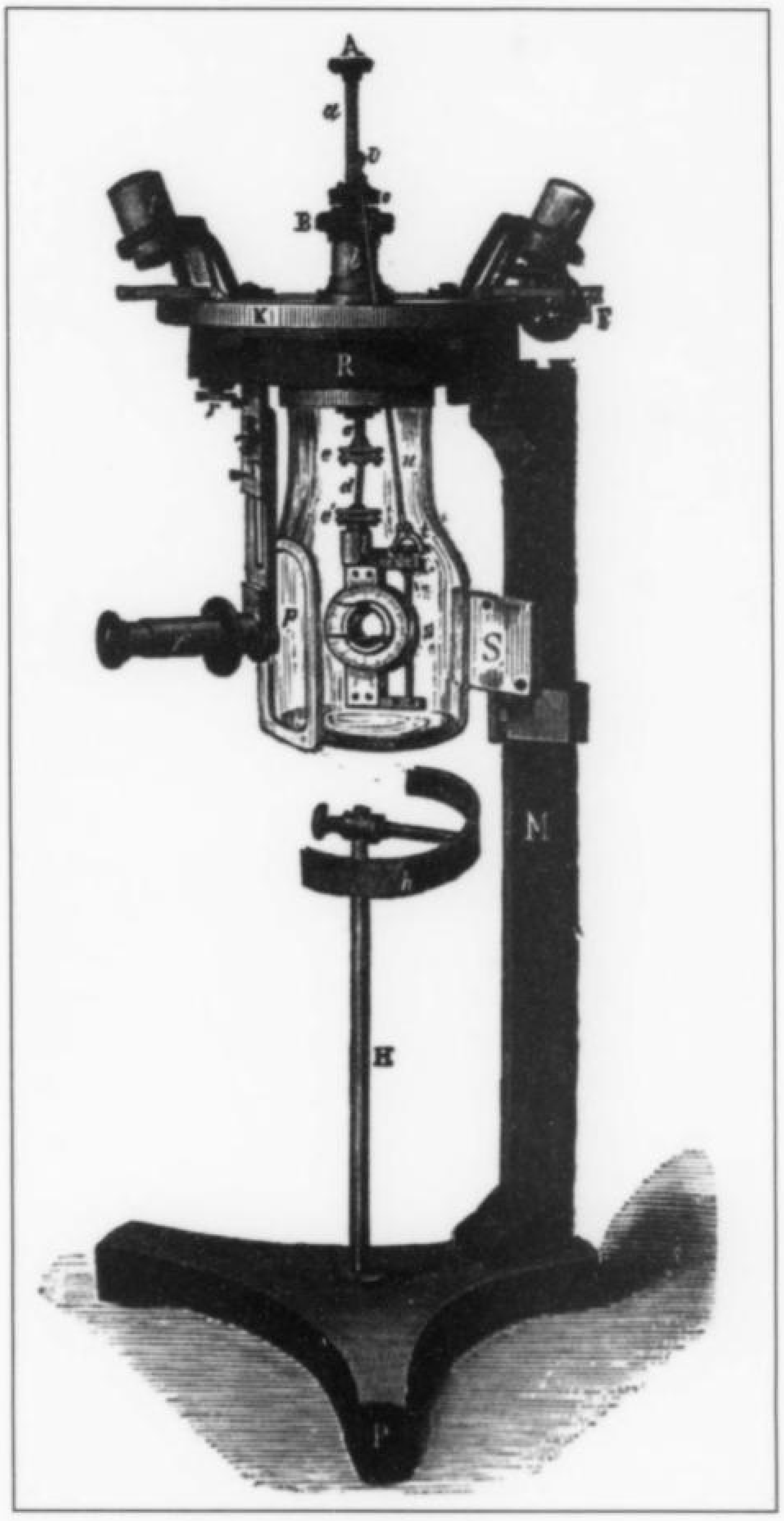


***Figure 29.* Contemporaneous steel engraving of a Kohlrausch total reflectometer made by Apel in Göttingen/Germany. This instrument is characterized by its pear-shaped glass vessel and a highly sophisticated crystal holder. From Tutton, 1911.**

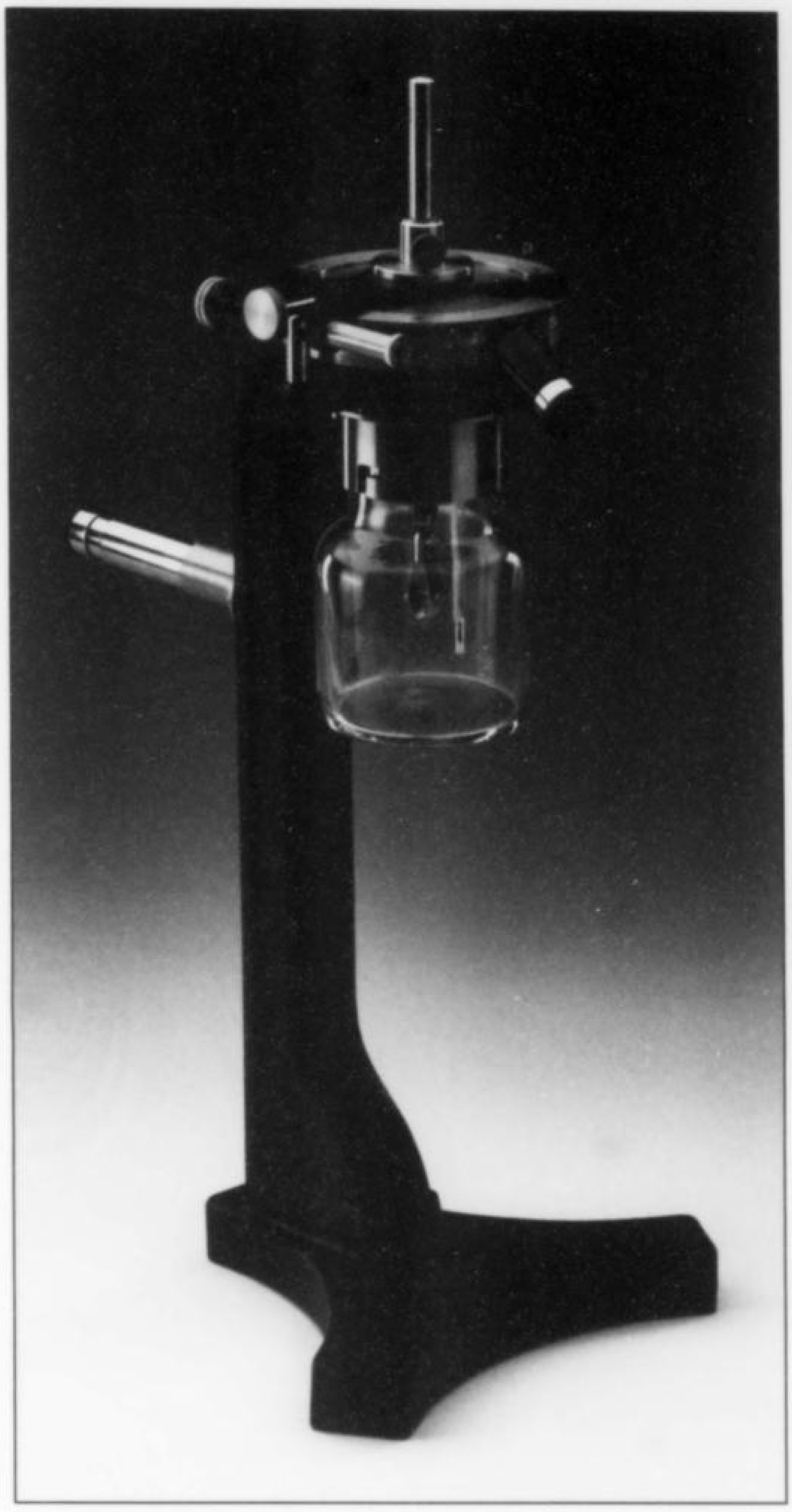


***Figure 30.* Simplified Kohlrausch total reflectometer as distributed by Fuess in Berlin, Germany ca. 1900. Photo Peter Kubath and Olaf Medenbach.**

The Kohlrausch total reflectometer (Fig. 29) is mounted on a heavy base plate supporting a triangular column approximately 30 cm in height. At its upper end it carries a divided circle (10 cm diameter) including two verniers and read out lenses. On its underside there is a detachable pear-shaped glass flask with a flat bottom to house the liquid. This vessel has a plane-polished window where it faces the observation telescope. The crystal with its polished face is mounted on a cork plate which is suspended on a holder into the flask. The latter rests on a very complicated adjusting apparatus allowing recordable three-dimensional manipulations from outside the glass cell. A clamping screw can lock the axis of the graduated circle and the crystal holder for either independent or simultaneous rotation. The observation telescope is arranged horizontally either on an outside slide or, in later models, in a collar of the main column as in the device shown in figure 30. The axis of the telescope is perpendicular to the axis of the divided circle. In order to view and to facilitate adjustment of the polished crystal face, the telescope may be converted into a low-powered microscope by simply replacing lenses. A simple sketch (Fig. 31) was provided by Tutton (1911) illustrating the Kohlrausch principle in a horizontal section. Diffuse light enters from one side (s) onto the crystal (c). It is reflected and observed by the telescope (T) through the window (P) of the flask (F) filled with liquid (L).

Wilhelm Apel in Göttingen offered the original Kohlrausch total reflectometer with articulated adjusting device for 160 Marks; the company also provided abundant accessories for this instrument. In 1891 the firm of Georg Barthels, also from Göttingen, asked between 100 and 150 Marks "depending on size and accessories." A slightly

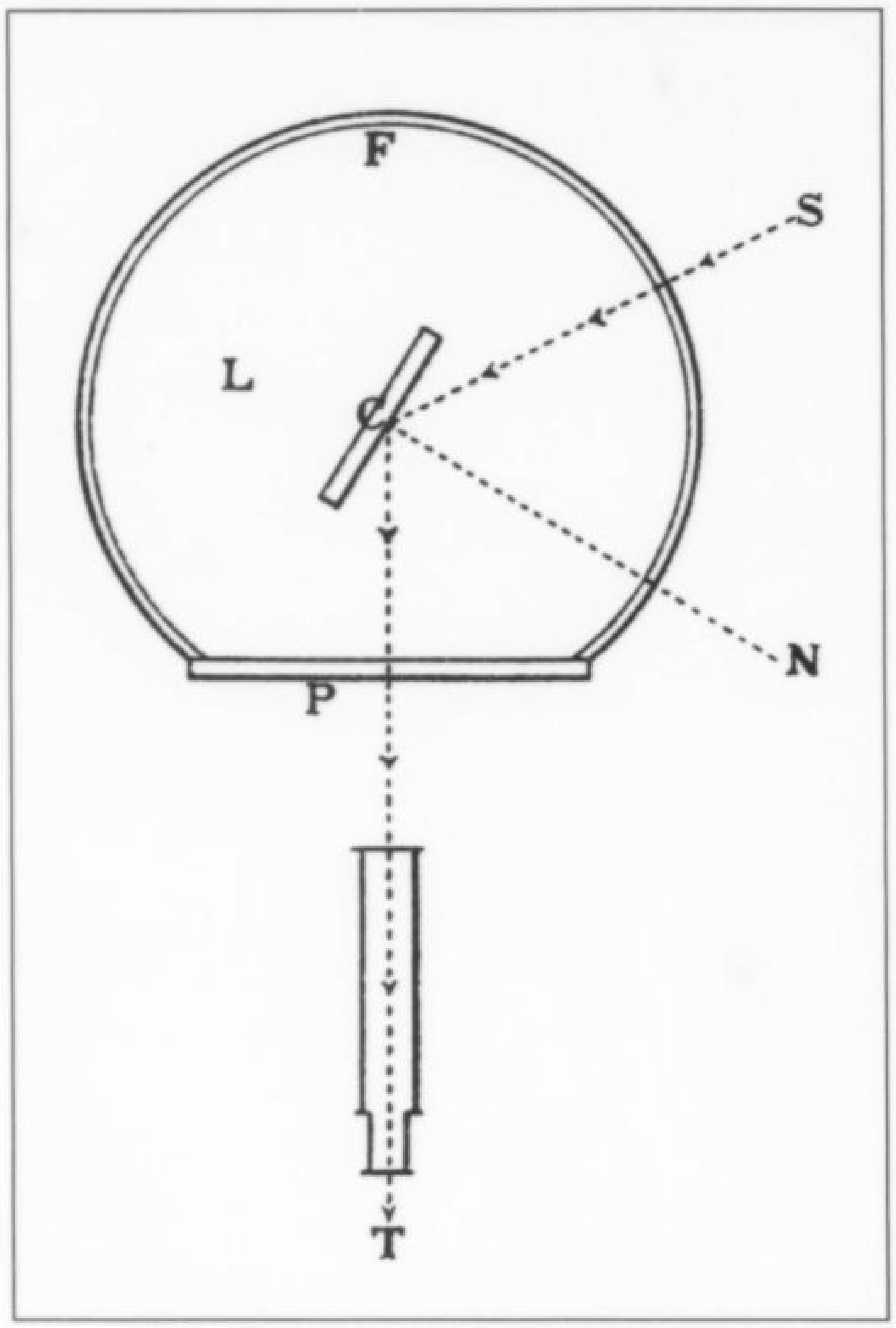


***Figure 31*. Schematic sketch of a horizontal section through a Kohlrausch total reflectometer. C is the crystal, F the glass vessel, P the plane-parallel window, and T the telescope. The vessel is filled with a highly refractive liquid. The diffuse monochromatic incident light propagates from S and is reflected at C, and the critical angle is observed through T. From Tutton, 1911.**

modified version, lacking the sophisticated adjustment device, was offered by Fuess, Berlin in 1909 for 175 Marks (Fig. 30).

Suspended Goniometers used as Total Reflectometers

It was M. Bauer of Königsberg (Kaliningrad) who first recognized (1881) that optic axis angle goniometers originally devised by Des Cloizeaux (1817–1897) and improved in 1871 by Groth (1843–1927) were suitable also for the Kohlrausch method. These instruments include a horizontal graduated circle with a centering and adjusting crystal holder suspended below instead of being positioned above (Fig. 33). The other prerequisite for Kohlrausch studies is a parallel-sided glass trough to be filled with a liquid with a high refractive index into which the sample is immersed. This cell is supported by a rectangular small table adjustable for height. The axial angle goniometer also comprises an observation telescope modifiable for a diminishing image. Bauer summarized all the necessary conversions from a goniometer to a total reflectometer.

During the first two decades of the 20th century these inverse axial angle apparatuses were improved, supplemented and equipped with additional innovations including small heating units. The resulting "universal mineralogical instruments" could be conveniently used as goniometers, for instance for the study of growing crystals in solutions, and for studies in polarized light as well as in reflectometry.

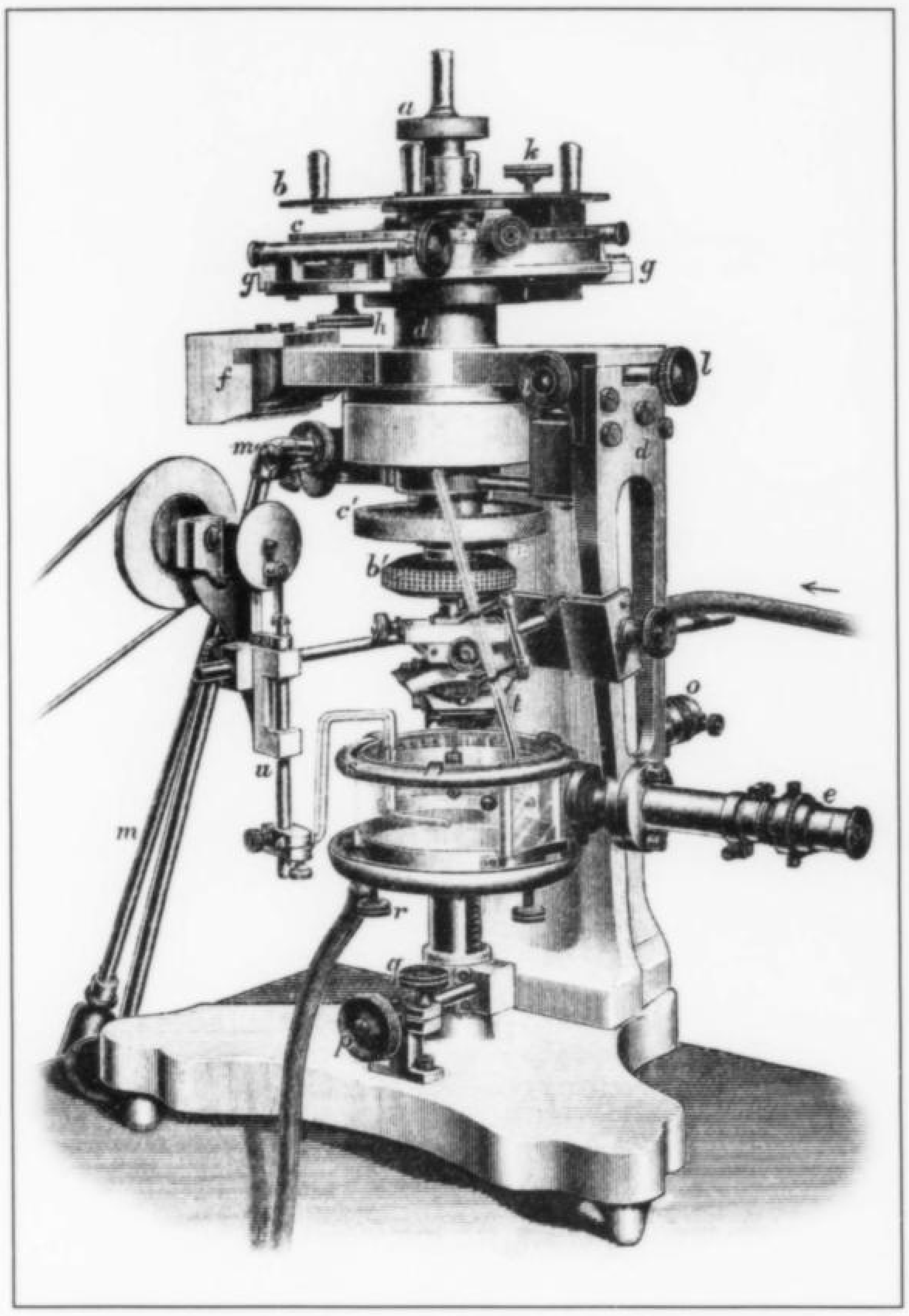


***Figure 32*. Highly sophisticated Suspended Goniometer-Total-Reflectometer designed by Miers (Troughton & Simms, London, ca. 1900). This instrument allows measurements at different temperatures thanks to an elaborate liquid closed loop that controls the temperature of the immersion cell and crystal. From Tutton, 1911.**

In 1899 Leiss published a description of an "improved total reflectometer" built by the famous firm of Fuess, Berlin and priced at 430 Marks. In this context the "crystal polymeter," also built by Fuess and priced at 2250 Marks, should be mentioned (see Fig. 90 of Burchard 1998). This three-circle goniometer—the largest ever constructed—likewise had a suspended crystal holder and was suitable for Kohlrausch studies. Fairly similar inverse universal apparatus were devised by Henry A. Miers (1858–1942) and were built by the London firm of Troughton & Simms. The model of 1904 still had two supporting columns for the optical system, thus limiting the effective operational arc of traverse of the observation telescope. The 1910 (?) model took care of this problem by employing only one broad column (see Fig. 32). Miers took great care to control the temperature of the liquid, demonstrated by elaborate regulation devices. A stream of water flowing through a perforated metal ring pipe at the edge of the cylindrical glass trough, and a stirring arrangement inside the trough driven by an electrical motor guaranteed temperature constancy, which is monitored by a thermometer. A "universal goniometer" by A. Hutchison (1913) and also built by Troughton & Simms, London, costing 30 Pounds, was very similar to the one of Miers. For both the Fuess and the Troughton & Simms

Figure 33. **Suspended goniometers are usually designed for the measurement of optic axial angles of crystals, but they are also suitable as Kohlrausch total reflectometers. The crystal is hanging on the adjustable goniometer head and is set into a trough with plane-parallel sides which is filled with a highly refractive immersion liquid. The divided horizontal circle enables the precise measurement of the critical angle. Shown is a No. I Optic Axial-Angle Goniometer made by Fuess in Berlin, Germany, ca. 1880. Photo Peter Kubath and Olaf Medenbach.**

suspended goniometers, a direct-vision spectroscope could be fitted to employ the method of Soret (see later heading).

Supplementary Glass Vessels for Fuess Goniometers

Most Kohlrausch total reflectometers were rather expensive, and it is not surprising that for economic reasons several supplementary devices were developed by Fuess, Berlin. All of these were suitable for use on goniometer Models 1 to 3 by Fuess. Especially the standard Models 2 and 2a were omnipresent at most mineralogical institutions of that time. The cylindrical glass vessels with appropriate crystal holders were designed to be filled with highly refractive liquids like monobromonaphthalene or methylene iodide. In 1896 two Munich mineralogists, A. J. Moses and E. Weinschenk (1865–1921), commissioned a three-part accessory from the local firm of Böhm & Wiedemann, priced at 25 Marks. The glass vessel was connected to the tube of the observation telescope by means of a rigid arm. The complexly constructed crystal holder replaced the small button that usually rests on top of the goniometer head and permitted unlimited manipulations of the crystal. Following the suggestions of Soret (see next heading) there was a second crystal holder nearby where a reference sample (fluorite) could be attached. A cylindrical cardboard casing could be inverted from above. It was covered by asbestos, and openings were cut in where adjoining the

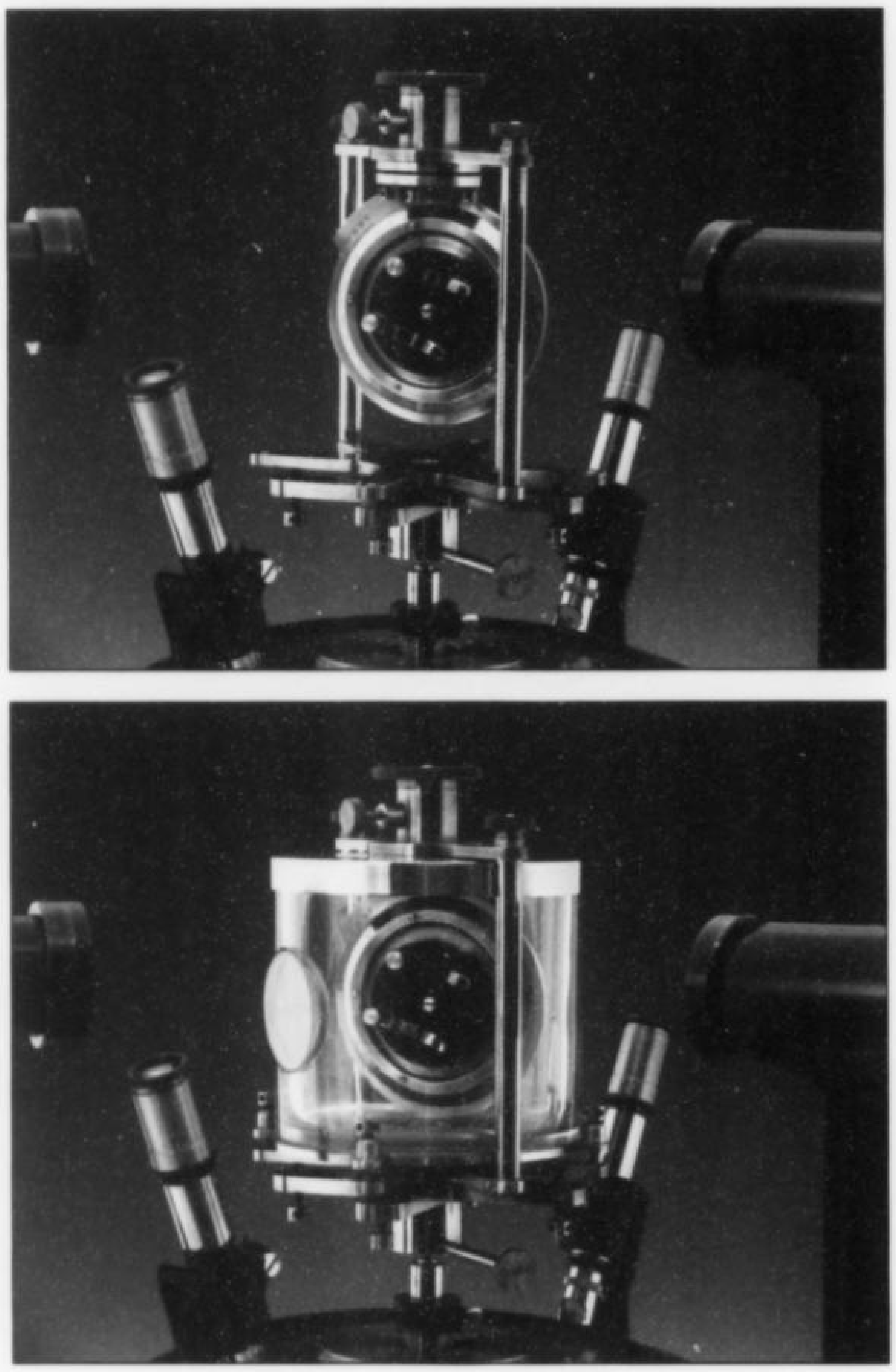


Figure 34. **Kohlrausch device designed as an accessory to the large No. I goniometer by Fuess, Berlin, Germany, ca. 1920. As with the suspended goniometer shown in figure 32, the measurement is achieved by the horizontal circle of the goniometer. The crystal is mounted on a metal plate that can be rotated from the exterior for the measurement of birefringent crystals.**

collimator and telescope lenses. This casing functioned as an air-bath and served as an insulator against temperature fluctuations.

A similar arrangement was proposed in 1908 by the Portuguese mineralogist V. Souza Brandão and was marketed by Fuess, Berlin for 90 Marks. It consisted of two parts: the simple C-shaped crystal holder was connected directly onto the top of the goniometer head. The arm for the glass cell was attached to the telescope tube by numerous articulations. It could be pushed aside but the original position with respect to the axis of the telescope was easily reproduced. There was no casing for temperature constancy present.

In 1898 Carl Klein (1842–1907) published a photograph of an "observation instrument following the Kohlrausch principle." Carl Klein gained recognition as a crystallographer at several German universities and was an inventor of a great many crystal rotating devices mainly to be employed with petrographic microscopes. Klein stated that C. Leiss of Fuess, Berlin looked after the construction of the 1898 instrument with "patience and devotion." This instrument remains somewhat enigmatic as there was no graduated circle, and it cannot be found in any of the Fuess catalogues; possibly it was one of a kind. A rectangular base plate supported two columns. One supported a rigidly mounted horizontal observation telescope. The other carried a cylindrical glass vessel with an inverted two-circle Klein rotating device that permitted rotation and recording of both the vertical and horizontal axis of the crystal holder.

In the final pages of his monumental book "Physikalische Krystallographie" (1905) Groth catalogued listings of mineralogical instruments by various German manufacturers. Included in this listing, under the heading of Fuess, is a "large total reflectometer suitable for goniometer No. I" priced at 270 Marks. This entry is somewhat puzzling since usually Groth described almost all instruments in his text, and there is no reference in any of the Fuess catalogues. However, there exists one "goniometer supplementary glass vessel" to be attached directly onto the goniometer head by means of two screws. It dates circa 1920 as is indicated by the nickel-plated parts (see Fig. 34). The cylindrical glass flask has a diameter of 10 cm and is adaptable exclusively to the large No. I Model goniometer. A rotational crystal holder may be suspended from above. Only the rotation within the plane of the crystal holder can be recorded. The critical angle corresponding to the total reflection is determined with great accuracy using the divided circle of the No. I goniometer. In front of the collimator tube of the goniometer a small monochromator may be inserted, enabling measurements of dispersion.

The Total Reflectometer of Soret

Measurements with Kohlrausch total reflectometers are hampered by some intrinsic disadvantages. For one, the refractive index is influenced by the temperature of the surrounding fluid. Secondly, measurements of dispersion require monochromatic light and thus different light sources (e.g. Geissler tubes). In order to overcome these shortcomings Charles Soret (1834–1904) of Geneva conceived an advanced instrument in 1883. This fairly complex apparatus (see Fig. 35) was built by the famous company SIP—Societé Genevoise pour la construction d'instruments de physique et de mécanique—headed by its then-director Théodore Turrettini (1845–1916).

Tutton (1911) provides an extensive description and illustrations of this highly sophisticated instrument. A cylindrical glass vessel housing the highly refractive liquid rests on a horizontal plate supported by a base. This liquid cell bears a perfectly plane glass window (b) where it faces the collimator (a). The rays of sunlight are directed onto the instrument by means of a heliostat. They are condensed by the collimator slit, pass through the window and are reflected by the immersed polished crystal plane surface. After reflection the light rays pass out of the vessel and may be observed by a horizontal direct-vision spectroscope. The frame of this spectroscope may be rotated freely around the glass cell. As the limit of total reflection is approached, the otherwise brilliant intensity of the spectrum is drastically diminished and a dark curtain traversing from red to violet may be observed in the spectroscope. The sharp edge of this curtain is influenced by the smoothness of the polished plate of the reflecting sample. The mechanical arrangement of the Soret apparatus is very complex and its description is limited to the essentials. The glass cylinder is closed on its top by a horizontal graduated circle (f). Within its central chamber it carries two concentric vertical axes. The inner axis (h) may be raised or lowered manually. At its lower end there are two crystal holders (d), one for the test sample and one for a perfectly known reference sample (e.g. a glass prism with known refractive index), with both of their polished faces adjusted parallel to the axis. To minimize errors caused by temperature changes, the Soret instrument facilitates readings in rapid succession of both the test sample and the glass prism. The outer axis can be manipulated by a milled head (g) and it is rigidly connected to a horizontal vernier (h) to read out degrees on the graduated circle. There is also a connection

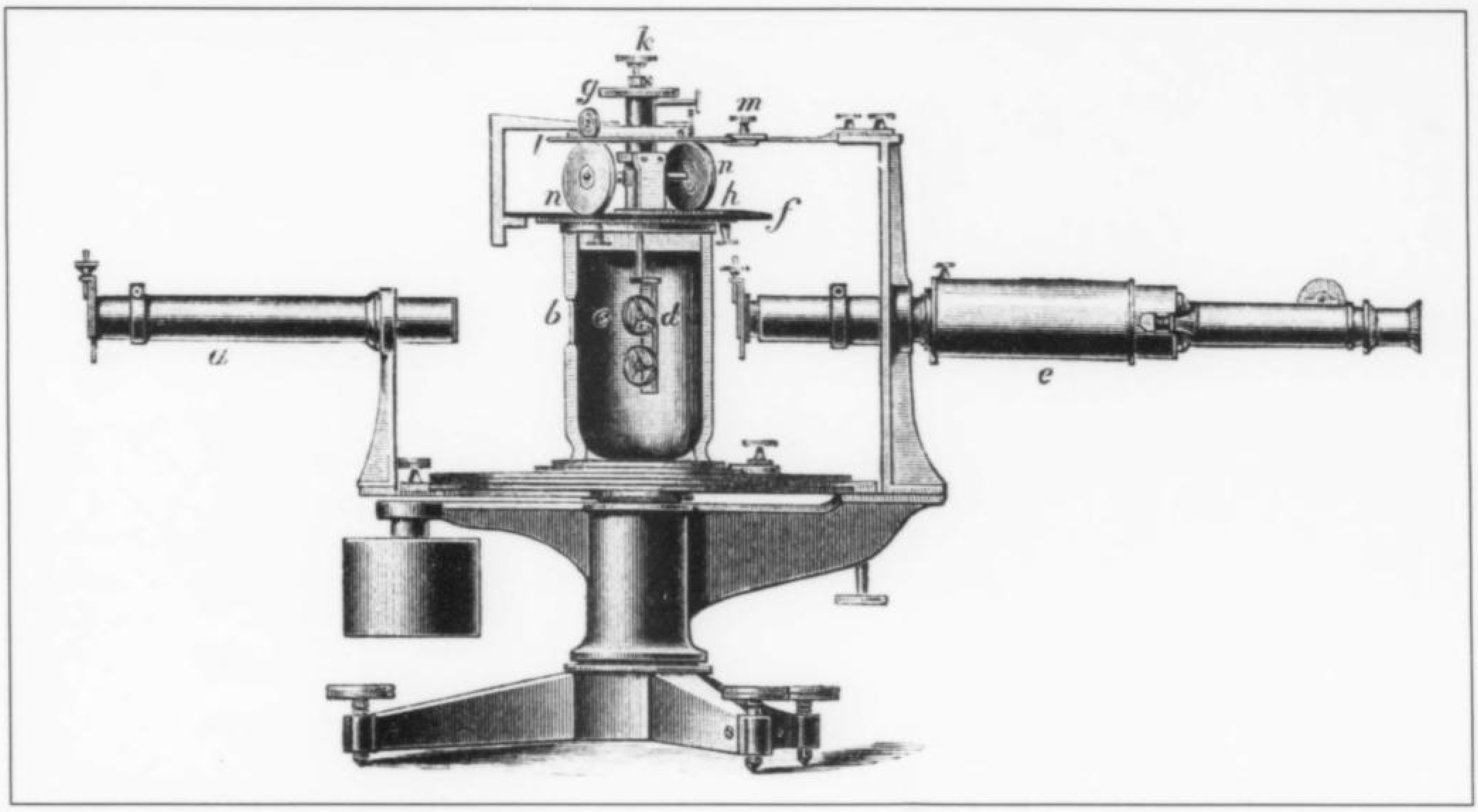


Figure 35. **The Soret total reflectometer enabled very precise measurements even of the dispersion of a crystal due to the fact that a glass prism with perfectly known optical data is placed adjacent to the sample in the same trough. Sample and glass prism are measured consecutively. Thus the glass prism serves as an internal standard. From Tutton, 1911.**

(m) with the pillar of the observation spectroscope. As the latter is rotated around the glass vessel it carries with it another horizontal plate (l) which presses on two small vertical wheels (n) revolving at exactly a half-radius of the graduated circle (f). This mechanical device renders it possible to alter the angle of incidence while maintaining at the same time the reflected rays on the spectroscope slit, as the axis carrying the vernier rotates with half the angle of the spectroscope. A set of readings of the limiting angle are taken with light reflected on one side. The spectroscope is then rotated around and the same procedure is repeated on the other side. The difference of angles between the two positions is double the angle of total reflection required. The refractive index may then be calculated taking into account the temperature adjustments determined by the successive measurements of the reference glass prism. In 1889 Perrot of Geneva improved the adjusting crystal holder to speed up the successive alignment of the two samples into the path of light. Despite the fact that the determination of both Soret and Perrot proved very accurate and reproducible, it appears that the apparatus was never produced in any great quantity.

III. MICROSCOPIC IMMERSION METHOD

In mineralogical practice this is the most frequently used technique for samples for which a smooth plane surface is difficult to obtain because of the grain size, hardness, internal cracking, or other unfavorable circumstances. It is also the simplest, quickest, and most expedient of all the methods, requiring no elaborate grinding

Figure 36. **The Berek universal-stage total reflectometer by Leitz, Wetzlar, Germany, ca. 1950. This is a rare accessory to the standard universal stage and permits the determination of the index of refraction of a chosen immersion liquid by measurement of its critical angle. In a first step, crystals are immersed in a liquid with an index slightly above that of the crystal. Then the whole assemblage is heated by means of a resistance-heating unit until a match between the crystal and the liquid is achieved. Subsequently the index of the liquid—and thus also of the crystal—is measured.**

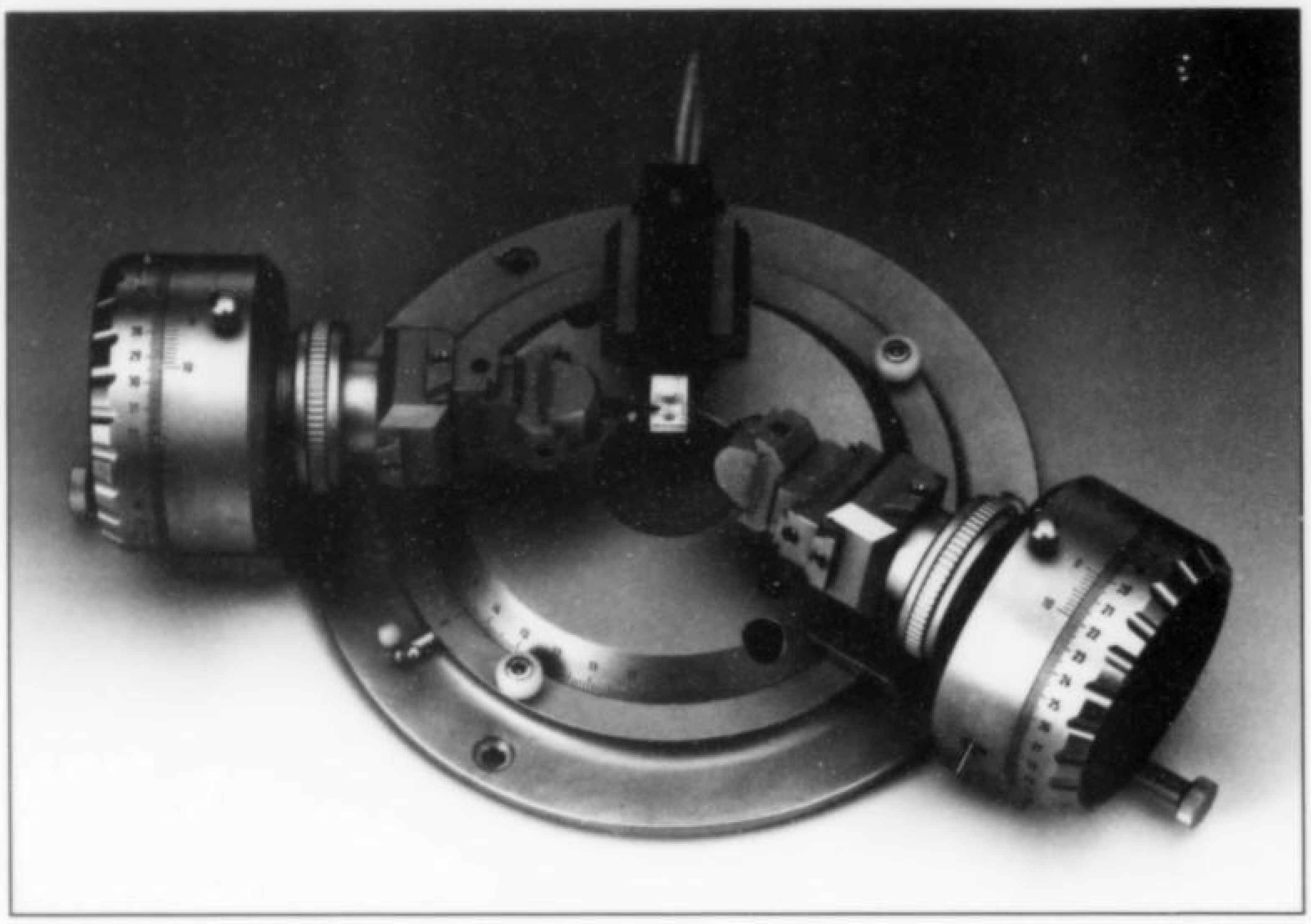


Figure 37. Micro-Refractometer Spindle Stage. Spindle stages are used for the rapid and precise orientation of birefringent crystals for the immersion method. In this elaborate instrument, a crystal with well known optical properties is used as an internal standard. Use of this crystal standard enables very precise measurements. Medenbach, Witten, Germany, 1995. Photo Peter Kubath and Olaf Medenbach.

or other sample preparation; only a mortar & pestle and a set of calibrated immersion liquids are needed. For the immersion method one generally employs a standard polarizing microscope and a grain mount of the crystals to be measured. The accuracy depends on the precision with which the match between the refractive index of the immersion and that of the crystal can be set. Suitable methods of finding this match are the Becke-line (a line of light which results from diffraction at the boundary face between two media of different refractive index, and which disappears at the point of match; an accuracy of ±0.002 is attainable by this method), phase contrast (an optical method which otherwise finds its use chiefly in medicine and biology—Piller, 1952), or "dispersion staining" (an optical staining based on refraction at the boundary between media of different dispersion—Dodge, 1948; Laskowski *et al.*, 1979). The measuring process and its accuracy can be further enhanced considerably through the λ-T-variation method of Emmons (1929). By this method the immersion liquid is first roughly adjusted to the grain to be measured, e.g. by mixing two liquids with different indices of refraction. The fine-tuning and precise match is subsequently set by variation of both temperature and wavelength of light.

Problems with this method are: (1) obtaining an appropriate orientation of anisotropic grains for measuring principal refractive indices, and (2) determining the refractive index of the immersion liquid at the moment of the match. The selection of crystals in suitable orientation can be made from microscopic observations using interference figures, or, much more elegant and precise, through the use of rotation apparatuses as accessories to the microscope (e.g. the universal-stage, also known as a U-stage, and the spindle-stage). With the universal-stage there are flow-through cells for heating by temperature controlled liquids, and the spindle-stage can also be furnished with heating cells for this purpose.

Of course it is imperative that the refractive index of the fluid at the moment of match with the crystal is known or quickly determinable. To this end, Emmons (1929) used an external Abbe total reflectometer, whose prism is circulated around by the same fluid as the cell which holds crystal and immersion, and thus is at the same temperature.

For high precision measurements by the immersion method, two special devices with *in situ* refractometers were designed: the universal stage total reflectometer and the micro-refractometer spindle-stage.

The Universal-Stage Total Reflectometer

The universal-stage total reflectometer is a special attachment for the Leitz universal-stage; it consists of an upper hemisphere with a small central hemispherical well that holds an immersion liquid that is chosen to have a slightly higher index of refraction than the crystal. This is placed onto a special glass slide forming the flat lower cover of the immersion cell. Orientation of the sample for determining the principal refractive indices proceeds by the standard universal-stage method. Subsequently the temperature is raised by a special resistance heating device, whereby the refractive index of the immersion liquid is lowered until the match is reached. At the point of match the universal stage is tilted about its horizontal axis until total reflection occurs on the interface between the glass slide which holds the crystal, and the immersion liquid. The angle of the tilt yields the exact refractive index value for the immersion liquid, and therefore also for the crystal. In principle the universal-stage total reflectometer resembles a classical hemispherical total reflectometer, though combined with the universal adjustability of a universal-stage. Berger (1942) showed that with this equipment a precision of better than ±0.001 is attainable.

The universal-stage total reflectometer is not very easy to use, and thus it has never been widely adopted. Therefore these instruments are rather scarce.

The Spindle Stage

In principle the spindle stage is a modern version of earlier rotation devices with immersion cells (e.g., Klein's trough devices) which were widespread around 1900 (Medenbach *et al.*, 1998; Kile, 2003). Through a computer-supported interpretive process the spindle-stage can be used to quickly and precisely orient a single crystal for measurement of indices of refraction, and subsequently to determine the values by the immersion method (Bloss, 1981; Dyar *et al.*, 2008). In 1965, Feklichev und Florinsky suggested an internal refractometer for such devices. The refractometer is a second crystal with perfectly known optical data and orientation, which is placed in the same drop of liquid as the unknown. This refractometer crystal is mounted on a second spindle, and, during rotation, its index of refraction varies with the angle. In practice, the unknown is oriented first by the spindle-stage method, then the index of the immersion liquid is varied until a match is achieved (e.g. based on observation of the Becke line or dispersion staining); the

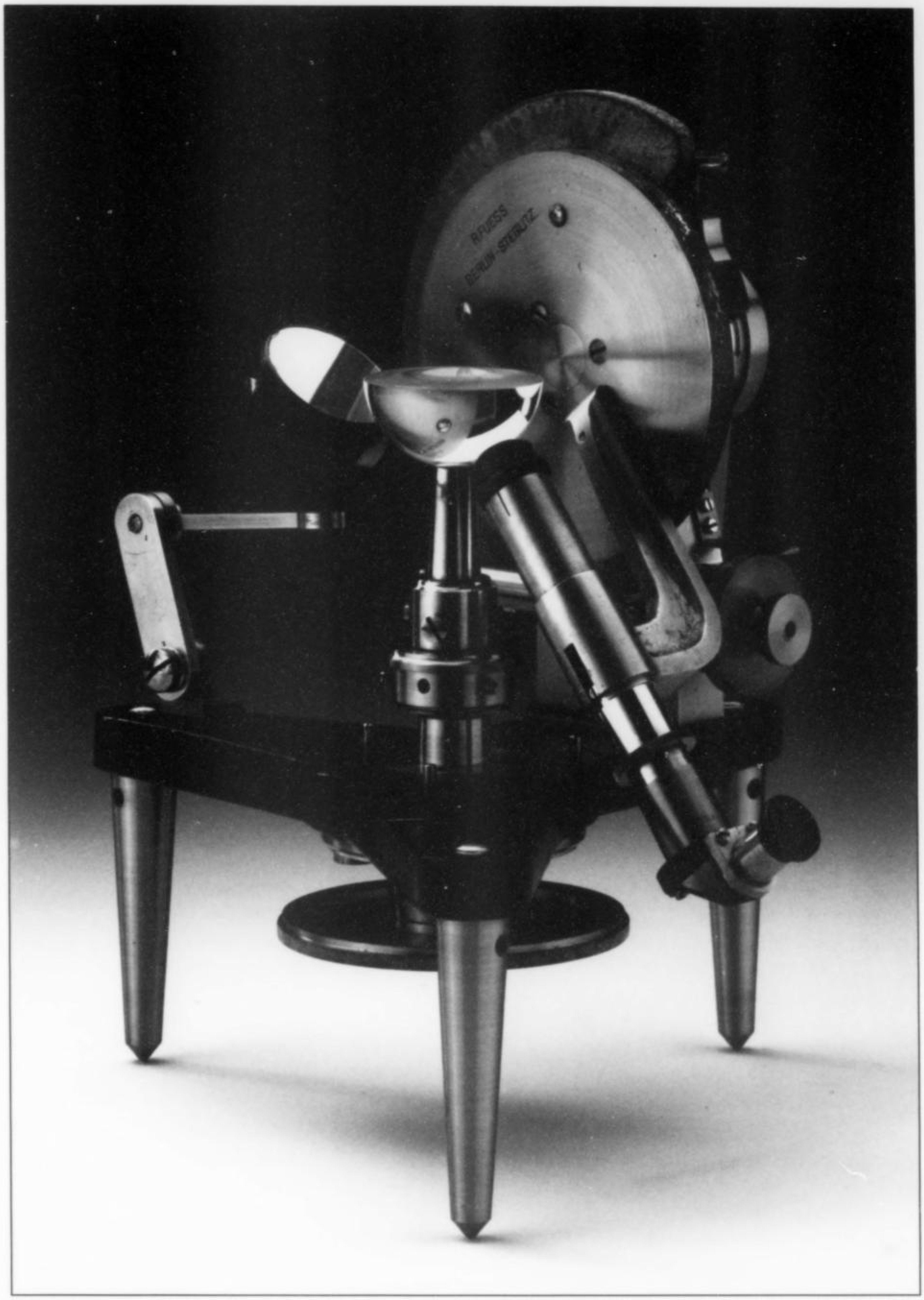


Figure 38. The Fuess No. II reflectometer in its pre-1900 design. The dimensions are comparable to the No. 1 reflectometer shown in Figs. 21 and 22, but it lacks the ability to select crystals in transmitting polarized light. Nevertheless it was a very suitable instrument for precise measurement of refractive indices. Photo Peter Kubath and Olaf Medenbach.

refractometer crystal is then rotated until it also matches the index of the immersion liquid. The value calculated from the angle of the refractometer crystal is thus identical to the one for the immersion liquid and the unknown. An improved micro-refractometer spindle stage employing this method was described in 1985 by Medenbach (Fig. 37). With this instrument it is possible to measure even the smallest grains with an accuracy of ±0.0003.

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The Friends of Mineralogy, Inc.

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Visit the National Friends of Mineralogy website:
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GOALS OF THE ORGANIZATION

- To preserve and protect mineral specimens for education and research
- To promote the preservation of valuable specimen localities and mining deposits.
- To encourage the collection of minerals for their research and educational value.
- To advance programs of mineral study and the educational activities of amateur groups.
- To promote the dissemination of information about minerals, mineral localities, collections and mineral studies.

FRIENDS OF MINERALOGY 2007 AWARDS

Best Article 2007, *The Mineralogical Record,* "Famous Mineral Localities: Bou Azzer, Morocco," v.38, n. 5 p. 338; G. Favreau, J.E. Dietrich, N. Meisser, J. Brugger, L. Ait Hadddouch and L. Maacha.

Best Article 2007, *Rocks & Minerals,* "Greenockite and Associated Uranium-Vanadium Minerals from the Huron River Uranium Prospect, Baraga County, Michigan," v. 82, n. 4, p. 298; S.M. Carlson, G.W. Robinson, M.J. Elder, J.A. Jaszczcak, and T.J. Bornhorst. (This was a tough call because there were so many fine articles to choose from.)

Best Article 2007, *extraLapis English,* (No. 10 – Opal, p. 14)—WERNER LIEBER AWARD, "Rainbows, Harlequins and Pins Afire: Play of Color in Opal"; M. Weibel.

Best Educational Case, TGMS, 2008—Individual, Dr, Georg Gebhard, "Silver"—A very clever and artistic presentation of silver oxidation (the moon waning) and chemical combinations.

Best Educational Case, TGMS, 2008—Institutional, Gemological Institute of America (GIA) and Geo-Literary Society—"George F. Kunz and his contribution to the gem and mineral literature of North America"

In conjunction with the Best Article awards, FM presented a check for $200 to each of the magazines, *The Mineralogical Record, Rocks & Minerals, and extraLapis English.*

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Support organization:
The Gem and Mineral Council

California State Mining and Mineral Museum

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Specialty: Comstock ores, worldwide minerals, mining artifacts, Mackay silver

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E-mail: adomitrovic@desertmuseum.org
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ABOUT MINERAL COLLECTING

PART 4 OF 5

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Some personal observations, ruminations, reflections, reminiscences, ramblings, digressions, grumblings, approbations, wisdom and advice gleaned from 50 years of collecting and dealing in minerals

Quality and Price Relationships

Over the years there has been an upgrading of standards for judging the quality of a mineral specimen. What was thought to be a good specimen in 1900 might today be considered only fit for study purposes. The reason for this is the large increase in mining activity which has gone hand and glove with the industrialization of the 20th century, and vast increases in the quantity, quality and speed of communication, transportation, and travel. These factors, with a concomitant increase in disposable income and available leisure time for people in wealthier countries, have combined to call forth quantities of specimens unimaginable to collectors of a century ago. Specimens of most mineral species known at the turn of the century have been eclipsed by better specimens from newly discovered localities. This is a trend which will presumably continue into the immediate future.

One can argue that at some point we will have used up all the richer and more easily extracted mineral resources of our planet and will have been reduced to processing sea water and low-grade mineral deposits which will produce few specimens. This should not happen any time in the next few hundred years. However, if you're still worried, be of good cheer! The other planets of our solar system undoubtedly have mineral deposits with fine mineral specimens just waiting for the first space-going collectors and dealers. But Earth first; we will mine the other planets later!

The perfection demanded by today's collectors and the high prices they are willing to pay are linked to small quality differences that the collectors of a few generations ago would find puzzling. The stamp and coin hobbies have also seen a dramatic escalation in prices based on tiny differences in the quality of their goods. The pricing scale of specimens is logarithmic. If the price of a good specimen is in the X range, the price of a fine specimen may be X^2 and the price of the *very best* specimens may be X^3. The breathtaking prices of the best specimens are the result of competition—the innate drive of humans to excel and be the best at what they do. The powerful and the wealthy will want the best cars, airplanes, boats, homes, hotel rooms, paintings and sometimes mineral specimens. This isn't going to go away anytime soon, so I guess we will just have to deal with it. All we can do is jump into the fray and get going as best we can!

Most dealers put their price on the specimen labels, but some do not. Those who don't are frequently dealers from third-world countries like Pakistan, India and Morocco. Many of these dealers can be seen at the larger gem and mineral shows. They prefer to size the customer up visually before putting a price on their specimens. They don't realize how much this irritates people like Americans

Collection of Albert Seba
(1665–1736)
Malachite
Probably Siberia

Albert Seba (1734–1765) was a wealthy Amsterdam pharmacist. The illustration shown here is from volume 4, plate 103, Figure 1 of the book about his collections of naturalia, *Locupletissimi rerum naturalium accurata descriptio*. Seba's entire collection was auctioned in 1752, in order to pay for completion of the publication of the lavish four-volume folio-size catalog.

and Germans, who will often just walk away rather than ask the price and then haggle over it. Third-world dealers are raised in cultures where unpriced goods and haggling are the norm. It is what they are used to and comfortable with, and they see no reason to change. Also, putting labels and prices on each specimen is a lot of extra work, and must be done over when moving between shows in Europe (using the Euro) and America (where prices must be in dollars).

The Internet is an excellent place to check out prices. Bear in mind that the price on the label or advertised on the Internet is not necessarily what the specimen ultimately sells for. Often the final selling price is less than the sticker price, and sometimes the price will be sharply discounted if the specimen has been in the dealer's inventory for a long time. If the material being offered for sale is something new, the price will likely be much firmer. Some dealers expect that most of their customers will hammer them for a discount and have already calculated that into the price. Other dealers tend to stick with their prices come hell or high water. They worry that if they become known for always giving a discount when pressured, it will just make life more difficult for them.

Sometimes specimens are sold on the installment plan, and it is not unheard of that specimens are repossessed for non-payment. Obviously that is not good for a collector's informal "credit rating" with dealers, and word tends to get around when someone chronically has a hard time paying for what he buys.

Confidentiality and exclusivity are frequently important aspects of mineral sales, and dealers often sell very fine specimens directly to special customers, so these pieces are never even seen at mineral shows. And even if they are at the show, they will frequently be hidden away in a drawer or a box under the counter. Some collectors are concerned that, if a specimen is in a display case with a price on it, that means that others have already seen it and rejected it. Not wanting to buy a specimen that others have regarded as unworthy for whatever reason, such customers feel much better buying a fine specimen shown to them exclusively: the secret treasure hidden away under the counter.

Often the buyer makes it plain to the dealer that he is not to divulge the price paid for the specimen or who bought it. Most collectors want the price they pay for specimens kept quiet, feeling that if it became known it would cause other dealers to mark them as big spenders and jack up the price of their offerings. Or maybe they are embarrassed about paying what they know or suspect is a somewhat inflated price for something they nevertheless can't resist. Others may not want their spouses to know how much they are spending on specimens.

When you ask for a discount on a specimen or discuss terms of payment, be sure to do it in private. If you hammer the dealer for a discount in front of others, he will likely not give it to you. To give a discount with others listening is like broadcasting to the world that you will always give a discount if asked, and no dealer wants that reputation. Discounts depend on the dealer, and each dealer will have different policies. These policies can be flexible, depending on how much the dealer needs the money and how much the customer is buying. If you pick up a $10 specimen from a dealer's front table and ask for a discount, it will likely not be forthcoming. The material that dealers put on their front tables is usually considered almost expendable, so if some kid comes along and breaks off a few crystals or drops the specimen it is no big deal. Front-table material is used as a buffer to help protect the more valuable specimens displayed in the back of the booth. If valuable specimens are on the front table, they will very likely be kept under glass and away from the groping hands of curious children.

Most collectors have a love-hate relationship with the prices of specimens. For more than 100 years we have been complaining of the outrageous prices of fine mineral specimens, and we love to tell stories about getting great specimens at bargain prices—these coups are among our most cherished memories as collectors. People who heard of the few crazy prices paid in the Freilich auction in 2001 were predictably horrified. What worried them most was that, if the prices paid were "real" (and how could they not be?), this meant they would soon have to start collecting micromounts and could never hope to buy another good full-size specimen for their collection! But high prices are a two-edged sword; they also make people realize that their own collections must be worth more than they thought, which is cheering. But if push came to shove they would rather their collections be worth less if it meant that they could afford to buy more fine specimens. I think collectors in general are like this.

A curious thing about the value of minerals is that, for specimens to be really valuable, it helps if at least a moderate number of them have been found. If the mineral is so rare that only two or three specimens were ever produced, most collectors may never be aware of them, and thus a market value for them cannot establish itself. Rather than pay a high price, the average collector will be merely puzzled by the specimen and view it as a curiosity rather than a valuable rarity. After all, if this is a highly desirable specimen, why don't their friends or local museums have one and why haven't they seen one in pictures? An absence of knowledge discourages purchasing. They have no yardstick by which to measure the desirability of the specimen. Truly advanced collectors and dealers are always looking for these "hen's teeth" that others lack the confidence to buy.

If you want only to collect the finest specimens like those pictured on magazine covers, hang on to your shorts and your wallet. The best specimens today can cost you tens of thousands of dollars each. Many have been sold for well over $100,000. I have heard of a few that have supposedly sold for more than a million. Paul Desautels, former curator of minerals at the Smithsonian Institution, and one of the most respected gem and mineral curators of all time, often said that fine mineral specimens have always been undervalued. How much does a good Rembrandt cost? What is the cost of a good French Impressionist painting or a Picasso? He always reasoned that fine mineral specimens should be worth at least as much as fine works of art. So rejoice, all you greedy collectors out there: plenty of bargains are still available!

Perhaps the single story which most accurately describes the soul of a true collector is one told about Professor Clifford Frondel. When he was showing a group of collectors some of the treasures in the back room of the Harvard Mineralogical Museum, he said, "Here in this drawer we have some particularly fine examples of a rare twinning law of quartz. There are only six known specimens in the world. See, you can count them: one, two, three, four, five, six."

A Specimen-Handling Protocol

As a young collector I learned most of what I know about specimen handling the hard way, through trial and error. If you take to heart what I am going to tell you, it will save you a lot of pain and embarrassment. When you get a chance, you might want to pass this on to other young collectors. It will stand them in good stead as well. Proper specimen handling is really no more than politeness and common sense.

The best way to learn about mineral specimens is to handle and look at them closely from a variety of angles. Without this kind of experience, many things about minerals will be difficult to learn and remember. Often just the heft of a specimen (its density) is enough to clue you in to what it is, so the experience of actually handling specimens is very important.

No matter how wealthy you are, the fact will always remain that most mineral specimens will always belong to other people. So if you want the privilege of handling these specimens, you must gain the confidence of their owners by demonstrating that you will not molest their delicate and cherished little children but that you will handle them with proper care. Most collectors are glad to show other collectors their collections, and some will tell you far more about their specimens than you really want to know. Most collectors, if approached in an intelligent fashion, will be only too happy to open their homes and collections to you; therefore it is critical not to abuse the privilege thoughtlessly.

So there you are, in front of a specimen cabinet, or leaning over a drawer full of specimens. What do you do? Do you reach out and grab the most colorful specimen, exclaiming, "Wow, man! Bitchen!"? Although my vernacular may be dated, and such a response might rate high with Bevis and Butthead, I would advise against it. Before your trembling fingers reach for that jewel you should find out how your host feels about people handling his specimens. A good deal of how he feels about your handling his specimens is related to how knowledgeable he feels you are. If he feels you could not identify 50 species on a good day, he is going to be reluctant to let you touch any of his specimens. If, however, you look closely at the exquisite blue furry specimen, making no effort to touch it, and comment, "That is one of the best Grandview cyanotrichites I have ever seen, I collected at the mine three times and was never able to get any that good," you will have gone a long way toward gaining his confidence. At one stroke you have demonstrated that: (1) you know a good specimen when you see one, providing of course, it is a cyanotrichite you have identified and it is indeed a good one; (2) you know more than just the name of the mineral you are looking at and are skillful enough to discern the correct locality by knowing some of the sometimes subtle but positively identifying characteristics of the specimens from that particular occurrence; (3) you know enough about specimens to know how incredibly delicate cyanotrichite is and therefore have not picked it up; and (4) you have paid him a compliment on his good taste.

Collection of Friedrich Schmidt
(1799–1863)
Pseudomalachite
Libethen, Hungary

Friedrich Schmidt was a physician in Messingen, Germany, and was well known as someone knowledgeable about minerals and fossils. The illustration shown here is from Plate 33, Figure 4, of his *Mineralienbuch* (1855). Schmidt obtained many of his specimens from the Berlin mineral dealer Dr. August Krantz.

Perhaps next to the cyanotrichite is an incredible, drool-provoking azurite rose from Bisbee, Arizona that you would murder your grandmother for, which you would like to fondle for a minute or two, even if you could never hope to own anything so fine. The correct procedure is to say something like this: "That is a wonderful Bisbee azurite. May I examine it more closely?" The answer will almost certainly be yes, unless you have already committed some social or mineralogical blunder or the collector is a real hard case. When you have permission you should wait a moment to see if the collector is going to pick it up and hand it to you. If he makes no move in that direction, you may assume that you now have permission to pick up the specimen.

Before you actually pick it up, note carefully how the specimen is sitting on the shelf or lying in the drawer. You do this so you can

Collection of Albert Seba
(1665–1736)
Wire Silver
Kongsberg, Norway

Albert Seba owned the prosperous "German Pharmacy" in Amsterdam, and traveled widely, bringing back a rich variety of natural history specimens. The illustration shown here is from volume 4, plate 100, Figure 21 of the book about his collections of naturalia, *Locupletissimi rerum naturalium accurata descriptio*.

put the specimen back exactly as it was before you touched it. Be careful how you pick the specimen up. Do not try to pick up any specimen by grabbing it by the largest crystal. Try, if possible, to avoid touching any of the crystals, and pick it up by its underlying matrix. If it is a small specimen, pick it up carefully with your thumb and forefinger. If it is larger than an apple, use both hands to pick it up. If you have picked it up with your thumb and forefinger, *as soon as possible* place the cupped palm of your other hand under the specimen. This gives the collector the warm and comfortable feeling that, should the specimen somehow slip from your fingers, it will drop no more than an inch into the soft palm of your other hand rather than onto the floor or, even worse, onto another of his cherished specimens in the drawer.

When you have finished looking at the specimen, return it carefully to the exact spot from which it came, in its original orientation. If doing so is at all awkward or dangerous (perhaps the shelf is rather crowded with other specimens that could be bumped), feel free to hand it to your host and say, "I'll let you put it back." Especially if the collector handed you the specimen in the first place, hand it back to him when you are done, as he obviously does not want you to pick up or replace specimens. In time he will usually give you a free hand with the collection.

It is also a good idea, but not absolutely necessary, to remove any rings you may be wearing. I have seen collectors heft a specimen in their hand to get a feeling for the density of the mineral. With each heft, the specimen would clank against a ring. This does not leave a good feeling in the mind of your host. In a few instances I have seen collectors wearing bolo ties or regular ties bend over a drawer of specimens to look at them, and seen the metal tips of the bolo tie or the tie hit the specimens. It would be unusual for the end of a regular tie to damage a specimen, but the metal ends of a bolo tie can certainly cause damage. Also, if you are wearing glasses (as a lot of us must), be sure they fit snugly and will not suddenly drop off into the drawer when you are hovering over it face-down.

Why is it necessary to point out what would seem to be such obvious precautions? Well, it has to do with the nature of humans and their innate desire to experience new things. To the average man or woman, a fine mineral specimen is appealing in the way that fire is to a young child who has never seen it. The first instinct is to reach out and directly experience a beautiful new facet of reality. I once saw a 70-year-old lady encountering a fine acicular ulexite specimen for the first time. It was behind the glass of a display case with a prominent "Do not touch!" sign beside it. I watched in fascination as her universe narrowed down to just herself and that specimen. Her hand reached way out around the glass of the display case until she could touch the delicate white acicular crystals. Had she succeeded, the specimen would certainly have been damaged. I had to yell at her to get her to stop. This was her first lesson in specimen handling protocol. She got mad and walked off in a huff. Anyone reading this magazine should be well beyond that point of innocence.

How Many Specimens Can You See at Once?

Some people apparently have total recall. That is, they are able to look at things once and can remember them perfectly. Most of us do not have that ability, and you will find that when you look at a mineral collection you will be limited in what you can later remember about individual specimens. Usually we will only remember a few favorite specimens well enough to describe them. The more specimens you see at any one time, the fewer of them you will be able to remember.

If you are able to actually handle the specimens you will be better able to remember them than if you just look at them. This is why there is no substitute for having your own mineral collection that you can study and handle to your heart's content. If you are looking at a large mineral collection you will get square eyeballs after a while; it just becomes too much, and you will need more than one visit to form a good memory of more than just a few of the specimens. When you visit a large display collection like the one on display at the British Museum of Natural history, or even a comparatively more modest one like that at the Natural History Museum of Los Angeles County, you will be overwhelmed by what is on display. You will need to visit such a collection many times to absorb what it has to teach you. And even then, after many visits, you will still see fine specimens that, for some reason, you did not notice before. I find that a collection of more than 500 specimens is difficult to absorb in a couple of hours. You may find that 500 is about your limit as well. The Tucson Gem and Mineral Show is the ultimate experience in sheer sensory overload; people often become overwhelmed after a couple of days of looking at specimens, and must go away and do tourist things for a day or two to "refresh the palate" before returning to look at more specimens. They need some time to absorb what they have seen and learned before more can be assimilated.

Dealers, curators and collectors who handle a lot of specimens develop strategies for looking at large collections. This frequently takes the form of scanning the collection for unfamiliar specimens.

If you have seen several hundred good adamite specimens from Mapimí, Mexico it would require a really exceptional one of these to catch your eye. When scanning over the contents of a drawer you tend to look for the unusual specimens, very exceptional specimens or those that you have not seen many of. The rest you just tend to skip over. A knowledgeable dealer may scan over a drawer of minerals so quickly that it is almost insulting to a collector, but that may be because the dealer has seen hundreds of better specimens and there are no surprises for him. I think everyone develops this habit. When you are beginning to learn about specimens you will need a lot longer to look at collections than later on, after you have seen and handled many thousands of specimens.

I remember once setting up a display case of my best azurites, after I had been collecting for about 15 years. Martin Ehrmann, a well-known dealer specializing in high-quality minerals, came over and casually examined a few of the specimens and even picked up two or three of them for a closer look. After a couple of minutes he wandered off without so much as a word. Didn't he realize how good the specimens were? How could he wander off with no comment? The fact was that he had seen, handled and perhaps even sold better azurites than I had in my display case. What I didn't realize at the time was that, if he had not thought my specimens were quite good, he would have taken barely a glance before walking on past.

Protecting Your Minerals

The best advice I can give you about protecting your minerals is that you should keep them in a cool, dark, dry place and touch them as little as possible. But that would not be very much fun. If you become a serious collector you may soon find that your mineral collection is worth more than the car you drive or even the house you live in. At the end of 20 or 40 years you might shock yourself if you totaled up how much your collection is worth. So, even if you don't hide it all in the root cellar, here are some things you may wish to do.

Catalog your minerals and record what you paid for the specimens and from whom you got them. Some collectors request a receipt with every purchase and file the receipts at home. Make sure your specimens are labeled and in an attractive cabinet. This will help to make your specimens look important and may keep unknowledgeable people from throwing them out later. Keep the most valuable ones under lock and key. You would not want to scatter hundred-dollar bills around the house where they could be picked up and possibly damaged or even stolen by casual visitors. If you live in earthquake country there are special counter-measures you should take to protect your collection; read Tony Kampf's article on "Earthquakes and mineral collections" in the July–August 1994 issue of the *Mineralogical Record.*

Earthquakes have destroyed many specimens. Willard Perkin, an old collector/dealer I knew in Glendale, California, converted his one-car garage into a mineral display room. The garage had big, almost floor-to-ceiling, glass-fronted, glass-shelved display cabinets lining its sides. A moderate earthquake shattered the big sliding glass fronts and shelves, and all the specimens were spilled out onto the cement floor or cascaded down on top of each other, mixed with sharp shards of glass. In another earthquake a collector living near San Francisco had some of his display cases thrown across the room with enough force that they dented the opposite wall. In some parts of the world earthquakes are a real threat to specimens.

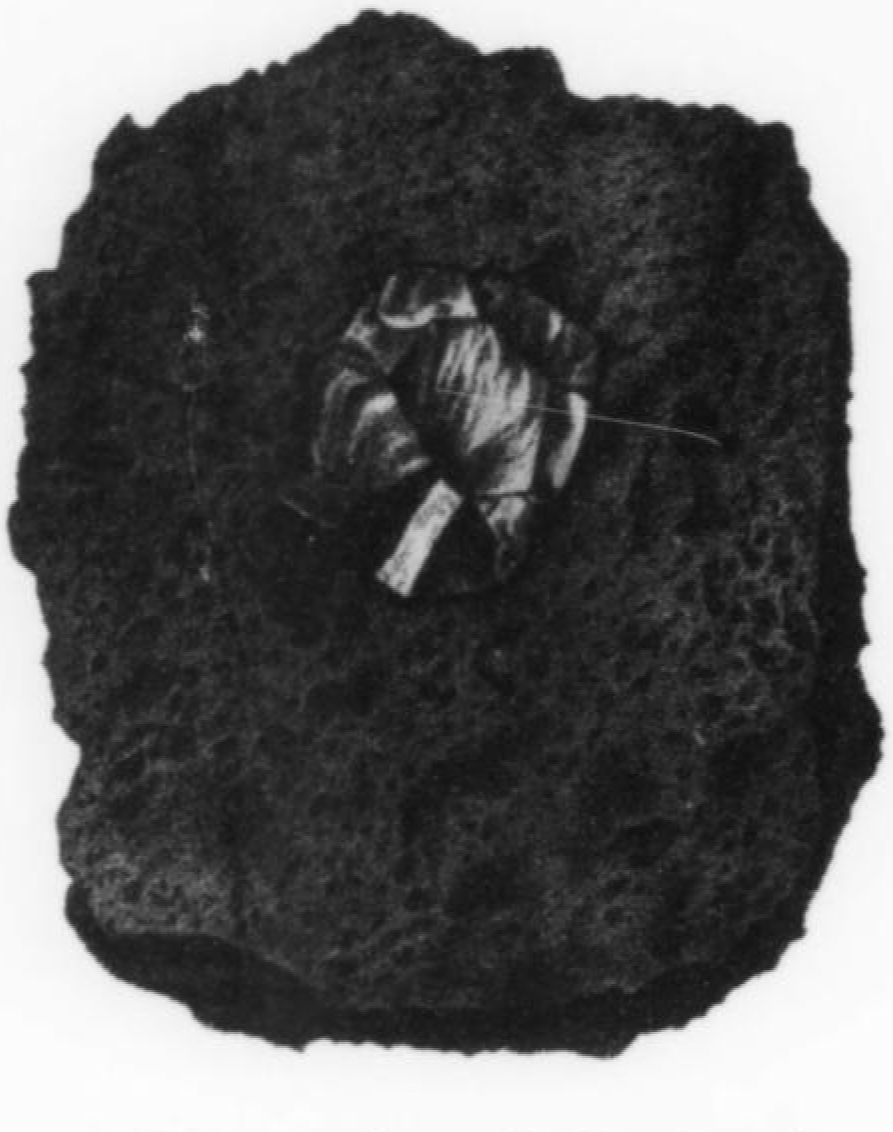
Protection for your collection can take many forms. Years ago I visited Arthur Montgomery in his apartment in New York City. He let me study his collection to my heart's content and take pictures of whichever specimens impressed me. After I had finished handling his pyrite specimens, he took out a cloth and polished the faces of the pyrite crystals to remove my fingerprints. I thought he was just being an old fuddy-duddy, but since then I have learned he was not. I have seen pyrite specimens with old fingerprints on them that could not be wiped off. Organic compounds in fingerprints can be strong enough to permanently etch the surfaces of pyrite crystals.

Collection of Jean Gigot d'Orcy
(1733–1793)
Wire Silver
Kongsberg, Norway

Jean Baptiste François Gigot d'Orcy, a wealthy French patron of natural history, was Receiver General of Finances for Châlons. He collected fine minerals for over 40 years and had one of the finest collections in France until his execution during the Reign of Terror. The illustration shown is an unpublished watercolor by René Louis Swebach Desfontaines (1750–1833). Gigot d'Orcy's collection was purchased by an American, George Gibbs, in 1804 and later acquired by Yale University.

Cataloging Your Collection

If you like specimens and collect good ones, you will eventually decide you should catalog your collection and make uniform, attractive labels. Initially collectors don't care about making labels or cataloging their specimens. As time passes, though, some collectors begin to realize that they are not going to live forever and start to think about what they would like to have happen to their collections when they die. This typically happens when the collec-



Collection of Friedrich Schmidt
(1799–1863)
Hauyne Crystal in Basalt
Naples [Vesuvius?], Italy

Friedrich Schmidt was a physician in Messingen, Germany, and was well known as someone knowledgeable about minerals and fossils. The illustration shown here is from Plate 11, Figure 4, of his *Mineralienbuch* (1855). Schmidt obtained many of his specimens from the Berlin mineral dealer Dr. August Krantz.

tor realizes that he has spent more on his specimens than his house is worth. At this point, cataloging his collection and making good labels becomes a desirable objective.

The old standard way to catalog specimens is to assign each a unique number, glue or paint that number onto the specimen, and enter the number in a bound ledger book with a description of the specimen and information about its locality. The next step is to write or type a label to keep with the specimen. There is still much to recommend this time-proven method. But now, with the advent of computers with word processing and database programs, we are seeing a change in the way many collections are cataloged and labeled. Database programs are used to enter the data about each specimen, and increasingly a digital image is placed in one of the database fields. Then labels are generated on the computer and printed out. The more sophisticated cataloging programs will allow you to create and/or select the kind of label you want for your specimens; when you are finished cataloging specimens for the day, pushing a few buttons will print out labels for them.

These programs allow you to quickly do things which would be very time-consuming with the old ledger system. For instance, you may want to know how many calcite specimens you have in your collection, or how many specimens from Tsumeb you have, or how many calcite specimens from Tsumeb. With the proper database program this can be determined in a few seconds, and reports about those specimens can be printed just as quickly. The more advanced programs have fields for almost every imaginable attribute you might want to record about your specimens, find-and-replace functions, spell-checkers, tabbing and table view sequencing functions and much more. Such programs will allow you to spend less time with the drudgery of cataloging your collection and making labels.

Making Labels for Your Specimens

There are three basic kinds of labels you may wish to make for your specimens: specimen labels, box labels and display labels.

Specimen Labels

Of the three types, the specimen label is the most important. I call them "life-saver labels." These are labels to be glued directly onto the specimen. Once a label is separated from its specimen, the clock starts ticking on how long it will be before someone throws that specimen out in the trash. The specimen label should contain, at the very least, the locality information about where the specimen came from. If there is room enough, then you can also put the species name and the collection name and catalog number on the label as well. It is not easy to find the time to do this work, but it will preserve the specimen and make it last longer before someone who doesn't know what it is chucks it into a garbage can. If you have a good database and label-making program, then, when you are printing out your display and/or box labels, you can quickly make up specimen labels at the same time.

Most advanced collectors have old specimens from the Foote Mineral Company of Philadelphia in their collections. The wonderful printed labels Foote glued onto the backs of many of his specimens show the name, chemical formula, locality, and at the bottom, the revered name "A. E. Foote, M.D." or "Foote, Philad'a." Many of these specimens are not great by today's standards, but we keep and cherish them because of the fine old labels still attached to them. This clearly demonstrates the long-term value of the attached specimen label.

If you collect specimens which are too small to place labels on them, as would be the case with thumbnails, you can mount them on a base and keep them in thumbnail-size Perky boxes with the label affixed to the bottom of the box. Some collectors use a glue gun to affix thumbnail specimens to clear Plexiglas bases that are large enough to have a label attached to the front. Likewise, if you collect micromount specimens you can put the label on the micromount box. Lids can get switched, though, so affix a label to the lid *and* the bottom of the box holding the specimen. This way, the specimen will not easily be separated from the label. Placing small specimens in an egg carton with a hastily scribbled label on the outside or on a scrap of paper inside is an invitation for the trash man.

For attached specimen labels, I recommend that you give them a final coating of marine spar varnish or polyurethane, which will help them survive future cleaning in soap and water and/or an ultrasonic bath. If you use a font size smaller than 5 points, it will be difficult to read, but will at least preserve the vital information, even if it can only be read with a hand lens. Modern printers set on maximum resolution can easily print very tiny labels.

Display Labels

A display label is one you will put with a specimen when you place it in a display case. The species, locality, and whatever else you put on the label should be neatly centered on the label to give a pleasing, professional look. These days, some collectors like to have a custom-made clear acrylic base for each specimen, with the species and locality etched or cut into the front face of the base. If your specimens are valuable enough to justify the cost, this is a very attractive alternative and is not as visually distracting in a display as paper labels might be.

Box Labels

A box label is one you place with the specimen in a box or cardboard tray. The species, locality, and other data should be placed near the top of the label, so you can read it without touching the specimen. The label should be placed in a vertical position against the back wall of the box where it can most easily be seen by someone opening the drawer. These are sometimes called "tombstone labels." If you use an open cotton-lined "jewelry box" with its lid covering the bottom, the label can conveniently be stuck in the back space between the box and the skirt of the lid. Any printing near the bottom of the label will likely be hidden by the specimen or the box. If the label has locality data near its bottom the viewer may have to roll the specimen forward a little to read the data, or pull out the label. Placing the data near the top of the label will avoid unnecessary handling of your specimens.

If instead you put the box label on the *bottom* of the box, under the specimen, you will have to pick up the specimen to see the label information. The constant rocking of the specimen as the drawer is opened and closed will often cause the label to become dirty and worn. If you try to stabilize the specimen with a layer of cotton to prevent it from rocking around, then the label is protected but is obscured completely. So it isn't such a good idea to put the label under the specimen.

In most large collections, what is needed are good box labels and not display labels. Make box labels for everything, and when you are creating a display, you can then make special display labels. When it is time for the specimens to go back into their boxes you can store the display labels behind the box labels until you are ready to use them again in the future. If you have a good cataloging and integrated label-making program, it will be quick and easy to make new labels for your specimens.

When you make your labels, use a heavy acid-free paper, photo paper or some sort of archival-grade paper. Make sure that the printing ink is fast and durable and will not smudge or run when wet. Laser printers are good for this purpose; the labels you make with them will last a long time.

Another way to increase the chances that your labels will be valued and saved along with your specimens is to make the label design really elegant and attractive in its own right. A fine, collectible-looking label makes the specimen look more valuable, and will more likely be retained instead of discarded by future owners. For inspiration, look at some of the thousands of labels that have been posted in the Biographical Archive portion of the Mineralogical Record's website, www.MineralogicalRecord.com. The Mineralogical Record label collection is the largest in the world, and contains many beautiful examples.

When making labels, tradition calls for the most general locality name (the country name) to be last in the string of locality data. Ahead of it is placed the main political subdivision of the country in which the specimen was found. This means the state, province, canton, department, oblast, circle, etc. Next is the name of the secondary political subdivision (county or parish in the U.S.), then perhaps the mining district, township, mountain or mountain chain, the nearest city, town or village, and finally the mine or prospect name.

Usually the most specific locality datum, like the mine name, if known, is placed first in the string of locality data on the label. Sometimes dealers will prefix the mine name with the part of the mine or the name of the pocket of minerals from which the specimen was taken. In most instances, unless the dealer himself or his associates mined the specimen, it is not possible to know which part of the mine it came from. Therefore, if a dealer too frequently places this kind of ultra-detailed data on his labels, you should suspect that the locality details may be fabrications.

Collection of Henry Heuland
(1778–1856)
Realgar on Native Arsenic
Nagyag, Romania

John Henry Heuland was among the best known of all English mineral dealers of the 19th century, and was also a friend of James Sowerby. He had a predilection for fine specimens, and his determination to obtain good locality information was ahead of his time. The illustration shown here is from Sowerby's famous book (1811) *Exotic Mineralogy* (vol. 1, Plate LXX).

I would advise you to put as much locality information on your labels as possible, and, where possible, not to use abbreviations. To some extent this depends on how much space is available on the label. In many instances, it is not clear what the locality names on labels mean. Are they the names of a political subdivision, a mountain range, a city, a town or village, a valley or what? I would like to know these things, wouldn't you?

In some instances the collector or institution may wish to reverse the order of the locality information on labels from the most general to the most specific i.e., from country down through the specific mine name. For my micromount collection, on the top of the micromount box I place a small label strip with the species name(s). Across the bottom of the box top, I place a label strip, which has the country name first. This allows me, in the calcite division of the collection, to quickly place all the calcites from the U.S. together and then the calcites from California together, etc. In this way I can quickly find any group I am looking for.

Why Accurate Localities are Hard to Get

A mineral locality can be as near as your back yard. If you found a big gold nugget there you could label it "My back yard" and add the address of your house, the city you live in, the town and country.

Collection of Wilson Lowry
(1762–1824)
Acanthite with Calcite
Locality unspecified

Wilson Lowry was a British artist who pioneered steel-plate engraving. He was also a mineral collector and friend of James Sowerby. The illustration shown here is from Sowerby's famous book (1811) *Exotic Mineralogy* (vol. 1, Plate XXXII). The Lowry collection, highly regarded by the Count de Bournon, was sold at auction in 1830.

That would be very specific; anyone could look at the label and find the locality with a high degree of precision. The goal of all locality descriptions on labels should be to allow a person to take that information and, with minimum effort, find exactly where that mineral came from. Almost all labels fall short of that ideal. Aside from an exact street address, perhaps the next best locality that can be given is an exact latitude and longitude. Of course, very few labels have that (none at all are in the Mineralogical Record collection of over 15,000 labels). Next best is to give as much locality data as you can so that a person can know as precisely as possible where the specimen came from. A mine name is good, but the nearest village, town or city, state, region, mining district, province, country, etc. should also be given. This is because some mine names can apply to more than one mine, and the names of mines can change over time; it is important to avoid ambiguity.

Why are labels often not very detailed? First of all, to write an exact and complete locality takes more time than most people want to spend on the task, even if they know the complete and exact locality information. Most people who write labels for specimens that are sold to collectors, curators or mineralogists have never been to the locality themselves, so most of the information they put on their labels is second or third-hand. This information may or may not be correct; its accuracy depends ultimately on how knowledgeable, trustworthy and informed the source is. Ultimately you must look at the locality data that comes on the label with the specimen and decide if the person who made the label really knows what he is talking about.

Aside from pure laziness, the main reason why labels are often imprecise or inaccurate is that divulging the exact, correct locality information may in some way be financially disadvantageous to the original seller. If you find a big gold nugget in your back yard, you may not want to tell the world where you found it until you are sure there are no more to be had. This may be doubly true if you don't own the mineral rights on your property or are renting or leasing the property. If there is a bunch more, the owner of the mineral rights could come in and scoop up all the gold and leave you sitting on your hands.

Suppose you own a mine in San Benito County, California that produces the best known crystals of benitoite in the world. You don't live at the mine because there are no gas stations, convenience stores, or fast food outlets nearby. Further limiting your desire to live at the mine site is that during some parts of the year the weather is terrible and the clay in the area turns to a super-slippery goo when it rains, preventing access even to four-wheel-drive vehicles. How eager would you be to give full locality information about your mine? In this particular case, the locality has been well known for years, and maps and directions to the mine are not difficult to come by because field collectors, especially those from Los Angeles and San Francisco, have for generations made it a point to visit the locality whenever they are in mineral-rich San Benito County looking for other minerals. The mine and the surrounding area have been happy hunting grounds for generations of collectors. They know that, if there is no one actually at the mine to run them off, then they can collect there as much as they want. This has always been a real aggravation for the various owners over the years.

Or suppose you have made a lucky connection regarding a previously unknown locality for pink garnet crystals in Mexico. You make a trip to visit the occurrence on a big cattle ranch in the Sierra de Las Cruces in Coahuila state. At the entrance to the ranch is a sign that says "If you are not a Catholic, do not enter here." You are introduced to the owner of the ranch and get permission to visit the locality away up near the top of the mountain. You get horses from the rancher and off you go. When you finally get there, it is an amazing sight. There are pink garnets all over the ground that have weathered out of the host rock. All you have to do is pick them up, and you gather up as many as you and your horses can carry. From the top of the mountain you look down and see a big dry lake that you are told is Lake Jaco. When you get back home you prepare the garnets for sale and label them "Lake Jaco, Mexico." Well, it turns out that the boundary between Coahuila state and Chihuahua state runs along the foot of the mountain and that Lake Jaco is in Chihuahua state and not Coahuila. Do you put the exact correct locality on your labels, even though doing so would allow anyone to go there and pick up more garnets and most likely destroy the market for the garnets that you had gone to so much trouble to find and collect?

Or suppose you are a mineral dealer in Changsha, China and one day a runner brings some mediocre stibnite crystals into town to sell. No one is going to make much money on these because they are really not very good compared to other stibnites that have been coming from other mines. The funny thing about these stibnites is that some of the thin crystals look a bit red under a strong light. That is really strange. Perhaps you should confirm that these crystals are really stibnite. You have them X-rayed by a friend who works in the geological survey. Oh my goodness! They are not stibnite but rather *kermesite*. You buy up all of the specimens and you find out from the runner where they came from. As far as you can tell from information available on the Internet, these are the *world's finest specimens* of kermesite. Now is your big chance! There are foreign buyers coming every week for specimens who will pay thousands of dollars for these, maybe tens of thousands of dollars. You can make enough money to buy a house and a car and still have some left over. (Only three people in every thousand own a car in China.) There is a chance here to become wealthy. You go to the mine and make sure that you get all the specimens available and keep others from getting any. Let's see, what should you put on the label? Well, you can be sure it won't be the correct locality and not even the correct province. Perhaps when you are finally sure that there will not be any more kermesites you will give out the correct locality. This sounds like the thinking of a normal man.

In the Deccan trap rock formation of India in Maharashtra state near the industrial city of Pune (formerly Poona), which is famous for its zeolite specimens, is the little town of Wagholi. The Wagholi complex of rock quarries produces basalt aggregate for the building of roads and other uses. The city of Pune is glad to have all the quarries in this somewhat out-of-the-way place but still not far from the city. It is a dusty place because of all the blasting, rock crushing and screening of the crushed rock. Also, any rocks sent flying by the blasting in the quarries will just land in other quarries and not in crowded residential areas, as is the danger in some of the quarries near Bombay. Several quarries in the Wagholi quarry complex produce wonderful specimens of cavansite and pentagonite, but you never see the names of the individual quarries on the labels for the cavansite and pentagonite specimens. Why not? The reason is that the quarry owners pay a royalty to the government on each truckload of rock that leaves their quarries, and they are not eager for the government to know that anything but basalt is found in their quarries. If the government found out that valuable mineral specimens were also being found, a high rate of taxation on the specimens would be instituted, creating a big headache for the quarry owners. The owners and the local mineral dealers all realize this and have more or less agreed not to broadcast the names of the individual quarries. The Indian dealers who sell the specimens are happy to comply because that will make it harder for would-be competitors to find their sources of cavansite. All the local dealers know the names of the various quarries that produce different kinds of cavansite and pentagonite, but they realize it is in everyone's best interest to avoid giving a more specific locality name than "Wagholi" on the specimen labels.

Early in my career as a mineral dealer I wrote an article about the zeolites from the Deccan traps for the *Mineralogical Record* and was confronted with the decision of how much precise and specific locality information I should give on the various quarries I had visited and described in the article. I decided to be very candid about the localities. I was so candid, in fact, that one of my competitors here in America asked me why I would want to give such accurate locality information, pointing out that it was really not an intelligent thing to do. Well, by the time of that conversation the cat was already out of the bag, since the article had already been published, but I thought long and hard about what he had said. A few months later *Lapis* magazine picked up the article and translated it into German for its readers. A few months after that, I was in India and visiting one of the new mineral dealers in Bombay, and he mentioned that he had seen my article in *Lapis*. I had never seen the article and asked if he had it and if I could look at it. He admitted to having the article but was reluctant to produce it. I persisted, and eventually he brought it out from a back room. To my amazement, every locality I had mentioned was underlined in red. It looked very much to me as if an Indian mineral dealer was using my locality directions to find the producing localities. I thought about that for a long time as well. My eventual conclusion was that in the long run it didn't make much difference if an accurate locality reference was available or not. The people who are really interested in finding the localities will find them, with or without such help. If one wishes to mislead people by giving bogus locality information, he may prolong his financial advantage at a locality for a while, but he will also eventually become known as someone who gives fictitious locality data, and will earn the enmity of those people whom he has sent on wild goose chases. In the long run this may actually be harmful financially, although it is almost impossible to measure how much is lost and how much gained.

Collection of Caze de la Bove

(1740–1824)

Cinnabar

Idria, Carinthia, Austria

Baron Gaspard-Louis Caze de la Bove was a French administrator (Intendant du Brittany et Dauphiné). Specimens from his natural history collection were illustrated by Louis Swebach Desfontaines in Fabien Gautier d'Agoty's (1781) *Histoire Naturelle*. The one shown here is Plate LXI, of which only two copies are known to exist.

A few mineral dealers have been known to label specimens from one locality as being from somewhere else. This is usually done to give the specimen added value. A prominent British field collector, Arthur Kingsbury (1906–1968), always seemed to be coming up with wonderful new finds from new localities in England. No one else could ever find similar material at those localities. He gave his collection to the British Museum and it was eventually discovered that many of the localities he gave for his specimens were completely fabricated. Specimens from well known British localities

Collection of Edward Daniel Clarke
(1769–1822)
Vivianite
Kerch Peninsula, Ukraine,
Black Sea Region

Dr. E. D. Clarke was a well-known professor at Cambridge University in England, an active mineral collector during his many travels, and a friend of James Sowerby. The illustration shown here is from Sowerby's famous book (1811) *Exotic Mineralogy* (vol. 1, Plate III). Clarke's mineral collection was purchased by Cambridge following his death.

were found to exactly match specimens that Kingsbury claimed were from entirely different localities. In this case the motive was apparently not monetary, but merely to gain a reputation as a great field collector rivaling or exceeding the reputation of the famous Sir Arthur Russell, an envied fellow countryman. Another dealer in Colorado became notorious for labeling specimens from well known foreign localities as being from localities in Colorado. It became a bit of a joke. Whenever there was a specimen with a very suspicious locality, someone would joke that it must be from that Colorado dealer.

The examples given above are but a very few of those that could be given to show why good, accurate locality information is hard to come by. If you buy a specimen of a mineral that is from a newly producing locality, the likelihood of getting bad locality information on the label is much higher than it would be if you had bought a specimen from a classic locality. This should not necessarily deter you from buying the new specimen, because in the long run the probability of the correct locality becoming known is quite high.

So how does good locality information become known? It becomes known because men of good will visit the localities, confirm what kind of specimens come from them and report in the literature what they have seen. Simple as that!

Making Your Specimens Look Important

If you want to protect and preserve your specimens beyond your immediate lifetime, you need to make them look important. This is because after you die your spouse, children, or even someone you don't know, who doesn't know anything about specimens, may get their hands on your collection. If the specimens are wrapped up in newspapers in an old cardboard box, the chances of their being thrown out in the dumpster are quite high. I can't even begin to tell you how many times this has happened to individuals, as well as at schools and museums. If, on the other hand, you make or buy a beautiful hardwood cabinet and display your specimens attractively inside, with well made labels, the chances are that others will think them important and the probability of their survival will be much higher. I have known people with collections whose value is greater than those of their homes, who nevertheless wrap their specimens in newspaper stored in old cardboard boxes. For some incomprehensible reason these people will not spend an additional one or two percent of what their specimens are worth to display them attractively.

A few years ago a good friend and long-time business associate from Brazil came to visit me. He had in tow a fellow businessman from Hong Kong who ran a big jewelry manufacturing company, with 2,000 to 3,000 employees working in mainland Chinese factories. Both of these gentlemen knew something about mineral specimens but not a great deal. I showed them all of my better specimens and, as an afterthought, showed them my micromount collection. The Chinese gentleman was more impressed with the micromounts than with my big flashy stuff. He could not have sight-identified more than a few of the species even if they had been larger specimens. He didn't look at any of them with a hand lens or a microscope but seemed mesmerized by the orderliness of the collection, all the identical little boxes each with its careful tiny lettering describing the treasures within. He turned to me and said in an excited voice; "Perhaps some day you can make me a collection like this one." This is a good example of why you want to make your collection look important.

Cleaning Mineral Specimens

This subject could easily fill a book, and in fact it has: Richard Pearl's *Cleaning and Preserving Minerals* (1971). Dealers and field collectors are the ones who really must learn the most about cleaning because they are the ones who must prepare specimens for sale. For maximum return on their investment, dealers must clean, trim and present the specimens as attractively as possible. On www.mindat.org there is a chat group devoted solely to the cleaning of mineral specimens. If you have a particular specimen to clean, read the archived threads that have discussed the particular kind of cleaning in which you are interested, or ask questions about your particular cleaning problem. This is where you will get the best advice. As a collector, you will perhaps want to clean your specimens from time to time, and this will most probably take the form of washing them in soap and water.

Some specimens are so delicate that you should not, under any circumstances, wash them in soap and water or scrub them with a brush; such treatment may ruin the specimens. Some minerals form fine, acicular crystal "hairs" which will not survive even being placed in water. These include such minerals as cyanotrichite, okenite, and some mesolites, whose crystals, if wet, will typically mat down and stick together. Some people have claimed success in cleaning these types of specimens by using non-aqueous liquids with low surface tension like diethyl ether (which is extremely flammable). Having had extensive experience in handling chemicals, I would not recommend trying this method unless you are intent on burning your house down.

Other specimens having needle-like crystals may be stout enough to withstand being placed in water, but may be damaged by brushing of any kind. Sometimes placing them or holding them upside down in the tank of an ultrasonic cleaner is an effective method of cleaning them.

Be careful to avoid thermally shocking your specimens. Make sure that the specimens you want to wash are at the same temperature as the water in which you clean them. Pour out the water into the container to be used and then let it stand beside the specimens until they equilibrate in temperature. Once you become familiar with the properties of the specimens you want to clean, you may not have to do this. It is not likely that water out of the tap will thermally shock quartz, calcite or many other minerals sufficiently to damage them, but cerussite and fluorite specimens, among others, can be quite sensitive to thermal shock.

Recently fabric guns have come into the hands of dealers and collectors. These were developed and used in the dry-cleaning industry to remove stains from fabrics. They have a spring-loaded piston which rapidly pumps back and forth (60 times a second?), causing the gun to expel an intermittent jet of cleaning solvent. This jet of liquid hits and vibrates the fabric in the area of the spot, usually cleaning it out in a few seconds. The stream, though intermittent, appears continuous, and the gun creates a buzzing sound; thus these instruments are sometimes called "buzzer guns" by collectors.

The first fabric guns to become available were European-made models costing several hundred dollars. They were so useful, however, that dealers would buy them anyway because they could make money with them. Now fabric guns are substantially cheaper: Chinese-made models are available for $75 or less. The mineral enthusiast uses water in these guns in place of cleaning solvents, and the guns have revolutionized the cleaning of mineral specimens. They can clean specimens in a tiny fraction of the time required by hand washing, and can often clean dirt out of places which were previously impossible to clean. The force of the fluid stream against the specimen can be very powerful, though. If you hold your finger directly in front of the nozzle, these guns can drive the fluid through your skin. The force of liquid impact diminishes quickly with distance from the nozzle. At a distance of about 3 feet the jet breaks up into a mist of liquid. You can clean delicate specimens with this device if you do not hold them too close to the gun. If you do, the gun can easily blow some crystals right off the specimen. A little experimentation will quickly teach you how best to use this wonderful cleaning tool.

Another common type of cleaning is the removal of "iron stains" from specimens. There are several kinds of chemical solutions that can effectively remove iron oxide stains, but the choice of the best one depends on the particular mineral you need to clean. Before you use chemicals to clean a specimen, clean the specimens as thoroughly as you can, preferably with a fabric gun (high pressure water). This will allow the chemicals to remove the irons stains faster and more completely.

Some minerals, like quartz and the blue-green variety of microcline feldspar called amazonite, are fairly durable, and you can use acids to clean them, although the hot acids over a period of time will roughen the surfaces of amazonite crystals. Some minerals, like hemimorphite and calcite, will simply dissolve if you put them in acids to remove stains. In addition, environmental concerns have made it difficult to obtain some acids and to dispose of them properly. Strong acids are also intrinsically dangerous, and unless you know how to handle them, it is better to clean your specimens without them.

Collection of Richard Phillips
(1778–1851)
Bournonite
Herodsfoot mine, Cornwall, England

Richard Phillips at first joined his family's printing business but later became a prominent English chemist and mineralogist who assembled one of the finest collections of Cornish minerals. He was 27 when he loaned this bournonite crystal to James Sowerby. The illustration shown here is from Sowerby's famous book (1806) *British Mineralogy* (vol. 2, Plate CXXXVI).

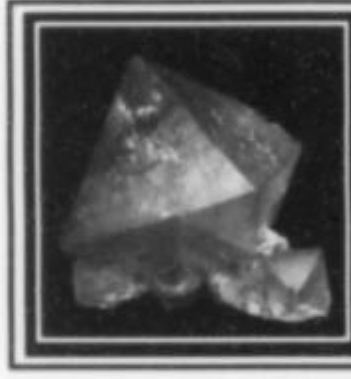
Probably the best overall iron oxide stain-removing method is to use a Waller solution. To make this solution you can Google "Waller solution" for the details, buy the chemical ingredients and mix the solution yourself. This reagent is particularly useful in cleaning iron stains out of acid-sensitive minerals like hemimorphite and ludlamite. Or you can buy a commercial product called "Iron Out" that is available in many large stores like Wal-Mart. It comes in a bottle as a fine powder; you mix it with water according to the instructions on the bottle and presto, you have a Waller solution. Then you immerse your specimen in the solution, and wait. This reagent has to a great extent replaced the use of strong acids like hydrochloric, phosphoric, and the weaker but poisonous oxalic acid.

Sometimes collectors or dealers will want to remove calcite from specimens to uncover crystals of other minerals that have been overgrown by the calcite. The best acid for this purpose, with some exceptions, is hydrochloric acid. This acid is still available in hardware stores and is also called muriatic acid or "pool" acid. You must be careful when using this acid, though. Use some sort of safety goggles to protect your eyes in case some of the acid splashes up onto your face. Use rubber gloves to protect your hands from contact with the acid when handling the specimens in the acid solution.

A 10–15% solution of concentrated hydrochloric acid is ideal for removing calcite. Place about a cup of acid in a gallon of water. When the specimen is placed in the solution, the calcite will react with the acid by generating carbon dioxide, which bubbles off. If the bubbling stops but calcite still remains, this means that the initial charge of acid has been neutralized and you must add more acid to remove the rest of the calcite. Often you can clean up, or make less obvious, small areas of damage on calcite crystals by dipping a cotton swab in the acid and gently stroking the area of damage with the acid-filled cotton swab. This is an old trick that has been in use for more than a century to make bruises on calcite "disappear." When you have finished using the acid solution, add chunks of calcite or marble or limestone chips to neutralize it and then you can dispose of it down the drain.

Dioptase and inesite are easily damaged by acids. Even acetic acid, which is the active ingredient in vinegar, can damage these minerals. For some reason, a weak solution of nitric acid is much gentler on these minerals than other acids. Another common mineral that you may wish to remove from some specimens is gypsum. Gypsum is slowly soluble in water, and the best way to remove it is just to place the specimen in slowly circulating water. In a few days the gypsum will disappear.

Some mineral dealers have impressive facilities to clean, trim and prepare specimens for sale. Often these are rooms that contain various kinds of ultrasonic cleaners, high-pressure water cleaning equipment, air abrasive tools, chemical baths, fume hoods, vacuum chambers, heating ovens, etc. Some even offer to clean, trim and repair your specimens for you; sometimes the cost of such services on a single specimen can be several hundred dollars.



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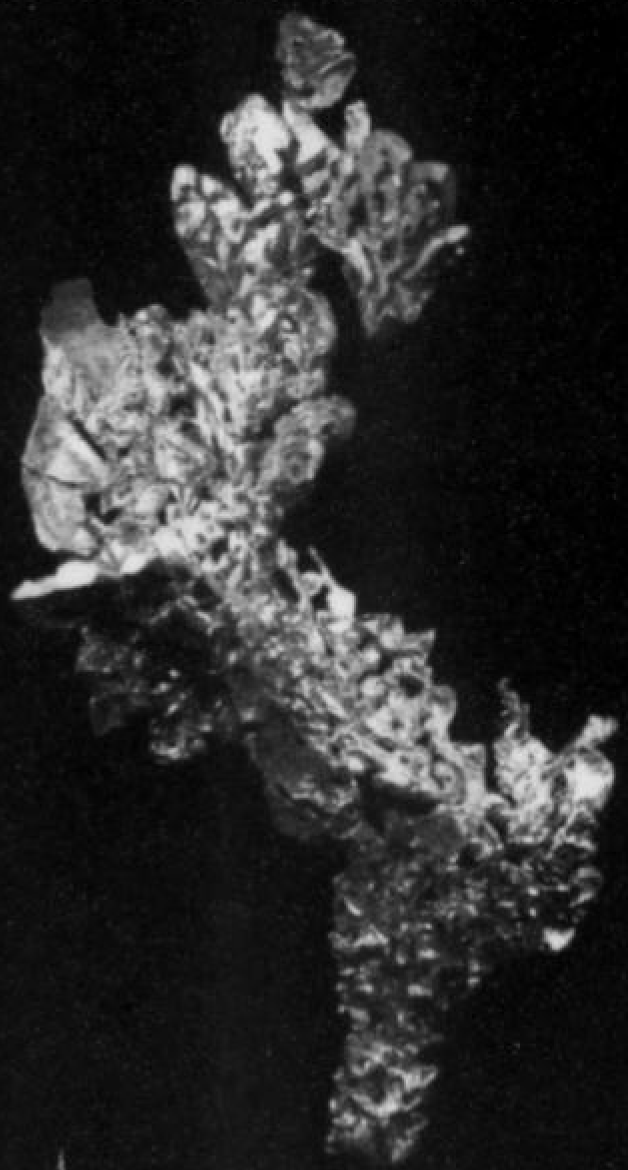

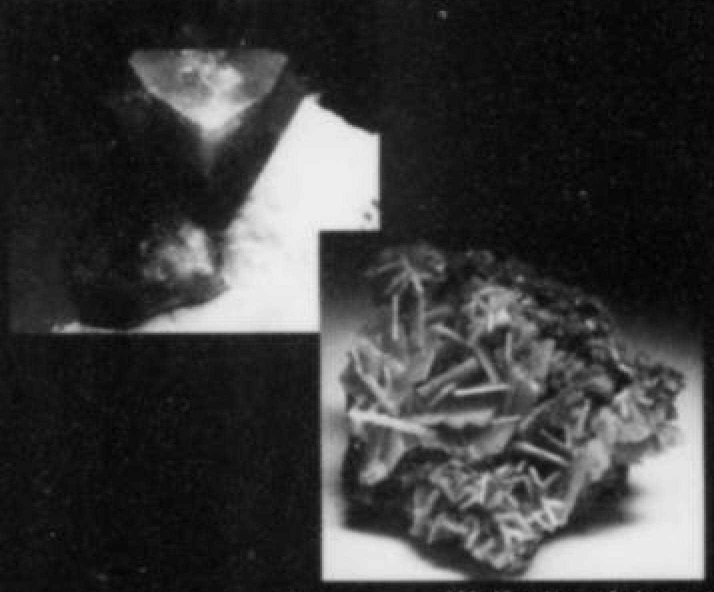

RED CLOUD WULFENITE WENDELL E. WILSON

Legal Nuggets

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Collectors, Investors and Dealers (Oh, My)

During a trip to Berlin in 1891, Mark Twain was mistaken several times for Theodor Mommsen, the eminent German historian and archeologist. Reputedly, Twain became embarrassed when, as he entered a beer hall, the assembly jumped to their feet and pounded their mugs in a toast, only later to find that he was not Mommsen, the true object of their affection. This caused Twain to comment in his diary: "Been taken for Mommsen twice. We have the same hair, but on examination it was found the brains were different."

We mineral afficionados are sometimes prone to misidentifications, particularly when it comes to identifying ourselves as a collector, an investor or a dealer. In these times of expensive rocks there is, perhaps, more tendency than ever to blur those categories. Some collectors fancy themselves as dealers, at least if it means getting into the wholesale ballrooms at Tucson. Yet, other folks who regularly sell minerals, sometimes even at shows, shrink from the notion of being called dealers. And everyone would like to be an investor—at least if that means buying low and selling high. But, lurking behind these seemingly innocent labels are tax ramifications—and, for the unwary, potentially adverse ones.

The income tax law distinguishes between collectors, investors and dealers in a variety of ways. A key provision is section 183 of the Internal Revenue Code, enacted by Congress in 1969 to deal with so-called "hobby losses"—primarily, but not exclusively, those incurred by "weekend" farmers and horse breeders. This provision substantially limits most deductions relating to "an activity not engaged in for profit"—that is, an activity relating neither to an investment nor to a trade or business. Owing to this "hobby loss" section, mineral collectors may deduct their expenses or losses only up to the amount of gross income derived from the collection activities and, even then, subject to other significant limitations in the Code (*e.g.*, to be deductible, miscellaneous deductions must exceed two percent of the taxpayer's adjusted gross income). As a result, the wide majority of collectors can neither deduct the cost of creating or maintaining their collections, nor claim any losses associated with the sale of their minerals. The Code, however, offers collectors one financial ray of hope: they may receive favorable capital gains treatment on the income produced from the sale of their minerals, provided the minerals have been held for a minimum qualifying period.

Unlike collectors, investors may deduct certain costs as expenses incurred in the production of income, and may do so even if those expenses exceed their income from selling minerals. Like collectors, investors also receive favorable capital gains treatment on income produced from the sale of minerals held for investment. Moreover, the favorable tax treatment afforded to "like-kind" exchanges in which taxpayers can swap one specimen for another, potentially tax-free, applies to investors but not collectors.

Dealers too may benefit from this like-kind exchange provision. They may also deduct their expenses as trade or business expenses. But, unlike collectors and investors, they are precluded from receiving capital gains treatment. Dealers, however, enjoy one potentially significant tax advantage unavailable to the other groups: they can not only deduct losses, but may carry net operating losses back and forward to offset income in other years. (Of course, most of them would prefer not having more losses than they can deduct in a single year!)

There are, then, potential advantages and disadvantages to each tax status. Having weighed these pros and cons, many commentators believe that investors receive the most favorable tax treatment—deductible expenses, like-kind exchanges and capital gains treatment. Be that as it may, good tax planning may allow you to maximize your tax savings, while bad tax planning can leave you in a lurch. Indeed, no tax planning might leave you with the worst of two worlds. For example, failing to take deductions to which you are fully entitled in earlier years, only to find in later years, after those deductions can no longer be taken, that the IRS has saddled you with the loss of capital gains treatment.

So, how do we tell the difference between a collector, an investor and a dealer? In its usual helpful way, the tax law answers this question with two more questions.

First, is the activity engaged in for profit? The IRS often resolves this issue by relying on a list of factors, many taken from opinions in cases involving art owners. These factors include: (1) the manner in which the taxpayer carries on the activity—with the taxpayer more likely to have a profit motive if he uses financial projections, has accounting records, or a budget to control expenses; (2) the expertise of the taxpayer or his advisors—with taxpayers pursuing a profit likely to develop more expertise; (3) the time and effort expended by the taxpayer in carrying on the activity—with spending a great deal of time and effort a sign of a profit motive; (4) the expectation that assets used in the activity may appreciate in value—with that expectation really being at the core of a profit motive; (5) the taxpayer's history of income or losses with respect to the activity or similar activities—with long-term profitability being indicative of an intent to realize a profit; (6) the overall financial status of the taxpayer—with the existence of other large sources of income tending to suggest that the taxpayer is pursuing a hobby; and (7) whether the activity has elements of personal pleasure or recreation—with more pleasure meaning less profit motive.[1]

Now, before the last of these factors causes you to shudder, take heart, for the relevant IRS regulation hastens to add that: "[T]he fact that the taxpayer derives personal pleasure from engaging in the activity is not sufficient to cause the activity to be classified as not engaged in for profit if the activity is in fact engaged in for profit as evidenced by other factors whether or not listed." Note too that section 183(d) of the Code creates a presumption that an activity is engaged in for profit if income, in the form of a net profit, is realized from that activity over a certain number of years. These rules, however, are a bit complicated and beyond the scope of this brief column.

If the taxpayer lacks a profit motive, our inquiry is at an end; he is a collector, subject to the limitations of section 183 described above. But, if that individual passes the profit motive test, we reach the second of our queries: is he or she engaged in a trade or business? Here, we encounter yet another facts-and-circumstances test, distilled from decades of court decisions (many involving whether gambling is a trade or business). Among the factors relevant here are:

(1) Whether the taxpayer is involved in the profit-producing activity with continuity and regularity; (2) whether the taxpayer conducts frequent or substantial sales; (3) whether the taxpayer holds himself out to others as engaged in the selling of goods and services; (4) whether profit is expected to be produced not from the long-term appreciation of the asset, but from buying the item at a lower than retail market price and selling it at a market price; and (5) whether the taxpayer maintains books and records that are consistent with conducting a business (*e.g.*, ones that reflect the carrying of an inventory). If the answer to all these questions is "yes," the taxpayer is likely in a trade or business. Yet, in practice, the standard for determining trade or business status is more like that once famously penned by Justice Potter Stewart in describing obscenity—"I know it when I see it." If it looks like a trade or business, in other words, it probably is.

If we apply the profit motive and trade or business tests in tandem, we get the following three definitions:

(1) If you lack a profit motive, you are a ***collector***.
(2) If you have a profit motive, but are not in a trade or business, you are an ***investor***.
(3) If you have a profit motive and are in a trade or business, you are a ***dealer***.

Sound simple? Let's put these twin tests to work on a hypothetical case: Assume that Mr. Primorsky Nikolai occasionally travels to Europe to buy large Dalnegorsk collections. He retains the best specimens for himself, and then resells the rest, in a lot, to a friendly dealer. Sometimes, he makes a profit on these deals, but his financial goal is to come out even, that is, to sell the collection (minus the culled specimens) for about the price he bought it. Mr. Nikolai does not hold himself out as a mineral dealer. He sometimes runs ads that read: "Collector buys very fine Dalnegorsk collections. Top prices paid." He has no current intentions of selling his world-class Dalnegorsk collection. Indeed, while he periodically buys individual specimens directly from dealers, he rarely sells any of his own, even though most of them have greatly appreciated in value.

So what is Mr. Nikolai? A collector? An investor? Perhaps a dealer? Applying the factors above, we can surmise that he is most likely a collector. He appears to be motivated primarily by personal pleasure and does not appear to have a dominant profit motive—at least one that is reflected in his dealings. Because he does not have a profit motive, we need not look at the second test posed above—whether he is in a trade or business. But, looking at all the factors listed above, you can see how his tax status might be different if we modified the hypothetical situation a bit. What if, for example, Mr. Nikolai plans to sell his collection to fund his retirement, and has made financial and budget projections on that basis, seeking advice periodically from experts on the value of Dalnegorsk minerals? What if he keeps a detailed inventory of his collection and, to track the appreciation of his specimens, logs the results of comparable sales or auctions on the internet? What if he has no other significant source of income and, every few months, sells off several duplicate specimens that have particularly appreciated to realize some spending money? With a few tweaks of our hypothetical situation, then, we can improve the case for classifying Mr. Nikolai as an investor.

The astute among you (more likely, the self-interested) are probably asking by now: can a single taxpayer be a collector as to some minerals and an investor or dealer as to others? The answer is a resounding—maybe. The limitation in section 183 applies to "an" activity. In defining the quoted phrase, the IRS regulations[2] state that "where the taxpayer is engaged in several undertakings, each of these may be a separate activity, or several undertakings may constitute one activity." They further advise that "[g]enerally, the most significant facts and circumstances in making this determination are the degree of organizational and economic interrelationship of various undertakings, the business purpose which is (or might be) served by carrying on the various undertakings separately or together in a trade or business or in an investment setting, and the similarity of various undertakings."

Finally, the regulations make clear that while the Commissioner generally accepts a taxpayer's characterization of several undertakings as being a single activity or separate activities, that characterization will be rejected if it is "artificial" and "cannot be reasonably supported under the facts and circumstances of the case." The cases in this area—many of which involve farmers who held some land for cultivation and other land for investment—suggest that, at a minimum, if you are going to hold some specimens for investment and others in a collection or inventory, your recordkeeping should plainly reflect that difference. And those differences should also be reflected on your tax returns, which should report income and deductions, from year to year, that are consistent with your dual tax status.

Yes, there are limits to tax planning. Many of the basic facts that reflect who we are and what we do cannot easily be altered. Nonetheless, the moral of the story is that you should be aware of your tax status (or desired tax status) and plan and act accordingly, particularly, in avoiding activities that might cloud your status and, especially, in maintaining appropriate books and records. So, if you are an investor or collector, you might want to consider whether getting a full-fledged business license (and a business card to match) really are worth increasing the odds that the IRS will treat you as a dealer. Better yet, if you are going to expend significant dollars on mineral specimens or accumulate a collection that has become quite valuable, take some time to sit down with a tax professional and develop a long-term plan. Depending on your age, that plan might be dominated by estate tax considerations. Having that plan

(continued on page 182)

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[1] *See* Treas. Reg. § 1.183-2(b).

[2] Treas. Reg. § 1.183-1(d)(1)

Letters

“Fairness” in Pricing

How does an honest and conscientious mineral dealer (who also may be a collector) evaluate mineral specimens and determine their fair market value in today’s marketplace? I believe that, for the health of the mineral hobby, we as dealers must take some responsibility for the present phenomenon of runaway pricing, and I believe that buyers must work hard to gain knowledge, so as not to be misled too often. I would hope that dealers and collectors alike can agree that it is important to the hobby that “fairness” have an appropriate place in mineral dealings. But what is “fairness?” Are there any useful, objective standards by which this term can be defined? Some would say no, but I think that such standards do exist, and I would define them in terms of three major factors: (1) the judgment of a mineral specimen’s aesthetic properties; (2) the sales history of the specimen, and of similar specimens; and (3) the marketing skills that might be used in making the specimen available to interested collectors.

A mineral specimen’s aesthetic properties include form, color, clarity, luster, crystal size and lack of damage. These variables have been widely discussed in print, and their meanings are obvious for the most part. But aesthetic judgments hinge also on more subtle factors, some unique for each specimen, others more general but harder to define. A good example of one of the latter is the question of “balance” between the size of the crystal(s) and the size of the matrix. I have a friend whom I first met when I began mining “Herkimer diamonds” maybe 15 years ago; he and I have had similar paths of development, and yet he can still show me a specimen with tiny crystals covering the matrix and say “This specimen is superb,” whereas I will say (or think) that “This specimen is okay but a superb example would be a smaller matrix with larger crystals.” Granted, the judgments are subjective, but I’m sure nevertheless that the overwhelming majority of knowledgeable collectors and dealers will agree with me that a smaller matrix with well-placed larger crystals makes for a “better” specimen.

Wayne Thompson’s recently printed monograph *Ikons*—issued as a supplement to the January–February 2007 issue of the *Mineralogical Record*—offers some very clear examples of this criterion. The very greatest of mineral specimens will score at the top of the scale for form, color, clarity, luster, crystal size, lack of damage—and “balance” as well. For such specimens at the pinnacle of quality and desirability, there is no logical way to calculate a value; almost *any* price that someone is willing to pay must be counted as “fair.” They are worth indeed “whatever the market will bear.” It is for all the levels below this one that the concept of “fair market value” is more meaningful and more amenable to analysis. To arrive at this value, the dealer, having considered aesthetics, next thinks about the specimen’s sales history.

The sales history of a specimen is the number of specimens of the same mineral from the same locality that have already been sold, and in what price range. The international art market uses this criterion extensively, basing evaluations on previous auction prices realized for paintings by a particular artist. Here the “subjective” element has to do simply with how much the dealer knows (or is willing to say he knows) of these matters, and how his statements about them influence the buyer. Statements such as “I have not seen these available for years” or “the mine is closed” might be used, in good faith or otherwise, to justify high prices. I recently saw a Chinese green fluorite specimen being offered for sale in Tucson for $1350, but “keystoned” to half that price. Well, these particular green fluorites have been coming out literally by the ton for a couple of years. This was a modest, i.e. moderately good, cabinet-size piece which I thought was worth between $350 and $675. The “unfair,” or deceptive, element here was the mark-up/mark-down technique: the dealer’s pricing it at $1350 to begin with, then saying to the buyer “*You* can have it for half of that,” while even at that “discounted” price it was very near the top of the range of “fair” prices for the material.

The third pricing criterion involves the dealer’s ability to find and cultivate clients who may be interested in a specimen, and to persuade them to buy it. Advertising, photography, promotion, development of personal relationships, wordings of descriptions to highlight positive attributes of specimens—all these are important marketing skills. Specimen preparation techniques such as cleaning, trimming, acid-etching, oiling, and creative siliconing are important skills as well. Some of these techniques may be judged acceptable and others unacceptable, or something in between; such judgments, although “subjective,” flow from common-consent agreements within the collector community (several writers in the *Mineralogical Record* have defined the various preparation techniques, and have suggested ethical judgments on each). Recently I sold a parcel of three specimens from a single locality to another mineral dealer for $300. I made the sale in a wholesale context, judging my specimens to be worth about $525 retail. I knew the locality very well, and knew the quality of the specimens relative to what had come before from that locality; I also knew the price range in which earlier and better specimens from the locality had sold to people I know in the past. Later I found out that one of my specimens had been sold for $1850. I was a bit shocked, and had to question my own abilities to market mineral specimens. After some self-analysis I decided that (1) I had priced my three specimens according to criteria that I had been, and still was, comfortable with, and (2) I owed the other dealer congratulations for making significant profits; he had developed access to some high-paying customers

In the marketplace, everything depends on the dealer's motives. Does the dealer just want to make as much money as possible, even if he must be dishonest about what he regards as a "fair" price? Or does the dealer prefer to sell specimens for what he perceives to be "fair" market value, in order to maintain a reputation for fairness? Buyers need to be aware of which of these philosophies a dealer subscribes to. At the Rochester Symposium recently I was told a story by a well-known mineral dealer whom I respect—a woman well-versed in current market values. She was once looking at a nice miniature-size adamite specimen from Mexico. The seller was offering it at "keystone," i.e. at half the marked price. She was debating the $75 marked price (thinking $37.50), and said to the seller, "I don't know, I think $75 might be a bit steep." The seller replied "You saw a decimal point in the wrong place: it's not $75 but $750." And my friend just laughed and walked away. Nowadays we hear such stories all the time.

I have nothing against making money; in fact, I can always use more. But I do believe that dealers and collectors alike should agree that some concept of "fairness" has an important place in all mineral dealings, and I suggest that the three criteria described above are good ones by which to measure the "fairness" of any transaction where specimens below the very top quality levels are changing hands.

Rocko Rosenblatt
Rocko's Minerals
Margaretville, New York

Mexico-V

I greatly enjoyed the recent issue (Mexico Special Issue V), especially the article by Tom Moore describing the Apex mine at San Carlos, Chihuahua. In this article I was quoted as stating that "fine botryoidal masses of lemon-yellow mimetite from San Carlos . . . were once relatively plentiful." I did indeed state this, unfortunately incorrectly, in *Rocks and Minerals* v. 76 (2001). I have checked my original notes, and I should have attributed the abundant lemon-yellow mimetite to the famous San Pedro Corralitos locality, not San Carlos. I apologize for any confusion I may have caused.

Robert B. Cook
Auburn University

Texas Supplement

I agree with your comments (Notes from the Editors, January–February) about the benefits of the Texas Collections book to the mineral community, but there is more I would add: I feel very strongly that this book has an unprecedented benefit to the larger community in two ways. First, it shows a broad sweep through 29 collections of collectors who are fortunate to be part of a local "peer community" and who enjoy seeing and supporting each other. This aspect might amaze many collectors who live in relative isolation due to location or local competitiveness, and who might have thought that all others do as well. I hope it will inspire other collectors to come out of their shells more and become involved in the broader mineral community. Secondly, this spectrum of collections demonstrates that there is no right and no wrong way to collect. Each person focuses on what appeals to him or her most. This book, for the first time, shows a broad variety of mineral collections together, each one precious and valuable to its owners, regardless of whether their specimens have "trophy mineral" status or would win a Desautels award. I think it should be especially inspiring to new collectors working to find their personal comfort zones.

Rob Lavinsky
Garland, TX

Benitoite Mine

I want to congratulate you on your fine report on the Benitoite Gem mine (January–February 2008). The amount of research you had to do is remarkable. The only information in your article that I would like to correct is the story taken from the Kate Woods article, about how Bryan Lees, on a hunch, found a new shelf of benitoite schist. Actually Buzz Gray and I had found this faulted, dropped portion of the vein about 1½ years earlier. We removed about 65 feet of it, and there was still about 15 feet remaining when we sold the mine to Bryan. This remaining vein portion was pointed out to him prior to the sale. It consisted of tight, narrow veins (with benitoite) that unfortunately failed to produce much in the way of specimens or cutting material. Most of the benitoite crystals found are pale in color and tabular in habit. The specimen owned by Buzz Gray, shown in Figure 32, is the best specimen from this vein.

I just want to set the record straight on this small part of your wonderful article. Again, thank you for publishing the most accurate and interesting article on benitoite ever.

Bill Forrest

Errata

The pyromorphite pictured on page 36 of the Marc Weill Collection supplement is a mid-19th century specimen from the Merkur mine, Bad Ems, Germany (not the Bunker Hill mine). It was originally in the Marcus Baumstarck collection, and then the Paul Stahl collection before being acquired by Marc Weill via Rob Lavinsky.

In the list of donors toward the photo expenses involved in the *American Mineral Treasures Issue* (May–June 2008), Irv Brown should have been listed as well; he and Stuart Wilensky made a donation jointly.

In the 2008 Tucson Show What's New report, Bill Wray's award-winning searlesite crystal was pictured and estimated to be about 5 cm in size; actually it's 8 cm.

Legal Nuggets *(continued from page 180)*

is going to be particularly critical if you want to convince the IRS (or, heaven forbid, a judge) that you are holding some specimens in a collection and others to produce income.

So, the next time someone at the Tucson Show starts a friendly conversation by asking you whether you are a collector or dealer, think twice (and maybe ask to see credentials!). Better yet, if you are serious about your minerals, take a few moments before you go to your next show to do a little tax planning. If you don't, you might some day encounter the IRS revenue agent who once said: "The trick is to stop thinking of it as '***your***' money."

NOTE: This column is for educational purposes only and is not legal advice, or a substitute for such advice. Readers who have questions on this topic should consult with a qualifed lawyer.

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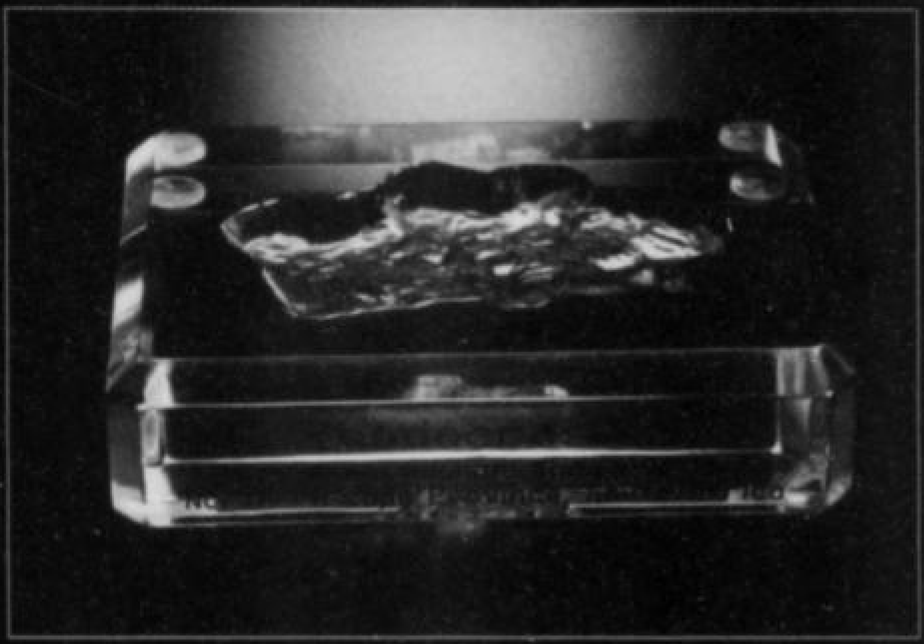

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