Gems & Gemology

The quarterly journal of the Gemological Institute of America

Gems & Gemology

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ABOUT THE COVER: Most laboratories color grade diamonds by comparison with master stones, a subjective procedure that requires very experienced personnel. In recent years, some laboratories have investigated the possibilities of color grading by machine, to provide a more objective procedure. The problems inherent with color grading by machine are discussed in detail by Dr. A. T. Collins in this issue. The 5.07-ct diamond on the cover has been graded D-color (flawless). The stone is courtesy of Jack and Elaine Greenspan, Sedona, Arizona. Photo ©1984 Harold & Erica Van Pelt—Photographers, Los Angeles, California.

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MANUSCRIPT SUBMISSIONS

Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors for preparing manuscripts in this issue of the journal or contact the Managing Editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

Basil W. Anderson
1901-1984

The gemological community lost one of its most accomplished leaders with the passing of Basil W. Anderson from a sudden heart attack on Friday, February 24.

Every time I view a gem's spectrum, or the apricot fluorescence of a Ceylon sapphire, or use a Chelsea filter, I make a mental bow toward London. A pioneer in the field of gem identification, Basil Anderson opened the London Laboratory in 1925, and subsequently built it into one of the foremost gemological laboratories in the world. Although the laboratory was originally started primarily to distinguish between natural and cultured pearls—a very important problem in the '20s—Anderson's probing mind led him to explore spectroscopy and other means of identifying different gem materials. His pioneering studies in the field of gemstone spectroscopy were reported in *The Gemmologist* magazine over a period of several years, and have been used by succeeding generations of gemologists ever since.

In addition to being a very effective laboratory gemologist, however, Anderson was a superb teacher who contributed greatly to the high regard with which the FGA diploma came to be esteemed all over the world. The quartet of B. W. Anderson, C. J. Payne, Robert Webster, and Alec Farn inspired awe wherever gemologists gathered; and Basil Anderson, deservedly, was regarded as the leader of that intellectually robust foursome.

Anderson's book, *Gem Testing,* which was first published in 1942, is now in its ninth edition, and continues to be the classic in the field. In his 1976 book *Gemstones for Everyman,* however, one can experience the full sense of Anderson's warmth and humanity. This timeless book discusses those everlasting objects—gemstones—in a delightfully appreciative manner that is unique. Reading *Gemstones for Everyman* is not only a wonderful experience, but it also gives a true flavor of the unconventional approach to gemology that characterized Basil W. Anderson, and shows very clearly his abiding love for gemstones.

In the last few years, Basil Anderson had recovered from problems with his eyesight and appeared to be enjoying his retirement with his lovely wife, Barbara. He continued to work hard, preparing the fourth edition for Robert Webster's *Gems: Their Sources and Identification,* which was published in 1983.

Probably no gemologist anywhere was more respected and loved than Basil Anderson. He will be sorely missed.

Richard T. Liddicoat, Jr.

THE GEMS & GEMOLOGY
MOST VALUABLE ARTICLE AWARD

ALICE S. KELLER   Editor

"An excellent year—thank you *Gems & Gemology*. Of the 30 journals I subscribe to, this one is the best all-round for science-writing-pleasure." . . . "Congratulations on a superb periodical. In all honesty, all the authors deserve first prize." . . . "*Gems & Gemology* is the finest source of information and pictorial reference and update to help all segments of the gem and jewelry field." . . . "Love this magazine!"

These are just a few of the many comments we received in this year's balloting for the most valuable article published in 1983. Other readers singled out the accuracy of specific articles, the importance of the regular sections (Gem Trade Lab Notes, Gem Abstracts, Gem News, and Book Reviews), the excellence of the reproduction (compliments of our color separator Effective Graphics and printer Waverly Press), and the fine photography (all of the covers for the 1983 issues were specially designed and donated by Harold & Erica Van Pelt—Photographers, Los Angeles). Our thanks to you, our subscribers, for helping us prove that the jeweler/gemologist would give full support to a professional journal: *Gems & Gemology* is now being mailed to more than 10,000 subscribers—a long way from the 1,400 we started with in Spring 1981.

Hundreds of you sent in ballots to indicate your choices for the most valuable article. The voting was so close this year that we had to declare a tie for the third-place award. The winning article for 1983 was "Kashmir Sapphire," by David Atkinson and Rustam Z. Kothavala, which appeared in the Summer issue. Placing second in the voting was Ron Ringsrud's article "The Oil Treatment of Emeralds in Bogotá, Colombia," which was published in Fall. The two articles that tied for third place were "Art Deco: The Period, the Jewelry," by J. Mark Ebert (Spring issue), and "Induced Fingerprints," by John I. Koivula (Winter issue). Cash prizes of $500, $300, and $100, respectively, will be awarded to the winning articles in each category. Brief biographies of the authors appear on the following page.

The editors and I would like to take this opportunity to thank those members of the editorial review board who worked so hard to maintain the standards of the journal. Special thanks go to Ralph Esmerian, Henry Meyer, David Atkinson, Jill Fisher, and Joe Borden, who were kind enough to serve as guest reviewers on specific articles during the past year.

As I hope this current issue indicates, 1984 promises to be another good year for gemology and *Gems & Gemology*. We will continue to do our best to live up to your plaudits and expectations.

DAVID ATKINSON

A native Australian, Mr. Atkinson came to California in 1977 after two years of travel throughout Asia, including Burma, northern India, and Afghanistan. His familiarity with these areas and knowledge of the local languages led him to specialize in rare gems and minerals of Asia. Since the expedition to Kashmir in 1981, he has returned to the region several times. He has lectured extensively on India's northwest frontier district and other Asian gem deposits. His company, TERRA, is in Santa Barbara, California.

Mr. Atkinson graduated from the University of Western Australia in 1971 with a combined major in mathematics and linguistics.
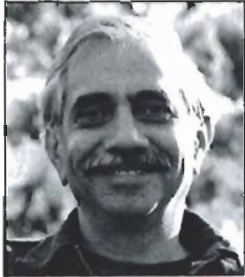
RUSTAM Z. KOTHAVALA

Formerly a lecturer in geology at Harvard University and director of the Harvard Science Center, Dr. Kothavala devoted most of his efforts from 1972 to 1982 to his firm, Crystals from India. During his many years as a mineral collector and dealer, Dr. Kothavala has traveled extensively and become a popular lecturer. He currently provides consulting services to museums and gem and mineral collectors through his company, Rustam, located in Oakland, California.

Dr. Kothavala has a master's in chemistry from Madras University, a master's in geology from the University of Arizona, and a Ph.D. in geology from Harvard University.

RONALD H. RINGSRUD

Mr. Ringsrud is a graduate gemologist and former sales manager of the GEM Instruments Showroom in Santa Monica. He presently imports emeralds for Constellation Gems of Los Angeles. A former resident of Manizales, Colombia, Mr. Ringsrud has lectured on various topics in Colombia, Nicaragua, and Mexico.

Mr. Ringsrud received his B.A. in Spanish and psychology in 1973 from the University of South Dakota, Vermillion. He has also studied Spanish and archaeology at the National University of Mexico in Mexico City.

J. MARK EBERT

As president of Ebert, Richter, Inc., of Los Angeles, Mr. Ebert is actively involved in the supply of loose diamonds and in the buying and selling of estate jewelry. In addition to his more than 10 years' experience in both the wholesale and retail ends of the jewelry industry, Mr. Ebert taught Diamonds and Colored Stones at GIA Santa Monica for five years. A certified gemologist, Mr. Richter has spoken before a large number of jewelers' organizations.

Mr. Ebert was born and raised in Pennsylvania. He graduated from Penn State University with a degree in history.

JOHN I. KOIVULA

Mr. Koivula is senior gemologist in the Applied Gemology Department at GIA Santa Monica. Specializing in photomicrography, Mr. Koivula recently placed in both the Nikon International Small World and the Los Angeles Microscopical Society's annual competitions. He also lectures extensively, and is currently working on a book dealing with inclusions in gemstones that is scheduled to be published in 1985.

Mr. Koivula received a B.A. in chemistry and a B.S. in mineralogy from Eastern Washington State University. In addition, Mr. Koivula is both a certified gemologist and a fellow of the Gemmological Association of Great Britain.

THE SANTA TEREZINHA DE GOIÁS EMERALD DEPOSIT

By J. P. Cassedanne and D. A. Sauer

The Santa Terezinha de Goiás emerald deposit, currently the most important source of emeralds in Brazil, lies northwest of Brasília, in the State of Goiás. The emeralds, most of which are stones of a carat or less, occur in a talc schist layer intersected by pegmatite. The emeralds are recovered by independent miners via trenches, pits, and tunnels at two prospects: Trecho Novo and Trecho Velho. The grade of the ore is: 1 to 6 parts of emeralds to 10,000 parts of ore. The density of the gems is 2.70; the refractive indexes are 1.580 and 1.588, with greenish dark blue/yellowish pale green pleochroism. The spectrum is typical, with two strong lines and two partial absorption bands; there is no fluorescence; pyrite and chromite are the most typical inclusions, with calcite crystals present in minor amounts.

ABOUT THE AUTHORS

Dr. Cassedanne is professor of mineralogy at the Geosciences Institute of the Federal University of Rio de Janeiro, Brazil; and Mr. Sauer is director of Lapidação Amsterdam, S.A., Amsterdam Sauer, Rio de Janeiro, Brazil.

The search for emeralds has been the primary motivation for many expeditions into the interior of Brazil, all with the hope of discovering emerald deposits as rich as those found in the Colombian Andes. Occurrences of emerald were noted early in this century, but none proved to be commercially important. Finally, in 1963, the first major emerald deposit was discovered in the São Francisco river valley, in the state of Bahia. Known as the Salininha deposit, it produced about 300 pounds (135 kg) of emeralds before it was exhausted. Today, the mine site is flooded by the waters behind the Sobradinho dam. Immediately after this discovery, in 1963–1964, a large emerald field was found at Carnaiba, also in Bahia. The output from the Carnaiba mines, which are still active, eventually placed Brazil among the world's leading producers of emerald. This position was reinforced by the opening, in 1978, of the Belmont mine near Itabira, Minas Gerais. However, it was the discovery in 1981 of the Santa Terezinha emerald deposit in Goiás that consolidated Brazil's position as a leading producer of emeralds (figure 1).

Even though a fourth deposit, called Socotó, has since been found near Carnaiba, it has not proved as important as the Santa Terezinha mine, which currently reigns as the center for emerald production in Brazil and yet about which little has been published. We propose, therefore, to describe the Santa Terezinha emerald deposit, including the geology, occurrence, mining methods, and gemological aspects of the stones produced.

LOCATION AND ACCESS

The Santa Terezinha emerald deposit is 230 km (143 mi.) northwest of Brasília, the federal capital, and about 275 km (170 mi.) north of Goiania, the capital of the state of Goiás. Approximate longitude and latitude are 49°20′W and 14°15′S (figure 2).

Santa Terezinha is a small town that has developed

Figure 1. An assortment of fine faceted and cabochon emeralds from Santa Terezinha de Goiás, Brazil.

with the mine. It can be easily reached by either land or air from Brasília or Goiânia. By land, the first two-thirds of the trip is made on the paved Belém-Brasília highway, via Anápolis. The remaining 85 km to Santa Terezinha, however, must be taken over an unpaved road (in good condition during the dry season) that passes through the towns of Itapaci and Pilar de Goias. Access to the mine site is via a good north-south road that crosses Rio do Peixe valley, a little over 20 km.

The city itself is situated on a large, partially eroded lateritic plateau at about 380 m (1,250 ft.) elevation. The main river in the region is the Crixás-Açu, which flows into the Araguaia, and eventually empties into the Amazon.

Originally, the area's vegetation consisted of *cerrado*, a low evergreen forest interspersed with high grass. Tropical vegetation occurs intermittently along the creeks, forming gallery-like forests. Much of the land is now under cultivation, and the original virgin forests have been replaced by open areas of grass or crops. This area has a typical monsoon climate: heavy rains occur from December through March, and the rest of the year is very dry.

HISTORY OF MINING IN SANTA TEREZINHA

Since 1920, emeralds have been produced sporadically in the state of Goiás, but only in very small quantities (Gonçalves, 1949). The best-known deposit is at Fazenda das Lages, near Itaberai, 34 km southeast of the town of Goiás and south of Santa Terezinha (Leinz and Leonardos, 1959). In 1966, a joint venture between Cia Itabras de Mineração and the mine owners produced 15 kg of emeralds of medium-low quality from a colluvial deposit.

In 1974, the so-called Serra Dourada deposit was discovered 36 km from Minaçu (Garimpo de Pela Ema), east-northeast of Santa Terezinha. A small emerald production from pegmatites injected
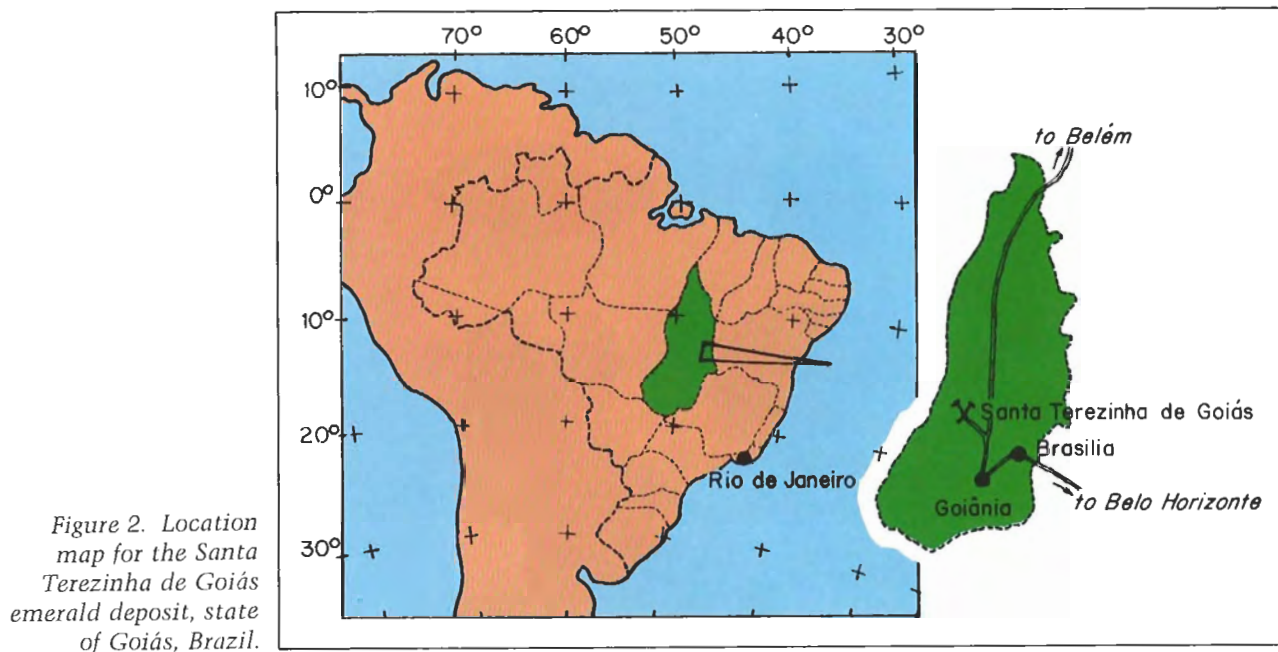
Figure 2. Location map for the Santa Terezinha de Goiás emerald deposit, state of Goiás, Brazil.

in mica schists was supported for about one year (de Souza and Zalán, 1977).

The Santa Terezinha emeralds were, in fact, discovered some years ago, when a farm road was opened by a bulldozer. The green "stones" were collected by children who threw them at birds. Nobody thought they were gems, probably because the crystals collected on the ground were heavily stained by iron oxides. In March 1981, however, a gem dealer from Governador Valadares identified the true nature of the stones. Immediately there was a rush of *garimpeiros* (independent miners) and work began on part of the lateritic plateau at a place called Garimpo de Cima ("upper mine," later referred to as Trecho Velho, or "old workings"). In June of the same year, emeralds were discovered in a north-south–flowing creek, to the north of the earlier deposit, and a new mine, called Garimpo de Baixo ("lower mine," later referred to as Trecho Novo, or "new workings"), was opened. After exploring the eluvium, the garimpeiros reached the underlying emerald-bearing rock, and developed the workings accordingly. Since 1981, the deposit has been worked continually with only short interruptions caused by heavy rains or technical problems.

GEOLOGY

The Santa Terezinha region is part of the Brazilian shield. Middle Precambrian rocks belonging to the Araxá Group (1100–1600 million years old; Barbosa, 1955) are exposed and unconformably over-lain by rocks of the Bambuí Group (570–1100 million years old).

The Araxá Group consists mainly of mica schists and quartzites, varying in thickness from a few hundred to almost 2,000 meters. Basic and ultrabasic intrusions and sills occur and appear to be contemporaneous with the sedimentation (Angeiras, 1968).

Sediments of the Araxá Group were metamorphosed during the Uruaçu tectonic cycle (de Almeida, 1971), resulting in north-south trending folds. During the main orogenic phase, syntectonic granitic batholiths were intruded as were alkaline rocks. Pegmatoid granites and granitic pegmatites were emplaced during a post-tectonic magmatic phase. It is in these metamorphosed rocks that the emeralds are found.

Garimpo de Cima—Trecho Velho. These workings, on the eastern side of a flat valley, are reached by an 800-m-long track that forks from the road of Rio dos Bois. Emeralds were first discovered in surface material southeast of the actual mine. The gem material was later recognized in situ in the underlying talcose schist; it is now being mined via large trenches, pits, and tunnels (figure 3).

The eluvial material is a sandy yellow to brown argillaceous soil containing angular fragments of milky quartz and hematite schist, quartzite, and talc schist; limonitized cubes of pyrite; martitic octahedrons of magnetite; and granules of laterite. Many emerald crystals up to 1 cm, heavily stained
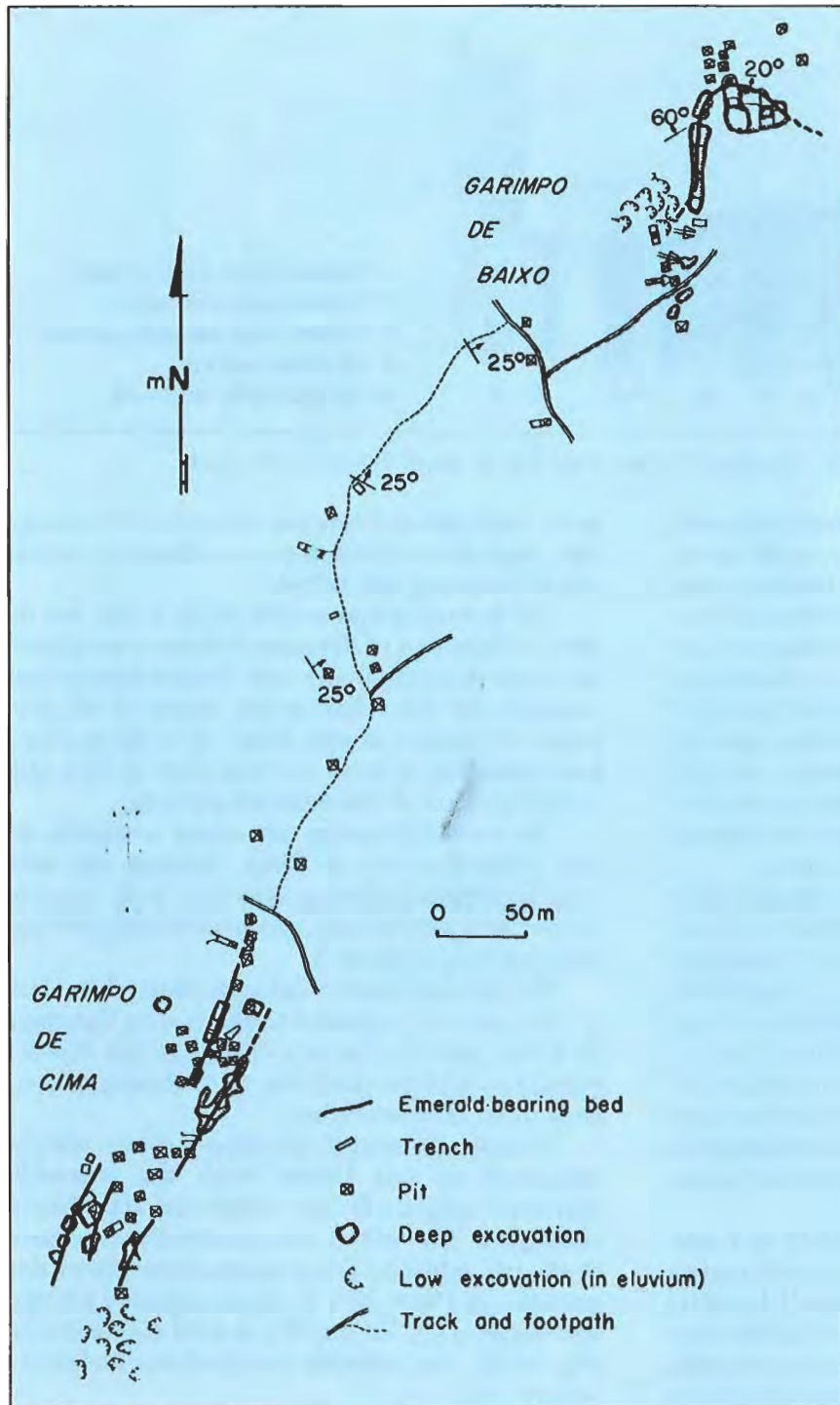
Figure 3. The two main workings, Garimpo de Cima and Garimpo de Baixo, of the Santa Terezinha emerald deposit (as of 1982).

Legend:
- ─── Emerald-bearing bed
- / Trench
- ⊠ Pit
- ○ Deep excavation
- ⊂ Low excavation (in eluvium)
- ⟋⋯ Track and footpath

by limonite, have frequently been found in the eluvium.

The finer-grained fraction of the eluvial material consists of the same rocks and minerals described above plus botryoidal coatings of manganese oxides, plates of mica and talc, unweathered pyrite, greenish brown to blackish prisms of tourmaline, colorless zircon, needles of rutile, and orange-red garnet crystals, as well as some monazite and ilmenite, rounded grains of chromite, and, rarely, fragments of light blue beryl associated with small bits of emerald.

The eluvial material, which is now worked out, generally produced emeralds of a lower qual-

Figure 4. A geologic cross-section of the Garimpo de Cima workings in Santa Terezinha de Goiás.

Labels in figure:
W
E
0 1 m
shored pit
1. Hematite schist, purple in color
2. Emerald-bearing talc schist
3. Feldspar schist with quartz veinlets
4. Weathered acid rock
5. Hematite schist, red in color

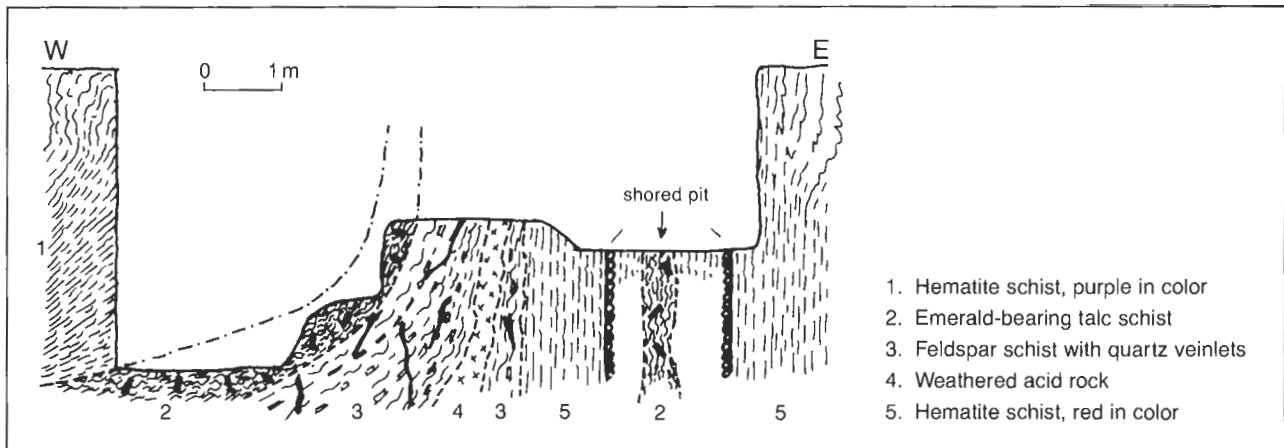ity than those found in the unweathered rock. However, studies of eluvial samples made by the Federal University of Rio de Janeiro indicate a correlation between the amount of beryl/emerald in the eluvium and that in the underlying rock. For example, a sampling of the fine heavy fraction of eluvium showed 0.35 g of emerald per 8 liters of sample. It is believed that this simple method, accomplished by "panning" the surface soil and examining it with a microscope, can be used to determine the lateral extent of the present deposit, and also to identify new producing areas.

At the Garimpo de Cima deposit, there are two distinct continuously mineralized beds of emeraldiferous rock which are called *linhas*, or streaks, by the garimpeiros. Each is presently worked by deep trenches, pits, and adits, depending on local conditions. Mineralized lenses were also observed, as was a third, relatively short, mineralized bed to the east. Most of the excavations on this third bed are caved in, and are presently abandoned. In all exposures, the wall rocks are subvertical schists that dip north.

The emerald-bearing rock consists of a partially weathered talc schist, pale brownish gray in color and stained by iron oxide. Small limonite nodules result from the oxidation of pyrite crystals. The emeralds always occur in small crystals, either as short prisms or as very cracked pieces, scattered or in groups. They apparently bear no relation to the schistosity or the strike of the talc schist. A cross-section of the deposit is illustrated in figure 4.

Garimpo de Baixo—Trecho Novo. This newer mining site lies on the west side of a south-north–flowing creek, intersecting the creek at its north end. Quartz-rich eluvium similar to that mined

at the Garimpo de Cima had been worked in irregular, shallow excavations prior to discovery of the emerald-bearing talc schist.

The vertical schist strikes north-south, but in the northern part of the mine it forms a periclinal structure that dips to the east. Several pegmatites intersect the talc schist in the region of the pericline. A number of pits, some up to 80 m deep, have been dug to mine the emeralds in this, the richest portion of the mineralized zone.

The emerald-bearing talc schist is similar to that of the Garimpo de Cima, although the wall rock is slightly different: quartzite beds outcrop in the northwestern pits, as shown in the geologic cross-section in figure 5.

The fact that there is only one mineralized bed in this area, as compared to the two in Garimpo de Cima, may be due to a change in the depositional facies of the quartzite, or to structural controls of Be mineralization.

The emerald-bearing talc schist is almost wholly composed of talc flakes, with the emeralds scattered irregularly but relatively abundantly throughout the rock. A semiquantitative analysis of the talc schist by X-ray fluorescence shows the presence of 1% to 10% Fe, approximately 1% Ni, and traces of Cr, Zn, and Rb, as well as prominent Mg and Si. It is probably an ultrabasic metamorphosed rock.

The pegmatites occur as veins or lenses that intersect the emerald-bearing talc schist and associated wall rocks. They are essentially composed of pearly white sericitized and kaolinized feldspar (in large crystals displaying curved cleavage surfaces), associated with some quartz (pink at times) and a few green and blue beryl crystals that have no gem value. Green talc in winding veinlets is abundant. Near its contact with pegmatite, the

emeraldiferous talc schist includes irregular bands of a grayish mica that has a golden luster similar to that found in the Carnaiba emerald field (Cassedanne and Cassedanne, 1974). Lastly, pockets and veins of quartz, frequently in vugs, commonly occur in the emerald-bearing talc schist and wall rocks.

Origin of the Deposit. It is probable that the emerald mineralization is due to beryllium-rich fluids released by the beryl-bearing pegmatites. The emeralds grew in the talc schist and from the schist incorporated inclusions of chromite, pyrite, and talc. Later tectonic folding caused fracturing of some of the pre-formed emeralds. In general, the deposit is of the mica-oligoclase-beryl type as defined by Smirnov (1977).

Figure 5. A geologic cross-section of the Garimpo de Baixo workings in Santa Terezinha de Goiás.
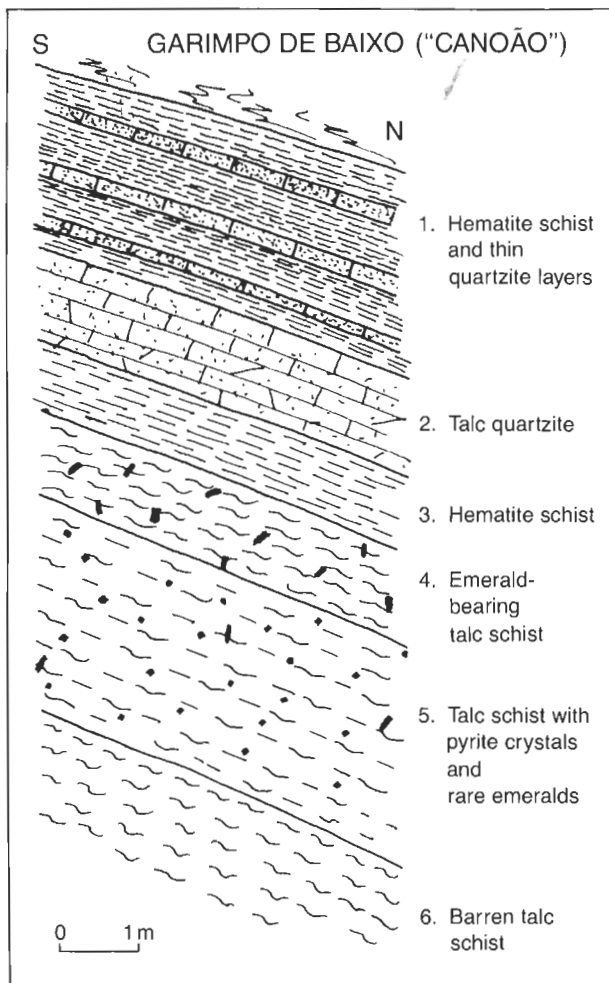
MINING METHODS

The Santa Terezinha deposit currently is mined only by garimpeiros using primitive methods. Each miner or group of miners works an area that is limited on the surface, usually 4 × 4 m, but can extend to any depth. This system of dozens of small claims has resulted in the disorganized development of the locality; currently the richest mining areas resemble the "Big Hole" of Kimberley at the height of its production.

The emerald-bearing talc schist is first exposed through trenches dug along the bed; small square pits are then excavated to remove the ore (figure 6). Because the weathered rocks are so unstable, the pits must be shored up with timber. Even so, security is marginal. The risks are increased by the great depths of some pits (most usually extend 10 to 50 m, but some go as deep as 80 m in Garimpo de Baixo) and the driving of adits from the bottom of other pits to recover more of the emerald-bearing rock. Almost all rock removal is done by means of hand tools; blasting is used only rarely, when exceptionally hard rock is encountered.

TREATMENT OF THE ORE

The recovered ore is treated on the site or taken by truck to washing plants near the mining camp or along the banks of nearby rivers or creeks. Usually, the ore is then concentrated by hand through simple sorting with a coarse sieve. However, a mechanized method is also widely used. With this method, the stockpiled emerald-bearing talc schist is gradually poured into a large vertical barrel called a "blender." The emerald crystals are separated from the soft talc schist as the blender arm rotates the ore in water; the fine material is then carried away by the overflow (figure 7). The process is interrupted periodically so that the concentrate that has settled to the lower part of the blender can be removed. The emeralds are then sorted manually with a sieve.

In recent months, some miners have decided not to process the ore themselves but rather to sell the emerald-bearing rock. Many trucks full of ore for sale now leave the mine site daily. A wheelbarrow with approximately 50 kg of ore is frequently the unit for a transaction. In August 1983, one wheelbarrow of ore sold for about US$150.

GRADE, PRODUCTIVITY, RESERVES

The grade of the ore has a wide range, from 1 to 6 parts of emerald to 10,000 parts of ore. The aver-

age yield is 11 carats per cubic meter, which is about 50 times richer than the Belmont emerald mine near Itabira (Minas Gerais). It is generally accepted that a truckload (about 6 cubic meters, or 10 metric tons) yields one kilogram of emeralds; the quality of the emerald usually varies depending on the specific locality from which the ore was mined.

Precise figures on the amount of emerald produced to date are not available, nor has adequate research been conducted to determine the full extent of the deposits. However, inasmuch as many intrusive ultrabasic bodies and sills are known to exist in the central part of the state of Goiás, where berylliferous pegmatites are common, it appears reasonable to suggest that other emerald occurrences may be discovered in the near future. For example, many talc schist outcrops were found during geological prospecting by Shell do Brasil in the townships of Crixás and Santa Marta, about 30 km from Santa Terezinha.

THE SANTA TEREZINHA EMERALD

In the talc schist, the emerald frequently occurs as well-formed but stubby crystals, generally less than 1 cm long. Crystal clusters also occur embedded in the talc, quartz, or mica host rock; often they have no gemological value. The emerald fragments encountered here are probably the result of fracturing that took place during tectonic events following crystallization and are seldom suitable for cutting. Many emeralds that included pyrite during growth have been found to be cavernous where the pyrite has altered, and are stained by iron oxides. The crystallographic forms are usually prisms and basal faces. The prism faces are generally dull, due to a thin coating of talc flakes which are removed by weathering or during the processing of the ore.

The emerald ranges in color from pale to very dark green with a distinct bluish green tone (figure 8); it is seldom yellowish green. Although in some crystals the color is evenly distributed, more often it is zoned parallel to the prism faces. Occasionally, the cores are colorless. Variation in color along the main axis, however, is seldom seen. The color is believed to be due to chromium.

In terms of cutting quality, many crystals contain numerous cracks, either parallel or perpendicular to the main axis. Inclusions are frequent

Figure 6. Square pits are used to excavate the emerald-bearing ore at the Garimpo de Cima.
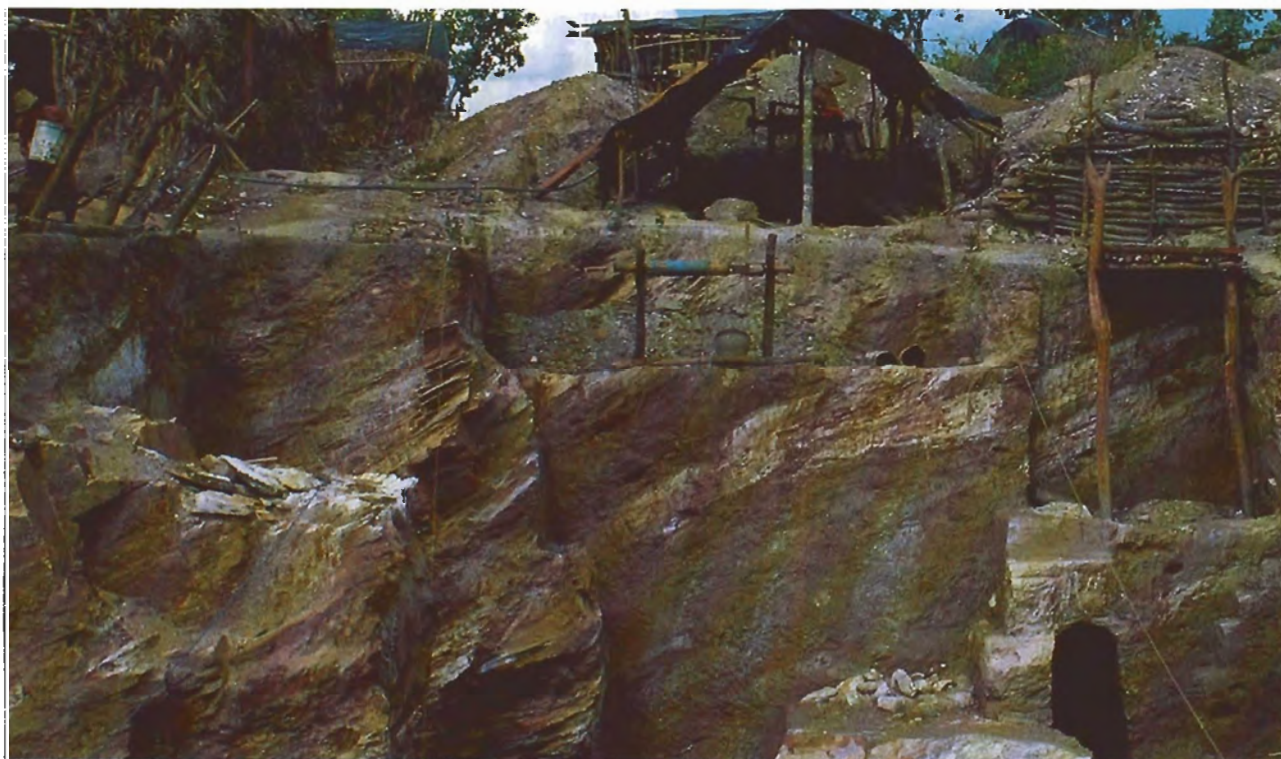
Figure 7. Ore is washed at Santa Terezinha de Goiás using large barrels, or "blenders," to separate the emerald crystals from the soft talc schist.

and scattered randomly. Some of the crystals examined had an almost opaque inner coating (iron and manganese oxides), and others showed a parallel intergrowth with quartz crystals.

The emeralds found in the eluvium, principally from the Garimpo de Cima, were often cracked, and had an unattractive blue gleam. The discovery of the Garimpo de Baixo, and subsequently the general deepening of its workings, has resulted in a higher percentage of relatively clean emeralds with a pleasant bluish green color, as well as the extraction of some fine yellowish green gems. The best faceted gems seldom exceed one carat in weight.

GEMOLOGICAL PROPERTIES

The physical properties of the Santa Terezinha emeralds are as follows:

- Specific gravity: 2.70 (+0.015; crystals included with pyrite may have an S.G. as high as 3.05)
- Refractive indices: o = 1.580 (±0.001), e = 1.588 (±0.001)

- Birefringence: 0.008
- Pleochroism: greenish dark blue/yellowish pale green
- Fluorescence and radioactivity: none
- Chelsea filter: inert to pink; usually the color is unevenly distributed
- Absorption spectra: sharp lines at 6920 and 6950 Å, and partial absorption between 6000 and 6350 Å and between 4000 and 4450 Å.

Crystals with few or no inclusions are perfectly transparent. The most important inclusions are pyrite, chromite, talc, and calcite, although other minerals have also been observed, as described below.

Pyrite (and limonite pseudomorphs after pyrite) is the inclusion most common to the Santa Terezinha emeralds. The pyrite occurs as sharp or slightly rounded cubes, isolated or in groups (figure 9). Numerous minute crystals may form tiny clouds.

Chromite is present as black rounded crystals or in octahedrons up to 2 mm wide. The large individual crystals are isolated, and the small ones

Figure 8. An assortment of emerald crystals from Santa Terezinha. The crystals average approximately 1 cm in length.

form irregular clouds or films and trails parallel to the basal faces (figure 10). Semiquantitative analysis of the chromite by X-ray fluorescence showed approximately 0 to 1% zinc and traces of manganese and nickel in addition to iron and chromium.

Talc flakes, generally white and silky, are so abundant in some emeralds that they make the crystal appear cloudy. The flakes are sometimes regularly oriented at 60° on the main axis of the emerald crystal.

Calcite occurs as transparent to translucent rhombohedrons and as irregular pinpoint-like flakes observed singly or in groups. Analyses have shown that some of the calcite contains traces of magnesium, suggesting a solid solution toward dolomite, another carbonate.

Among the other inclusions observed are hematite, which occurs as flattened reddish translucent crystals scattered throughout the emerald; ilmenite, which has been observed in plates resembling the typical inclusions of certain Minas Gerais aquamarines; and goethite, which we have tentatively identified in the brownish yellow parallel fibers that have been encountered in a very few emeralds. Fingerprints formed by calcite or

Figure 9. A well-formed pyrite inclusion in emerald from Santa Terezinha de Goiás. Magnified 45×.

Figure 10. Chromite inclusions in emerald from Santa Terezinha de Goiás. Photomicrograph by John I. Koivula, magnified 50×.
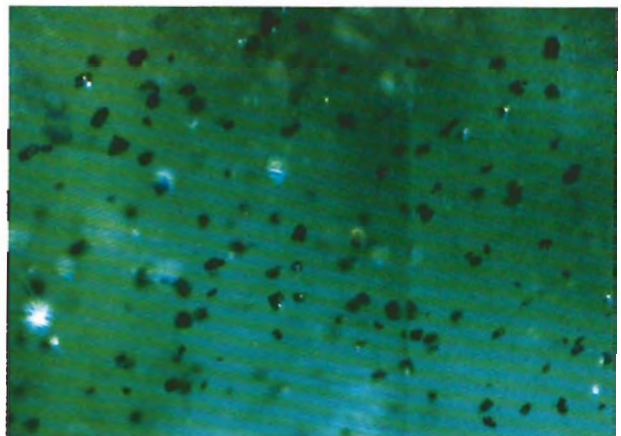
limonitized pyrite also occur, as do two-phase inclusions.

In contrast to other emeralds from Goiás, for example Fazenda das Lages, the Santa Terezinha gems are cleaner and more transparent. Rutile needles have been observed only in emeralds from the Fazenda das Lages deposit (Sauer, 1982).

CONCLUSION

Presently Santa Terezinha de Goiás is the main active producer of emeralds in Brazil. The emeralds are recovered from a Cr-talc schist layer intersected by Be-bearing granite pegmatites. The gems are small, yet of good quality. Chromite and pyrite are the most prominent inclusions, with calcite observed in minor amounts. Deep reserves that can be reached by pit mining promise another few years of production. It is also probable that there will be new finds in the vicinity.

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PITFALLS IN COLOR GRADING DIAMONDS BY MACHINE

By A. T. Collins

Diamonds are normally color graded by comparison with sets of master stones. This method is purely subjective and requires considerable experience. In principle, spectroscopic techniques should enable color grading with high precision by relatively inexperienced operators. In practice, there are at least two major sources of error—luminescence and scattered light—that may make spectroscopically determined color grades unreliable.

The color grading of diamonds by machine is seen as desirable by some gemologists for two reasons: first, it eliminates the subjective comparison with master stones by replacing them with a numerical color index, and, second, it can be carried out by relatively inexperienced operators. A number of laboratories have developed, and are developing, equipment with various degrees of sophistication for color grading diamonds. Read (1983) reviews those instruments that are available commercially. Although some techniques are believed to be reliable, others are known not to be. In this article, I draw attention to some of the problems that can arise in using spectroscopic instrumentation for color grading diamonds.

COLOR AND ABSORBANCE

It is not difficult to measure the relative transmission of a diamond at different wavelengths, but a description of how *strongly* the diamond is absorbing at a particular wavelength requires the calculation of a quantity that is related to the *absorbance* of the diamond. Consider in figure 1 a diamond shaped as a rectangular slab, and suppose that at a particular wavelength the intensity of the light incident on the diamond is I_o and the intensity of the light transmitted is I_t. Even for a completely colorless diamond, I_t is only 71% of I_o because light is lost by reflection at the two flat surfaces. For a diamond that also *absorbs* light (i.e., that has some color), a good approximation of the absorbance (A) is given by the equation:

$$A = \log_{10}(I_o/I_t) \quad + \quad \text{constant} \quad\quad (1)$$

where the constant takes into account the reflectivity losses mentioned above.

By comparing the above formula with that used for *absorption coefficient* (see, for example, Collins, 1982), we can see that absorbance is proportional to the product of absorption coefficient and thickness. Thus, if a large dia-
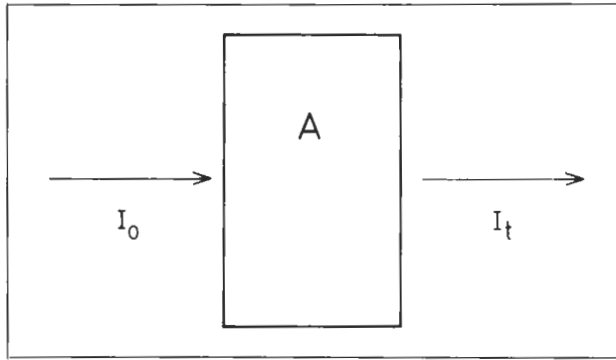
Figure 1. *Transmission of monochromatic light through a diamond with parallel faces. I_o and I_t are the intensities of the incident and transmitted light, and A is the absorbance at the chosen wavelength.*

mond and a small diamond are cut from the same piece of uniformly colored rough stone, the larger diamond will have a higher absorbance as well as a deeper color. The absorption coefficient of both diamonds will be the same, however.

Gem diamonds, of course, are not cut in the shape of a rectangular slab, and it is therefore not possible, regardless of the method used to measure the absorption spectrum, to *calculate* a value for the constant in equation (1). However, the vast majority of diamonds do not absorb light at the red end of the visible spectrum, so the standard procedure is to measure the absorbance spectrum and *choose* a value for the constant that makes A equal to zero at long wavelengths. A typical example for a Cape-yellow diamond is shown in figure 2. Diagram (a) shows the transmission spectrum in relative units, and diagram (b) shows the absorbance spectrum after adjusting A to zero at long wavelengths. Adjusting A to zero is equivalent to setting I_t to 100%, and the data in diagram (a) have been scaled in this way. Figure 2(a) therefore represents the *internal transmittance* of the diamond (i.e., the transmittance in the region of the diamond between the two reflecting surfaces); from such a spectrum in the range 380 to 780 nm, *chromaticity coordinates* can be calculated which describe the color, and the intensity of color, of the stone being investigated. There are problems, however, associated with luminescence and scattered light, which I shall deal with later in this article. It is also clear from the above that unless the diamond is known to be nonabsorbing at certain wavelengths, there is no reference point from which to scale the data, and calculation of the chromaticity coordinates cannot be meaningful. Consequently, scaling data for brown and gray
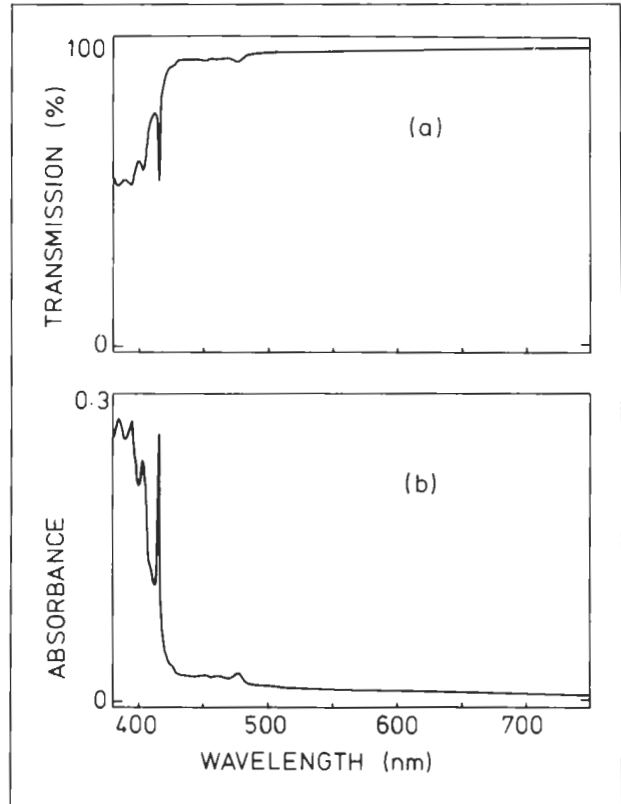
Figure 2. *Spectra, recorded with the sample at room temperature, for a Cape-yellow diamond shown as (a) relative transmission and (b) absorbance. The absorbance has been adjusted to zero at long wavelengths.*

diamonds, which absorb all the way through the visible spectrum, is likely to be particularly troublesome. These difficulties notwithstanding, the Laboratorio di Analisi Gemmologiche (Rome) claims to have obtained reliable results when color grading diamonds by this method (Andergassen, 1982, pp. 214–217), and the Hoge Raad voor Diamant (HRD—Diamond High Council) in Antwerp is working on equipment to color grade diamonds in this way (see, for example, Haazen, 1982).

INSTRUMENTATION

Most of the more sophisticated instruments for color grading gemstones make use of a monochromator or spectrophotometer fitted with an integrating sphere. In its simplest form, illustrated in figure 3, the integrating sphere has three apertures. Light from the exit slit of the monochromator is focused through the entrance port onto the sample placed at an opposite aperture. The inside of the sphere has a special white coating; the diffuse light

reflected by the sample is collected by the sphere and measured by the photomultiplier. Few samples will produce perfectly diffuse reflections; in general there will be a specular (i.e., mirror-like) reflection of the incident light from the surface. In some cases—e.g., for a sample of gloss paint or ceramic tile—this specular reflection may be considerable. If the color of the sample is to be measured accurately, it is important that the specular reflection not be detected by the photomultiplier. The sample must, therefore, either be placed at an angle to the incident light and the reflected component directed to an absorbing baffle (as shown in figure 3), or be mounted perpendicular to the incident light beam so that the specularly reflected light is directed back through the entrance port.

When using such a system to color grade diamonds, a number of difficulties arise. First, the diamond does not re-emit the light in a diffuse manner but rather in discrete directions, so that the inside of the sphere becomes illuminated with a number of bright spots. Depending on the orientation of the diamond, some of these spots of light may or may not be lost through the entrance port. Woods and Welbourn (1980) describe a method by which the sample is pre-aligned in a special holder before being mounted in the sphere, so that reproducible results may be obtained.

A second problem is that most commercial color-measuring instruments are intended to be used with relatively large samples. If only the table of the diamond is illuminated, all of the light reflected from the surface can be directed toward an absorbing baffle or back through the entrance port. The equipment described by Woods and Welbourn (1980) uses a condensing lens to ensure that this condition is obtained. However, if any of the facets are illuminated, some of the specularly reflected light will be detected by the photomultiplier. The errors caused by this scattered light, and by any luminescence generated in the diamond, are examined in the following sections.

MAJOR PROBLEM AREAS

Cape-Yellow and Other Yellow Diamonds. Most off-white and yellow diamonds owe their color to absorption by the Cape series of absorption lines; a typical spectrum has already been shown in figure 2. The most prominent feature of such diamonds is the line at 415 nm (the N3 zero-phonon line), and the intensity of this line is a measure of the color of diamonds of this type. This fact was used from 1972 to 1982 by Diamond Grading Laboratories (DGL)* in London to calculate a color index for the diamond under test.

The apparatus used by DGL contains an integrating sphere similar to that illustrated in figure 3. The instrument is first calibrated using a barium-sulfate standard white reflector instead of the diamond. Then, with the diamond in position, the monochromator is scanned over the wavelengths covered by the absorption peak. The photomultiplier's signal, multiplied by the calibration factor at each wavelength, is a measure of the relative transmission of the diamond *provided:*

1. The diamond exhibits no luminescence
2. None of the incident light that is reflected from the *front* surface of the diamond is detected by the photomultiplier
3. The diamond has been positioned carefully to minimize losses through the entrance port

If we assume for a moment that these conditions are met, then from the relative transmission values at about (a) 412 nm, (b) 415 nm, and (c) 420 nm (see figure 4), a color index can be calculated using the relationship $\log_{10}a + \log_{10}c - 2\log_{10}b$. This sum of three log terms is then multiplied by

Figure 3. Schematic diagram showing how the color of a sample is determined using a monochromator and an integrating sphere.

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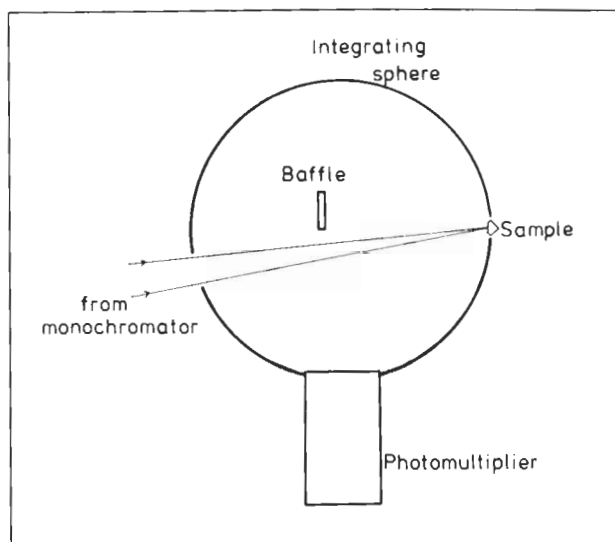
*DGL ceased trading in 1982.

Figure 4. Transmission spectrum in the vicinity of the 415 nm line, showing the wavelengths a, b, and c from which a color index can be calculated.

Figure 5. Absorption spectra of three rough diamonds recorded with the samples at liquid nitrogen temperature (77° K). The stones had all been categorized as Cape-yellow, but the absorption spectra are quite different.

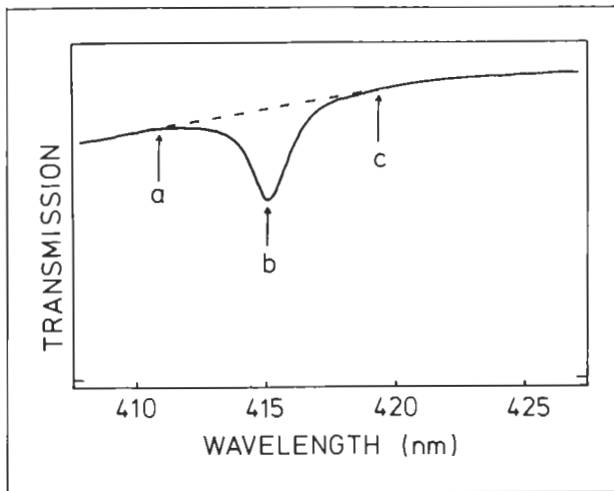10,000 to obtain the final color index. In practice, the three wavelengths are accurately chosen so that (b) is centered on the peak and (a) and (c) straddle the peak. This is important, since the peak may occur at slightly different wavelengths in different diamonds. Bruton (1978, p. 280) and Andergassen (1982, p. 147) give the above formula with (b) and (c) interchanged, and Andergassen shows a diagram which suggests that the readings (a), (b), and (c) are taken from an absorbance spectrum. The formula given here, applied to a *transmission* spectrum, is the only one that can be justified mathematically.**

The major limitation of the above method is that not all yellow and tinted diamonds are Cape-yellows. Recently in the Wheatstone Physics Lab-

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**The color index measured for a cut gemstone should be related to the strength of absorption of the 415 nm line measured in a rectangular slab of the same diamond. However, because of the complexity of the multiply reflected light path inside the cut stone, there is no easy way to relate the two measurements. In an ideal case, and in the absence of the types of problems described in this article, the same color index should be obtained when a cut gemstone is measured on different instruments.

It should also be noted that correct positioning of the diamond is important if reproducible results are to be obtained. The standard procedure adopted by Diamond Grading Laboratories was to determine the color index for each stone under investigation at least four times. Between each measurement the diamond was rotated through approximately 90° (by hand). If the four measurements were not in reasonable agreement, the test was repeated. When four moderately consistent values were obtained, the final index was taken as the average of the four readings. For some diamonds no such consistency could be obtained, and these diamonds had to be graded by comparison with master stones.

oratory, we examined a parcel of rough diamonds that had all been classified as Cape-yellow. Figure 5 shows the absorption spectra of three of these diamonds, recorded at liquid nitrogen temperature to emphasize the different absorption bands. Diagram (a) is the familiar Cape absorption spectrum; the spectrum shown in diagram (b) is that of the recently identified "2.6 eV band" (477 nm); and that shown in diagram (c) is the spectrum of the H3

Figure 6. Luminescence produced in rough stones selected from a batch of gem-quality brown diamonds. Long-wave ultraviolet radiation (365 nm) was used to excite the luminescence.

(503 nm) system, which occurs naturally in some diamonds. In addition to these three absorption bands, the absorption characteristic of type Ib diamonds can result in a tinted, yellow, or brown color, depending on the strength of the absorption. (The spectra mentioned briefly here are discussed in more detail by Collins, 1982.)

At first sight it may seem surprising that the three diamonds for which the spectra are illustrated in figure 5 appear similar in color. The reason is that the sensitivity of the eye decreases rapidly at wavelengths less than 450 nm; furthermore, the eye cannot detect the *structure* present in a transmission spectrum. The *perceived color* of these three diamonds is therefore mainly determined by the region of absorption below approximately 500 nm, which, after modification by the eye response, is similar for each stone. When the three diamonds are placed side by side, it is clear that they are, in fact, slightly different in color. But such a comparison *is* necessary, and it is obvious that a color grading based solely on the strength of the 415 nm line would yield completely inaccurate results for two of the stones. Even when a diamond appears to be a Cape-yellow, there may be a small amount of underlying absorption, so that the color index based on the intensity of the 415 nm line is in fact an underestimate. For the same reasons, the simple diamond photometer developed by Eickhorst will give false readings when used on dia-

monds other than those from the Cape-yellow series (see Bruton, 1978, pp. 277-280).

Luminescence. It is well known that many diamonds exhibit luminescence when they are illuminated by ultraviolet light (see, for example, Bruton, 1978, pp. 416–419). Blue is the most common color displayed in luminescence, but many other colors may be observed, particularly in brown diamonds, as shown in figure 6. The color centers responsible for the luminescence also have an associated absorption band, and it is the absorption of light in this band that produces the emission in the luminescence band. (These processes have been discussed in simple terms by Collins, 1982.) The luminescence is easiest to see when ultraviolet excitation is used, because the eye does not detect the ultraviolet light. Nevertheless, blue light is actually more effective at creating green luminescence, yellow light is more effective at creating red and pink luminescence, and so on. In short, light of any wavelength in the visible region can stimulate luminescence at longer wavelengths in a suitable diamond. However, I will restrict a detailed discussion to the absorption and luminescence in the N3 (415 nm) system.

Anderson (1943) noted that there was no relationship between the strength of N3 absorption in a particular diamond and the intensity of the blue

luminescence produced. It is now recognized that the proportion of absorbed light that generates luminescence depends on the concentration of one particular form of nitrogen in the diamond. Details are given by Thomaz and Davies (1978), and a simpler description of the processes involved has been outlined by Collins (1982). An important point in connection with the present article is that Thomaz and Davies have shown that for a brightly luminescent diamond, 30% of the energy absorbed by the N3 center is re-emitted as blue luminescence (i.e., the *luminescence efficiency* is 30%).

If the relative transmission of the diamond is measured using an integrating sphere, virtually all of the luminescence produced will be detected by the photomultiplier. Therefore, for a diamond with a luminescence efficiency of 30%, the transmitted light level *appears* to be $I_t + 0.3 (I_o - I_t)$. Its effect on the absorbance calculated is shown in figure 7. We see that the apparent absorbance is always less than the true absorbance, and that such divergence increases as the absorbance increases. For example, a diamond graded as "tinted color 3"

Figure 7. This diagram shows the effect of luminescence on the calculated absorbance. It compares the true absorbance with the apparent absorbance, obtained by measuring the transmission spectrum in the vicinity of the 415 nm line with an integrating sphere. The dashed line is for a nonluminescent diamond, and the continuous line is for a strongly luminescent diamond.
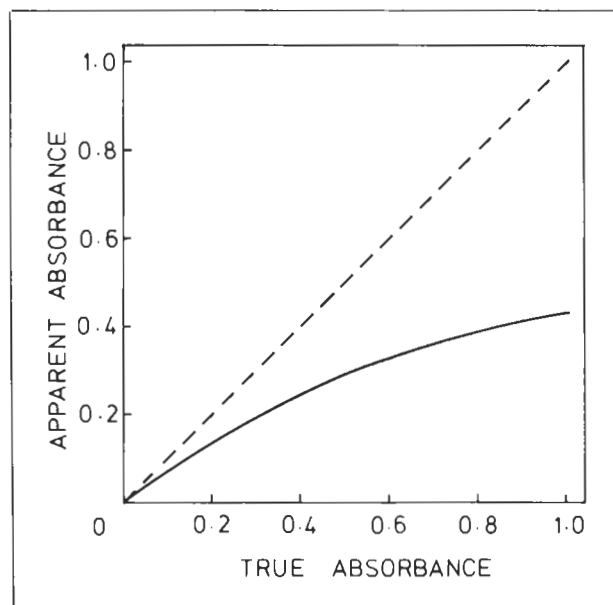
on the International Color Grading Scale (GIA grade of R and DGL color index of 12,000) would *appear* to be a "tinted color 1" (GIA grade of M and DGL color index of 6,500).

Diamonds with a luminescence efficiency as high as 30% are rare, but any luminescence will cause the color index to be underestimated, particularly in the case of strongly colored stones. DGL, for example, noticed that some strongly absorbing diamonds produced color indexes that were far too low, and they found it necessary to color grade these specimens by comparing them with master stones (R. V. Huddlestone, personal communication).

Luminescence, then, can seriously affect the color grade determined by techniques that rely on measuring only the intensity of the 415 nm absorption line. However, even if the whole spectrum is measured, the chromaticity coordinates will be in error if the diamond exhibits luminescence. The Eickhorst diamond photometer also responds to luminescence generated in the diamond by the incident light, and yields a false color grade for brightly luminescing diamonds (Bruton, 1978, p. 280).

Even if the errors caused by the detection of luminescence in color-grading instruments can be eliminated, the color grade determined may still differ from that obtained by comparison with master stones, since in daylight the transmitted light and luminescence are observed simultaneously. In particular, blue luminescence from a diamond in daylight can partially (or even totally) mask the yellow body color of the stone (Andergassen, 1982, p. 145).

Scattered Light. About 17% of the light incident on the front surface of a diamond is reflected. As noted above, when an integrating sphere is used, it is important that none of this reflected light be detected by the photomultiplier. If the incident light strikes only the table of the diamond, the direction of the reflected beam will be well defined and can be intercepted with a baffle plate or reflected back through the entrance port. However, if light is incident on any of the diamond facets, it is virtually certain that some of the reflected light will reach the photomultiplier. If a fraction (f) of the *incident* light is detected by the photomultiplier, the intensity of the transmitted light will *appear* to be $I_t + fI_o$. Figure 8 shows the effect on the calculated absorbance when 10% of the

incident light is mistakenly detected together with the transmitted light. The effect is similar to the error caused by strongly luminescent diamonds for which the apparent absorbance is always lower than true value.

It is, however, relatively easy to check an instrument to see if reflected light is a problem. A very strongly colored (industrial quality) diamond that does not exhibit luminescence and is completely opaque at a certain wavelength is placed in position on the integrating sphere. The signal detected when the monochromator is set to the wavelength at which the diamond is opaque should be zero. If it is not zero, then some incident light *is* being detected and will result in errors when diamonds are color graded. Many of the yellow/brown industrial diamonds have virtually no transmission at the blue end of the visible spectrum, so it may be helpful to have these stones available in a range of sizes, polished into brilliants, in order to carry out the scattered-light test.

Figure 8. This diagram shows the effect of scattered light on the calculated absorbance. It compares the true absorbance with the apparent absorbance obtained by measuring the transmission spectrum of a diamond with an integrating sphere. The dashed line is obtained provided no light scattered by the front surface of the diamond is detected by the photomultiplier. If 10% of the incident light is scattered by the diamond and detected by the photomultiplier, the continuous line is obtained.
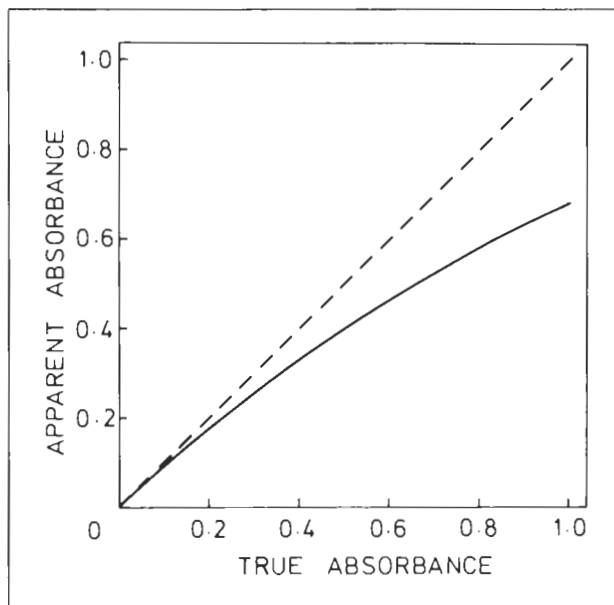
ALTERNATIVE TECHNIQUES

The problems associated with luminescence and scattered light can be largely eliminated if the transmission spectrum of the diamond is obtained by focusing light *through* the diamond using approximately opposite facets (Collins, 1982; Andergassen, 1982, pp. 217–220). Quantitative measurements are difficult to make because it is not easy to define the optical path through a faceted diamond. However, Andergassen states that for Cape-yellow diamonds a more precise color grading can be achieved with instrumentation than with master stones, provided a standard procedure is followed rigorously.

SUMMARY

I have discussed two techniques for color grading diamonds that use spectrophotometers fitted with an integrating sphere in which the diamond being tested is placed. One method that has been used (by Diamond Grading Laboratories) bases a color index on the intensity of the N3 line at 415 nm. This index can only be used for Cape-yellow diamonds, however, and an experienced color grader must first assess (purely subjectively) whether the color of a particular diamond is due solely to absorption in the Cape series of absorption lines. It is possible to confirm that this is the case by *measuring* the absorption spectrum over the whole visible region, but if that measurement is not taken, the presence of other absorption bands, undetected by eye, may result in an underestimation of the true color by the color index.

A better method of specifying diamond color is to measure the absorption spectrum over the whole visible spectral region and to calculate the chromaticity coordinates. This technique has been explored by Woods and Welbourn (1980), is being used by the Laboratorio di Analisi Gemmologiche (Rome), and is being further developed by HRD in Antwerp. Brown diamonds with an absorption that increases continuously from the red end to the blue end of the spectrum are still likely to be difficult to color grade by this method, however.

Any method that measures the spectrum of a diamond while it is placed in an integrating sphere is subject to two possible sources of error. Brightly luminescent diamonds will give a low color index using the DGL method, particularly strongly colored diamonds, and will also produce erroneous values for the chromaticity coordinates in

methods that analyze the whole visible spectrum (Woods and Welbourn, 1980). Similar errors are caused by the detection of light reflected from the front surface of the diamond.

Reflected light from the front surface can be directed to an absorbing baffle plate, provided that only the table of the stone is illuminated. If any of the facets are illuminated, however, it is virtually certain that some reflected light will reach the detector, and the color grading will not be correct. It is fairly easy to check the equipment with a polished opaque diamond; rectification of the problem, if it exists, will probably entail redesigning the equipment's optics. Woods and Welbourn (1980), for example, use an additional lens to ensure that the incident light is focused to a small spot at the center of the table of the diamond being graded.

If the only region of the spectrum being analyzed is in the vicinity of the 415 nm line, the luminescence problem can almost be eliminated by placing a suitable filter in front of the photomultiplier. For a complete scan over the whole visible spectral region, more elaborate procedures are required to minimize errors caused by luminescent diamonds. However, even when the sources of error in measuring the absorption spectrum are eliminated, there is no guarantee that the color index calculated from the data will correctly describe the color of the diamond, since when the diamond is viewed in daylight, the luminescence and transmitted light are observed simultaneously.

Van Goethem (personal communication) has had the opportunity to test all the diamond-grading instruments reviewed by Read (1983). He finds that almost all instruments give a reproducibility that is the same or better than the human eye. However, none gives the same results as the visual color grading. Van Goethem believes this is because the instruments do not work according to the correct physical principles used in practical color grading. For this reason, the HRD is developing its own apparatus (Haazen, 1982).

The equipment and procedures developed by Woods and Welbourn (1980) give results that are in agreement with visual grading for diamonds larger than 0.20 ct. However, they state that diamonds showing strong luminescence could produce anomalous results.

There are, then, many pitfalls in color grading diamonds by machine, and it is likely to be some considerable time before your sets of master stones can be permanently retired.

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THE EARLY HISTORY OF GEMSTONE TREATMENTS

By Kurt Nassau

This article examines the origins of gemstone treatment. Using such primary sources as Pliny's History *and the relatively unknown* Stockholm Papyrus, *the author has uncovered many ancient references to, and even recipes for, the simulation or enhancement of gemstones. Among the processes described are crackling and dyeing quartz, foilbacking, the making of doublets and triplets, boiling amber in oil, and heat treating sapphire to simulate diamond. Although some of the ingredients, such as goat's blood and leek juice, have been replaced by less exotic elements, it is interesting to note that through their crude experimentation, the ancient forerunners of modern science discovered basic methods and principles of gemstone treatment that are still in use today.*

Evidence for the use of gemstone treatments points back many thousands of years: heated carnelian, for example, was found in Tutankhamen's tomb—dating to at least 1300 B.C. Even the written accounts of treatments extend back almost 2,000 years. Yet surprisingly little has been published on some of these earlier accounts, especially the "recipes" from which the earliest gemological chemists worked, although many of these recipes are virtually duplicated by techniques in use today.

As part of my research into all aspects of gem treatment, I have studied, and in some cases updated translations of, many of these early references to gem treatment. The realization that so many treatment practices—crackling and dyeing quartz, foilbacking, oiling of emeralds, among others—were acknowledged and even recorded in detail by ancient chemists and historians is both fascinating and highly relevant in this decade when treatment has become a major focal point of gemology.

This article looks into these early documents, especially those that stand out as landmarks in the development of this most ancient practice. Following detailed examinations of Pliny's *History* and the almost totally neglected *Stockholm Papyrus (P. Holm.)*, I will concentrate on a number of relevant books, only occasionally using secondary sources and references from other fields to highlight specific points. The period covered extends from the first century A.D., which produced the earliest known writings on this topic, to the mid-17th century, coinciding with the publication of the first work on gems written by an experimental scientist.

FIRST CENTURY A.D.: PLINY

As in so many areas of historical interest, the earliest primary source is C. Plinius Secundus (born 23 A.D. and died 79 A.D., during the eruption of Mt. Vesuvius), the busy compiler of all that was known in his time. His
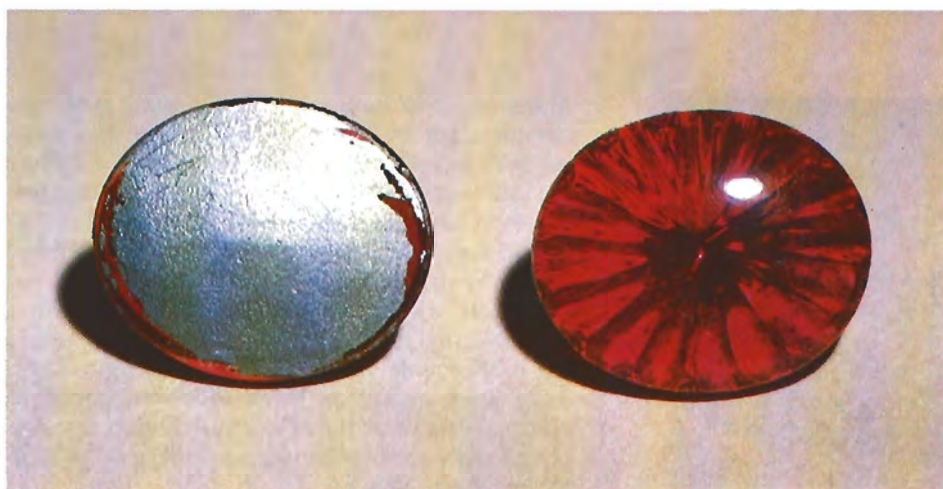
account of contemporary knowledge, published in 37 books, was based on notes that he professed to have made while reading more than 2,000 books. Some of these books dealt with gemstone alterations:

> I have in my library certain books by authors now living, whom I would under no circumstances name, wherein there are descriptions as to how to give the color of *smaragdus* [emerald, in part] to *crystallus* [rock crystal] and how to imitate other transparent gems: for example, how to make *sardonychus* [sard-onyx] from a *sarda* [carnelian, in part sard]: in a word, to transform one stone into another. To tell the truth, there is no fraud or deceit in the world which yields greater gain and profit than that of counterfeiting gems. (Pliny, Book 37, Chap. 75; from Ball, 1950, p. 195[1])

Pliny discusses many gemstone-enhancement techniques that are still in use today, almost 2,000 years later, including foils, oiling, dyeing, and composite stones. The use of shiny metal foils to make stones appear more brilliant (figure 1) or to

modify their color goes back at least to Minoan times (2000–1600 B.C.), according to Ball (1950). Pliny mentions their use on "*carbunculi* [red stones, including garnet, ruby, etc.] . . . for the exercise of cunning, when craftsmen force the opaque stones to become translucent by placing foil beneath them" (Vol. 10, p. 243); on "*sard* [carnelian, in part sard]. . . . that is backed with silver foil" (Vol. 10, pp. 249, 251); and with "*hyacinthus* [sapphire] and *chrysolithus* [topaz]" of quality less than the best, which "are backed with brass foil" (Vol. 10, pp. 267, 269).

Vinegar is used to make dull stones shiny (Vol. 10, p. 243), and "*smaragdi* [emeralds in part] . . . in spite of their varied colours, seem to be green by nature, since they may be improved by being steeped in oil" (Vol. 10, pp. 219, 221). One may assume that this refers to white or brown-appearing badly cracked stones which become an improved green on oiling, as is still done today. He also reported the well-known behavior of "*callaina* [turquoise]. . . . The finer specimens lose their colour if they are touched by oil, unguents or even undiluted wine" (Vol. 10, p. 255). In addition, amber "is dressed by being boiled in the fat of a suckling pig" (Vol. 10, p. 199); this is undoubtedly the clarification process rediscovered so much later (figure 2).

Dyeing and staining were widely used in ancient times as they are today. Even pigments made from ground-up malachite and azurite were thus improved: "*Armenian* [azurite] is a mineral that is dyed like malachite . . . " (Vol. 9, p. 297). Then there was: "the green called *Appian*, which counterfeits malachite; just as if there were too few spurious varieties of it already!" (Vol. 9, p. 297). This complaint is still being made today of new

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[1]*All notes in brackets within quotations are additions I have given for clarification. Several original spellings have been preserved to retain the flavor of the original account.*

In this quotation, the gemstone identifications are based on those given by Ball (1950). Apart from this elegant passage taken from the rather archaic 1601 translation by Philemon Holland which Ball used, and passing over the frequently used 1898 Bostock and Riley translation, we will hereafter cite only the modern Harvard University translation, begun by Rackham (Vols. 1–5 and 9, 1938–1952), continued by Jones (Vols. 6–8, 1951–1963), and completed by Eichholz (Vol. 10, 1962). They had access to more source manuscripts as well as to more sophisticated scholarship than previous translators, including the guidance of Ball's volume in gemological matters.

Figure 2. Stress fractures are common by-products when amber is heated in some form of oil, a practice reported by Pliny in the first century A.D. In modern times, this is done purposely to produce the brightly spangled amber shown here. Photo by Shane McClure.

imitations as well as of gemstone names. In addition: "it ought to be generally known that *amber* can be tinted, as desired, with kid-suet and the root of *alkanet* [a natural dye]. Indeed it is now stained even with purple dye [Tyrian purple]. . . . *Amber* plays an important part also in the making of artificial transparent gems, particularly artificial amethyst, although, as I have mentioned, it can be dyed any colour" (Vol. 10, pp. 201, 203).

The sugar-acid process for dyeing agates and other porous stones is apparently reported by Pliny (Vol. 10, p. 323), although the description has not always been accepted as such:

Moreover, *Cochlides* or *shell stones* are now very common, but are really artificial rather than natural. In Arabia they are found as huge lumps and these are said to be boiled in honey without interruption for seven days and nights. Thus all earthy and other impurities are eliminated; and the lump, cleaned and purified, is divided into various shapes by clever craftsmen, who are careful to follow up the veins and elongated markings in such a way as to ensure the readiest sale. . . . In general, all gems are rendered more colorful by being boiled thoroughly in honey, particularly if it is Corsican honey, *which is unsuitable for any other purpose owing to its acidity* (emphasis added).

Ball (1950) interpreted *cochlides* as being shell ornaments, but the "huge lumps" argues against this interpretation. Eichholz (1962, p. 323) more reasonably interprets these as large, inferior agates, boiled in acidic honey in order to bring out their color. Consider, now, the possibility of the use of an unmentioned final, slightly higher temperature heating step and one obtains something not too different from the modern sugar and heating or sugar-acid processes (figure 3). Also note that Pliny's description of how the patterns of "veins and elongated markings" are carefully followed, which is as true of clever craftsmen working with chalcedony and related materials today as it was almost two thousand years ago. This description could hardly apply to material derived from sea shells.

Finally, there is this passage on the making of triplets (figure 4):

Figure 3. This slab illustrates some of the many colors in which agate is dyed in Idar-Oberstein today. The brown section is typical of the color produced by the sugar-acid method Pliny describes. Photo courtesy of J. S. White, Smithsonian Institution.
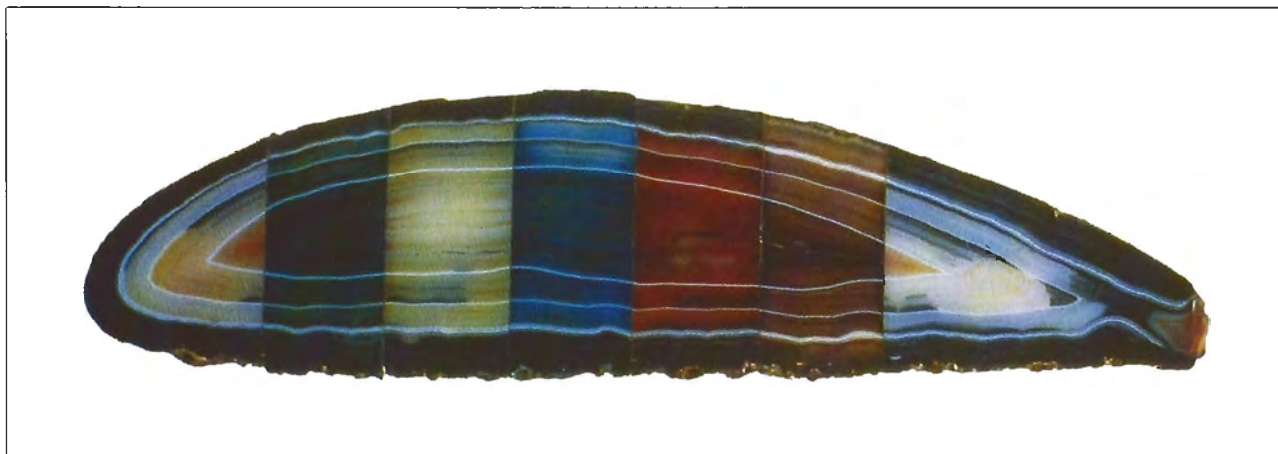
Figure 4. The piece on the right is an interesting adaptation of the technique described by Pliny: a "three-layer" cameo has been manufactured by gluing a white material to a reddish brown material and then painting the top figure in the white material black. The result is a convincing imitation of the natural, unassembled cameo on the left. The imitation piece measures 16.17 × 12.12 × 5.64 mm; the natural, 19.79 × 15.02 × 7.38 mm. Photo by Shane McClure.

Men have discovered how to make genuine stones of one variety into false stones of another. For example, a *sardonyx* can be manufactured so convincingly by sticking three gems together that the artifice cannot be detected: a black stone is taken from one species, a white from another, and a vermillion-coloured stone from a third, all being excellent in their own way. (Vol. 10, p. 325)

Ball (1950) cites the report by the Chinese ambassador to Antioch, the capital of Roman Syria, in 97 A.D.: "The articles made of rare precious stones produced in this country are sham curiosities and mostly not genuine. . ." (p. 81). The poet Martial, of about the same era, mentions *real* sardonyx, implying the existence of the false. Pliny also describes the use of glass to imitate valuable gemstones (figure 5). When one considers that almost nothing was known in Pliny's day about gemological testing, other than perhaps a very crude

estimation of hardness, it is surprising that there were any authentic gemstones at all noticeable among the many fakes.

About 300 A.D. Emperor Diocletian became so outraged by alchemy and related activities (such as the alteration and imitation of gemstones) that he ordered all books on these subjects to be burned (Ball, 1950). It is doubtful that this edict had much effect on such activities, although it may account for the relative scarcity of surviving documents on the subject.

For the reader interested in placing these activities into the framework of the science and technology of the period, Thorndike's (1923–1958) *History of Magic and Experimental Science* (extending from Pliny through the end of the 17th century), the Oxford *History of Technology* (Singer et al., 1954–1978), and F. S. Taylor's *The Alchemists* (1936) are detailed studies that can be recommended.

Figure 5. Glass has been used as a substitute for emerald and other fine gemstones since at least the days of ancient Rome, as mentioned by Pliny and illustrated by the earrings (third century A.D.) shown here. Photo courtesy of B. Zucker Precious Stones.

FOURTH TO FIFTH CENTURIES: THE STOCKHOLM PAPYRUS

In 1832 the Swedish Academy received a metal box containing 14 numbered papyrus sheets plus an unrelated fragment, all covered with early Greek handwriting. The gift came from Johann d'Anastasy, the Swedish-Norwegian Vice-Consul in Alexandria, Egypt, and an inveterate collector of early Egyptian documents. The 14 sheets had originally been a codex, a handwritten "book" consisting of seven folded sheets which had later been cut in half. These documents were subsequently examined by Otto Lagercrantz, who published the text with a German translation and commentary in 1913. Lagercrantz named it the *Papyrus Graecus Holmiensis*, abbreviated *P. Holm.*, and gave it the subtitle "Recipes for Silver, Stones and Purple." This papyrus is also known as the *Stockholm Papyrus*, under which title it was translated into English in 1927 by Caley. Neither Lagercrantz, a classicist, nor Caley, a chemist, was aware of the implications to gemology of this fascinating text.

From a variety of circumstances, Lagercrantz deduced that this papyrus was a copy made by a scribe about 400 A.D. in Greek-speaking Egypt. It was probably made for the purpose of accompanying the remains of a "chemist" in his mummy case, where it survived some 15 centuries in excellent condition. In all probability it was a copy of his laboratory working notes, no doubt in turn taken from an older document.

The small fragment contains a short magical incantation of no obvious meaning. The 14-page main text consists of three parts. The first part deals with metals and gives nine recipes for making copper look like silver, extending silver to double its quantity, and the like. The last part contains 70 recipes for the dyeing of wool and other substances, with emphasis on imitating the costly Tyrian purple dye.

The middle, and longest, section contains 73 recipes which deal with the falsification of pearls and gemstones; it represents the oldest extended recipe collection dealing with gems. Several examples from this virtually inaccessible text are cited here. There is in these recipes no attempt to duplicate anything but the color—or lack of it—of the desired gemstone. The counterfeiting is sometimes very simplistic, as in this recipe:

Bleaching Crystals

Dissolve rice in water, put the crystal in, and together with it, boil again the solution (Caley, 1927, no. 56; Lagercrantz, 1913, pp. 187–188).[2]

Ten of the recipes deal with improving pearls or imitating them; for example:

Cleaning a Pearl

When a real pearl becomes dull and dirty from use, the natives of India are accustomed to clean it in the following way. They give the pearl to a rooster to eat in the evening. In the morning they search the droppings and verify that the pearl has become clean in the crop of the bird; and moreover, has acquired a whiteness which is not inferior to the original.

Another Recipe

Quick lime, when it is not yet slaked in water, after having been burnt in the oven, carries hidden within it the fire; this is slaked with the milk of a dog, but that from a white bitch. Knead the lime and coat it in layers on the pearl and leave it there one day. After stripping off the lime, observe that the pearl has become white." (Caley, 1927, nos. 60 and 61; Lagercrantz, 1913, p. 189)

The first of these recipes presumably relied on the acidic digestive juices of the rooster to remove a thin layer of pearl; in another version (Caley, 1927,

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[2]*All quotations from P. Holm. are the author's based on the English translation by Caley (1927), using his recipe numbering, and on the German translation by Lagercrantz (1913), giving his pages, as well as on the Greek version given by Lagercrantz. A full translation and a detailed interpretation are being prepared for publication.*

Figure 6. These two pieces of quartz have been heated and then dyed to imitate emerald (1.77) and ruby (0.91 ct). The crackling of quartz and similar stones is one of the oldest gem treatment processes practiced by man.

no. 25; Lagercrantz, 1913, p. 172), the cock is cut open directly after feeding him the pearl. Some version of this technique reappears every few centuries, still frequently attributed to India.

With regard to the dyeing of gemstones, two separate steps are involved; these steps frequently appear as separate recipes, although they are sometimes combined. First the stone, usually crystal (i.e., rock crystal or quartz), has to be made receptive to the color. Four different Greek words are used for this preparatory step: *stufis*, which means "mordanting,"[3] but which could also mean corroding or etching (used 23 times in 14 recipes connected with stones); *araiosis*, which means "softening," "loosening up," or "opening up" (used 6 times in 5 recipes); and *malaksis* (used 4 times in 2 recipes) and *liosis* (used once) which both mean "softening." A detailed examination of the recipes indicates that all of these terms probably referred to the same process, namely cracking of the heated quartz or other stone as the first step so that the dye used in the second step could then penetrate into the cracks to produce the change in color—a practice still common in the 20th century (figure 6). Mention of the heating itself is often omitted, as might be expected for something so self-evident to an expert practitioner; indeed, many of the recipes are abbreviated as in the following extreme, where three recipes are tele-

scoped into one with only the essential ingredients given:

Another [Recipe for the Preparation of Green Stones]

Verdigris and vinegar, verdigris and oil, verdigris and calve's bile; these form emerald." (Caley, 1927, no. 21; Lagercrantz, 1913, p. 170)

Sometimes the crystal is first cleaned before the preparation step:

Cleaning of Crystal

Cleaning of smoky crystal. Put it into a willow basket, place the basket into the cauldron of the [public] baths and leave the crystal there seven days. Then, when it is clean, take and mix warm lime with vinegar. Place the stone in this and let it be mordanted. Finally: color it as you wish. (Caley, 1927, no. 16; Lagercrantz, 1913, p. 164)

In the next two recipes, the only piece of information missing is the exact temperature the stones should be when they contact the liquid so they will crack nicely without falling apart:

Another [Recipe for Mordanting and Opening up Stones]

Put the stones into a bowl, put on it another bowl as a lid, seal the joint with clay, and let the stones be roasted under supervision for a while. Then by degrees remove the lid and pour vinegar and alum on the stones. After this, color the stones with whatever dye you desire. (Caley, 1927, no. 54; Lagercrantz, 1913, p. 186)

Softening Crystal

To soften crystal take goat's blood and dip into this the crystal which you have first heated over a gentle fire, until it is to your liking. (Caley, 1927, no. 36; Lagercrantz, 1913, p. 179)

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[3]*This designation also occurs widely in the wool-dyeing section of the papyrus (e.g., Caley, 1927, no. 135; Lagercrantz, 1913, p. 226). The process there described is essentially the same as that used in modern mordant dyeing, whereby an aluminum salt is precipitated on the fiber and a dye is then attached to this precipitate, as one example.*

coals. Blow therefore with the bellows, till the figs or the dates burn and become charred. Then seize the stone, not with the hand but with tongs, and while it is still warm place it directly into the dye bath and let it cool there. Use as many stones as you wish, however not more than 2 drachmas [each in weight]. The dye, however, should be as thick as paste. (Caley, 1927, no. 29; Lagercrantz, 1913, p. 173)

Note particularly that the stone is so hot that it cannot be picked up by hand.

A wide variety of substances are used to provide the coloration itself. Some are based on copper and other metal salts, at times combined with the bile fluid from tortoises or cattle. The following recipe is the center one of the three on the back of papyrus sheet seven, which is reproduced in figure 7.

Preparation of Emerald

Mix together in a small jar 1/2 drachma of copper green [verdigris], 1/2 drachma of Armenian blue [chrysocolla], 1/2 cup of the urine of an uncorrupted youth, and 2/3 the fluid of a steer's gall. Put into this the stones, about 24 pieces weighing 1/2 obolus each. Put the lid on the jar, seal the lid all around with clay, and heat for 6 hours over a gentle fire made of olive-wood. When there is this sign, that the lid has turned green, then heat no more, but let it cool and remove the stones. You will find that they have become emeralds. The stones are [originally] of crystal. . . . (Caley, 1927, no. 83; Lagercrantz, 1913, pp. 199–200)

Other colorants are based on biological substances such as alkanet red, archille, bile, cochineal, "dragon's blood," heliotrope juice, indigo, leek juice, mulberry juice, and pigeon's blood. In some instances, the coloring matter is added in an oily form. Following are two of these oil impregnations, one based on a copper salt and the other on leek juice:

Another [Recipe for Preparation of Emerald]

Grind scraped-off verdigris and soak it in oil one day and one night. Cook the stones in this over a gentle flame as long as desired. (Caley, 1927, no. 77; Lagercrantz, 1913, p. 196)

Softening of Emerald

Put hard emerald into wax for 14 days. After this time grate garlic and make a cake out of it. Take out the stone and place it into the garlic cake for 7 days. Take leeks and squeeze out the juice. Mix with the leek juice an equal amount of oil, put this into
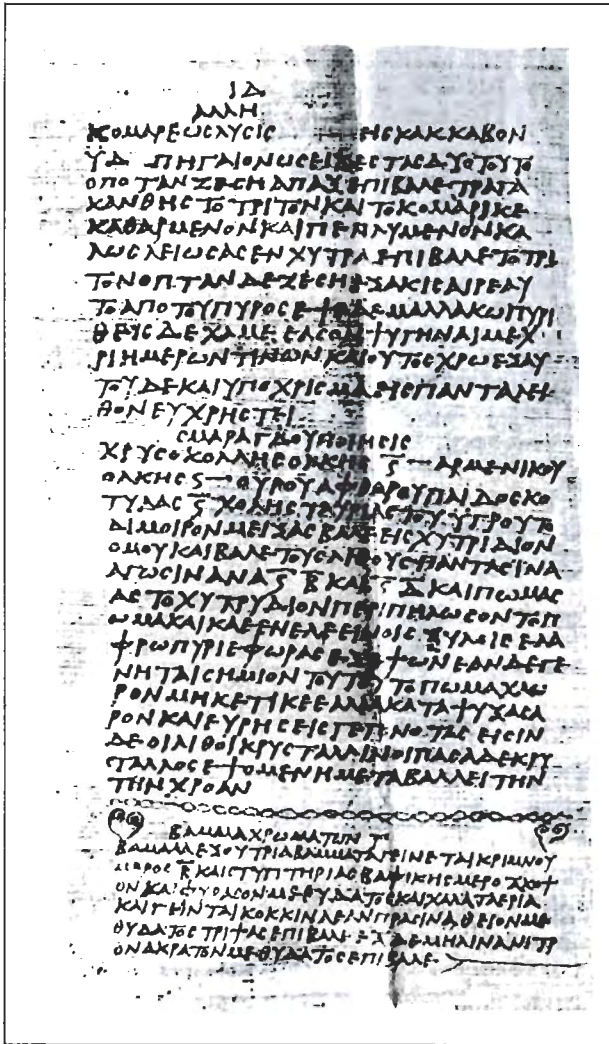
Figure 7. A page from Papyrus Graecus Holmiensis, *written about 400 A.D., the first manuscript to provide detailed gemstone treatment recipes.*

In this recipe is almost certainly found the origin of the curious fable that stones in general and diamonds specifically can be softened with goat's blood. Apparently the intent of the original process was merely to "loosen" or "soften" the stones by cracking them for dye penetration.

The two processes, preparation and dyeing, are sometimes combined into one:

Mordanting for Stones

Let the stone stand for 30 days in putrid urine and alum. Remove the stones and insert them into soft figs or dates. These should now be treated on the

a new pot, add the stones, and boil for 3 days, until they are to your liking. The stones should be in a basket, so that they do not touch the bottom of the pot. (Caley, 1927, no. 37; Lagercrantz, 1913, p. 179)

Note that there are no instructions to take the stone out of the cake. Once again, one suspects that the garlic cakes are baked or rather charred, just as are the figs or dates in the recipe given above, and that the stones are hot when they are dropped into the oily green leek juice to become cracked and absorb the green color at the same time.

The oily substances used are balsam sap, Canada balsam, cedar oil, liquid pitch, resin, and wax. Oiling with colored oil is still being practiced today by processes not too different from the following:

Cooking of Stones

If you wish to make ruby from Crystal, which has been prepared for this purpose at your pleasure [i.e., precracked], then take and place it in a *kerotakis* [a vessel usually used for melting wax with pigments] and stir in turpentine balsam [Canada balsam] and a little powdered alkanet [a red botanical dye], until the color sauce rises [bubbles?]. And then take care of the stone. (Caley, 1927, no. 31; Lagercrantz, 1913, p. 175).

It is interesting to note that with the exception of the pearl recipes, which deal for the most part with improving the pearl, almost all the other gemstone recipes in *P. Holm.* involve making one gemstone look like another. Only in the last-cited recipe dealing with what we would now call the colored oiling of emerald (and in a variant of it, no. 72 in Caley, 1927, and on p. 194 of Lagercrantz, 1913), does *P. Holm.* describe specifically a gemstone that is being improved as itself. Some of the other recipes dealing with nonspecific "stones" could, of course, be used for such improvements, yet the spirit of the work is clearly one of substitution rather than enhancement.

This unique manuscript represents the earliest comprehensive technical text giving explicit laboratory details. It is invaluable for the light it throws both on early chemistry and on early gemstone knowledge and techniques. Although Pliny, writing a few hundred years earlier, does mention some treatments, he provides none of the detail that makes the processes come alive in *P. Holm.* To Pliny, this was mere theory; to the user of the papyrus, this was clearly his life's work.

THIRTEENTH TO SIXTEENTH CENTURIES

For the next millenium and a half, through the Dark Ages and well into the Renaissance, Pliny's work, often containing many errors from repeated copying, served as the authoritative text for matters mineralogical and gemological.

Writing *On Stones* in about 1260, Albertus Magnus (Albert the Great), a clergyman and emissary of Popes, gives but a single sentence of relevance to treatments. Discussing the color of precious stones in Chapter 2 of Tract 2 of Book 1, he says: " . . . there is also found a stone having a great many colours . . . all its colours are caused by the different substances of which its parts are composed. The same explanation holds, more or less completely, so far as the dyeing of bodies is concerned." This statement seems quite straightforward when viewed in the context of precious stones and the dyeing processes as revealed by Pliny and others, but apparently puzzled the translator (Wyckoff, 1967, p. 43).

In 1502 was published *The Mirror of Stones*, a fascinating book by Camillus Leonardus (also known as Camillo Leonardi or Lunardi), a physician and astrologer of Pesaro, Italy. It is particularly interesting that it discusses not only gem treatments and simulants, but also how to identify those stones that are "not true" and the importance of experience and knowledge in this subject. The title page, shown in figure 8, acknowledges his sources, including Pliny. Excerpts from Chapter 9 of Book 1, from the 1750 translation, follow:

How to know whether Jewels are natural or artificial

Since these Times abound with Counterfeits in every Thing, but especially in the Jewelling Art . . . ; and as there are few unless such as have been long practis'd in them, can judge of them . . . we shall close the First Book with a few Things upon this Head. We say then, that these deceitful Artists in Stones have many Ways of Imposition. As first, when they make Stones of a less Value, and of a particular Species, appear of another Species and consequently of a higher Price; as the *Balasius* of the *Amethist*, which they perforate, and fill the Hole with a Tincture, or bind it with a Ring, or more subtilly, when they work up the Leaves of the *Balasius*, either with *Citron Sapphire* or *Beril*, into the Form of Diamonds, and by adding a Tincture to bind them, sell

THE MIRROR OF STONES:

IN WHICH

The Nature, Generation, Properties, Virtues and various Species of more than 200 different Jewels, precious and rare Stones, are diftinctly defcribed.

Alfo certain and infallible Rules to know the Good from the Bad, how to prove their Genuinenefs, and to diftinguifh the Real from Counterfeits.

Extracted from the Works of *Ariftotle*, *Pliny*, *Ifiodorus*, *Dionyfius Alexandrinus*, *Albertus Magnus*, &c.

By *Camillus Leonardus*, M. D.

A Treatife of infinite Ufe, not only to Jewellers, Lapidaries, and Merchants who trade in them, but to the Nobility and Gentry, who purchafe them either for Curiofity, Ufe, or Ornament.

Dedicated by the Author to C &sar Borgia.

Now firft Tranflated into *Englifh*.

LONDON:

Printed for *J. Freeman* in *Fleet-ftreet*, 1750

Figure 8. The title page of the Leonardus work on gemstones, published in 1502 and translated into English in 1750.

them for true Diamond. Or, very often they fabricate the upper Superficies of the *Granate,* and the lower of Chryftal, which they cement with a certain Glew or Tincture; so that when they are set in Rings they appear like *Rubies.* . . . A Deception may happen in another Manner; as when they make the Form and Colour of a true Stone from one that is not true. And this Deception is made from many Things, and chiefly from smelted Glass, or of a certain Stone, with which our Glass-makers whiten their Vessels, by adding divers permanent Colours to the Fire, as the Potters know; and as I have often seen *Emeralds,*

far from bad ones, at least for Use, made out of these Stones. These counterfeit Stones may be known many Ways, as first by the File, to which all false Stones give Way, and all natural ones are Proof against, except the *Emerald* and the Western *Topaz.* . . . The second Way to prove them is by the Aspect; for such as are natural, the more they are look'd at, the more the Eye is delighted with them; and when they are held up to the Light of the Candle, they shine and look fulgent. Whereas the Non-naturals, or artificial, the more they are beheld, the more the Sight is wearied and displeas'd, and their Splendor seems continually decaying, especially when they are oppos'd to the Light of a Candle. They are also known by their weight when they are out of the Rings; for those which are natural are ponderous, except the Emerald, but the Artificial are light. There is one Proof yet remaining, which is infallible, and is preferable to all the rest; namely, that the Artificial do not resist the Fire, but are liquified in it, and lose their Colour and Form when they are dissolved by the Fierceness of the Fire; and it is impossible but that in some Parts of them, some Points like small Bubbles must be seen in their Substance, produc'd by the igneous Heat, and will discover the Disproportion in their Composition, and their Difference from Nature in true Stones. Such false Stones may likewise be compounded of other Things than of Glass, namely, of many Minerals; as of Salt, Copperas, Metals, and other Things. . . . The Knowledge of Stones, and their Species, is acquired by great Experience, and from continual Uses, as they well know who employ themselves in this Kind of Exercise.

The range of treatments here alluded to includes an astonishing variety of colorations and assembled stones. His testing techniques, especially heating in fire, no doubt destroyed many genuine gemstones. Particularly noteworthy is his astute observation of the presence of small bubbles in imitations made of glass.

Next we consider the accounts of two master craftsmen in metallurgy and related arts: the *Pirotechnia* of Vannoccio Biringuccio, printed in 1540 in Venice, and the *Treatise on Goldsmithing* of Benvenuto Cellini, published in Florence in 1568 and translated in 1898. Both mention the use of colored foils placed behind gemstones, the use of a black backing or coating on diamond, and the heat treatment of a sapphire to turn it colorless. Biringuccio says of sapphire: "The best are the oriental ones. It can be made to lose its color by keeping it in molten gold over a fire for twenty-

four hours. With these baths they disguise it in the form of a diamond and try to deceive people" (p. 125). Cellini puts it thus: "There are certain sapphires, which the ingenuity of man can turn white, by putting them in a crucible in which gold is to be melted ['*Nel quale sia dell'oro che s'abbia a struggere.*'], and if not at the first heating, then at the second or third" (pp. 40–41).

Cellini gives highly detailed accounts of various treatment processes, particularly the use of shiny foils, some colored ones, and even colored cloth behind the gemstone in the cavity of the setting (pp. 24–29). In Italy at that time such activities were permitted with all gemstones, but tinting colored gemstones such as emerald, ruby, and sapphire was strictly forbidden by law. Curiously enough, the tinting of diamonds was permitted. There are details of a large diamond given by Emperor Charles V to Pope Paul, who gave it to Cellini to make an elaborate setting and to tint it. Using a clear undercoat of carefully selected pieces of gum mastic followed by a smoky layer consisting of a mixture of freshly prepared soot, selected gum mastic, freshly pressed linseed oil, almond oil, and turpentine, he almost doubled the value of the stone from 12,000 scudi to 20,000 scudi (pp. 31–39).

Cellini also reports that others used the blue dye indigo for tinting diamond, particularly for yellow ones, which "they make green, hence the yellow diamond with the blue tint made an admirable water; and, if it be well applied, it becomes one colour, neither yellow as heretofore nor blue owing to the virtue of the tint, but a variation, in truth, most gracious to the eye" (p. 36). Here he uses the quality term *water of the diamond* in the sense of achieving the most desirable pale blue-green or smoky colors, not in the usually attributed colorless sense. Could this perhaps have been the origin of this designation? Another technique was to use a black backing on diamond. In the words of Biringuccio (p. 122): "diamond . . . is . . . harder and much more lustrous and transparent than any other thing. If the skin of its earthiness is cleaned with art and then it is given its polish, it becomes very brilliant when a lustrous black color is placed underneath."

Illegal falsification was also achieved by the coating of pale stones, according to Cellini: "I once saw a ruby of this nature falsified ever so cleverly by one of these cheats. He had done it by smearing its base with dragon's blood[4]. . . . You would gladly

have given 100 golden scudi for it; but without the colour it wouldn't have fetched 10. . . . The color looked so fine and the stone seemed so cunningly set, that no one unless very careful, would have spotted it" (p. 26). Doublets were also widely made (p. 27):

> I mind me also of having seen rubies and emeralds made double, like red & green crystals, stuck together, the stone being in two pieces, and their usual name is 'doppie' or doublets. These false stones are made in Milan, set in silver, and are much in vogue among the peasant folk; the ingenuity of man has devised them to satisfy the wants of these poor people when they wish to make presents at weddings, ceremonies, and so forth, to their wives, who of course don't know any difference between the real and the sham stone, and whom the little deceit makes very happy. Certain avaricious men however, have taken advantage of a form of industry, made partly for a useful, and partly for a good end, & have very cunningly turned it to great evil. For instance, they have taken a thin piece of Indian ruby, and with very cunning setting have twisted and pieced together beneath it bits of glass which they then fixed in this manner in an elaborate & beautiful setting for the ring or whatever it was. And these they have subsequently sold for a good and first-class stone . . . . there was in my time a Milanese jeweller who had so cleverly counterfeited an emerald in this way that he sold it for a genuine stone and got 9000 golden scudi for it. And this all happened because the purchaser—who was no less a person than the King of England—put rather more faith in the jeweller than he ought to have done. The fraud was not found out till several years after.

In his *De Natura Fossilium*, published in 1546, Georgius Agricola discusses metal foils and their detection ("take the stone out of the ring and remove the coloring substance") as well as doublets (triplets in modern terminology) that are made of glass, of quartz, or of garnet and quartz, with a layer of dye. There are also doublets consisting of a diamond top with a base of quartz, corundum, or beryl (emerald). Then there are "filled" gemstones: "Certain amethysts are perforated and filled with minium or are deeply engraved and thin sheets of foil cemented beneath them so that they may be passed as carbunculi" (p. 116). Finally there is

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[4]"*Dragon's blood*" *is a natural vegetable dye, but the name was also applied to the red lead compound* minium, Pb_3O_4, *according to Agricola (1546).*
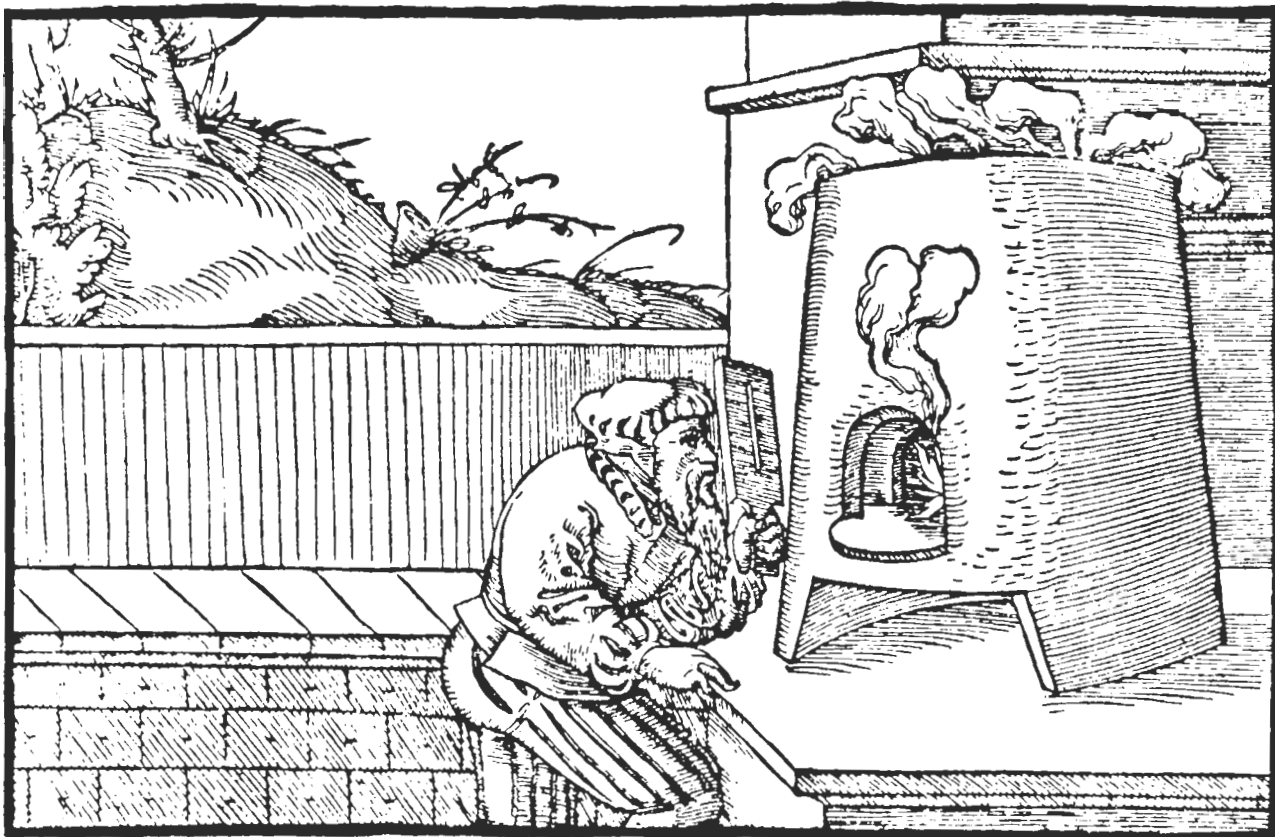
Figure 9. An assay furnace illustrated in Agricola's 1556 book on metallurgy.

dyeing: "The light-coloured or feminine sapphires can be darkened by dyeing. A king of Egypt was the first to dye this stone. Quartz and glass are also dyed to imitate sapphire . . . " (p. 130).

There is no discussion of gemstone treatments in Agricola's *De Re Metallica*, but there are many illustrations of the types of furnaces used in metallurgy at the time, shown in figure 9; these same types of furnaces were undoubtedly also used for heat treating gemstones.

In the 17th century, we have the *Gemmarum et Lapidum Historia* of 1609 by Boetius de Boot, a physician of Bruges, which appeared in a number of different forms over the next 40-plus years. In the French translation of 1644, there is discussion in Chapters 20 to 22 of the decolorizing by heat of sapphire, topaz, amethyst, and the like, to produce diamond imitations; the dyeing of stones, mostly with metal compounds (the use of gum mastic is considered to be "trivial and vulgar"); an extended discussion of metal foils; and an obscure description on how to harden gemstones. Several of the techniques are attributed to Baptiste de la Porte or de Porta, presumably derived from personal contact or from an earlier version of John Baptista Porta's *Natural Magic*, which was published in London in 1658.

In Book 6, "Of counterfeiting Precious Sones (sic)," Porta covers a variety of topics, including the making of colored glass imitations and various treatments. Chapter 5, "How Gems are coloured," is devoted to dyeing sapphire, amethyst, topaz, chrysolite, and emerald. In a detailed passage, Porta teaches how:

To turn a Saphire [sic] into a Diamond

This stone, as all others, being put in the fire, loseth his colour. . . . Many do it several ways: for some melt gold, and put the Saphire in the middle of it; others put it on a plate of iron, and set it in the middle of the fornace of reverberation; others bury it in the middle of a heap of iron dust. I am want to do it a safer way, thus: I fill an earthen pot with unkill'd lime, in the middle of which I place my Saphire, and cover it over with coals, which being kindled, I stop the bellows from blowing, for they will make it flie in pieces. When I think it changed, I take a care that the fire may go out it self [that is, he does not pour water on it]: and then taking out

the stone, I see whether it hath contracted a sufficient whiteness; if it have, I put it again in its former place, and let it cool with the fire; if not, I cover it again, often looking on it until the force of the fire have consumed all the colour, which it will do in five or six hours; if you find that the colour be not quite vanished, do again as before, until it be perfect white. You must be very diligent, that the fire do heat by degrees, and also cool; for it often happeneth, that sudden cold doth either make it congeal, or flie in pieces. All other stones lose their colour, like the Saphire; some sooner, some later, according to their hardness. For the Amethist you must use but a soft and gentle fire; for a vehement one will over-harden it, and turn it to dust. This is the art we use, to turn other precious stones into Diamonds, which being cut in the middle, and coloured, maketh another kind of adulterating Gems; which by this experiment we will make known. . . .

He then proceeds to describe "How to make a stone white on one side, and red or blew on the other," by a special heating process (pp. 183–184.)

Porta's Chapters 10 and 11 deal with "Of leaves of Metal to be put under Gems" and "How leaves of Metals are to be polished." Porta's book appears to have been one of the first of a continuing series of recipe books. Such books were intended to give the general public detailed instruction. They are particularly valuable in our investigation: since they were written for nonprofessionals, the directions tend to be much more detailed than are texts intended for the professional reader.

THE ADVENT OF THE SCIENTIFIC APPROACH

The publication in 1672 of *An Essay About the Origins and Virtues of Gems*, by Robert Boyle, represented the first work on gems written by a professional scientist who based his deductions on his own experiments and observations. In the 300 years that followed, techniques developed in the laboratory were used with increasing frequency and sophistication. By 1820, agate dyeing in Idar-Oberstein had been perfected to the point that it was practiced on a large scale and the agate sold as treated stone. For the first time, a gemstone material was altered commercially and marketed as such and not as a natural material.

By the middle of the 19th century, gemology had turned into a science. As authors studied each other's books and techniques, a certain uniformity appeared in the literature. The works of King (1883)

and Bauer (first published in German in 1896, then in English in 1904, and still an important sourcebook for the working gemologist) are representative of the level of knowledge and understanding of gemstone treatments from this period until well into the 20th century, when the discovery of irradiation provided a new approach to gemstone enhancement. Yet while the literature shows great advances during the last few years, many of the treatment methods in use today have their origins in the crude techniques practiced by Pliny's contemporaries and the master of *P. Holm.*

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NOTES
· AND ·
NEW TECHNIQUES

'COBALT-BLUE' GEM SPINELS

By James E. Shigley and Carol M. Stockton

The traditional gemological technique for distinguishing natural from synthetic blue spinel has involved the use of refractive index and absorption spectra. Recently, however, the standard interpretation of these tests has proved troublesome in the identification of several intensely colored blue stones that have R.I.'s in the range of natural blue spinels but that exhibit spectral features generally associated with synthetic cobalt-colored spinels. To establish the origin of these specimens, a detailed investigation of natural, flame-fusion, and flux blue spinels was carried out. Our results indicate that, while spectral features in the longer wavelengths are unreliable for separating these spinels, an iron-related absorption band at about 460 nm was seen only in our natural specimens. Flame-fusion synthetics may still be distinguished by their lower R.I.'s.

Several natural spinels with the intense blue color and so-called "cobalt" absorption bands generally associated with synthetic blue spinels have recently appeared on the gem market (figure 1). Such similarities to the synthetic material have led to difficulties in the recognition of these unusual natural stones by traditional gemological methods (Fryer, 1982). The present study establishes compositional and spectral means for the identification of these intensely colored natural blue spinels and discusses the occurrence of cobalt in them as a possible coloring agent.

DATA COLLECTION
Blue spinels included in our study consist of 18 natural and 10 synthetic (8 flame-fusion and 2

flux) stones (figure 2) that range from slightly grayish to vivid in saturation, light to dark in tone, and violetish to greenish blue in hue (as defined in GIA's colored stone grading course). The natural blue spinels include both cut stones and rough gem material acquired from several sources. While we cannot be certain of the exact origins of these specimens, they probably came from Sri Lanka. The flame-fusion synthetics consist of cut stones and boule fragments typical of the material that has long been produced by the Verneuil process. For the flux-grown specimens, we used two small (2–3 mm) octahedral crystals. We are unaware of the existence of any flux blue spinel crystals of sufficient size for faceting; nor have we encountered any of this material in already cut form. Moreover, flux blue spinel does not appear to be readily available in quantity in the gem marketplace, although Webster (1983) noted that clusters of the octahedral crystals have occasionally been used in jewelry.

Several types of data were gathered for each spinel studied: refractive index, specific gravity, inclusions, visible light absorption spectra (spectrophotometer and hand spectroscope), and chemical composition (microprobe, X-ray fluorescence, and neutron activation). A complete tabulation of these data and a comparison of our results with those reported by other investigators will be provided in a detailed account to be published elsewhere (Shigley and Stockton, in preparation).

DISCUSSION OF DATA
Physical and Optical Properties. The measured refractive indices of the natural and synthetic spi-

Figure 1. Two natural spinels (5.30 ct and 1.37 ct, respectively) that have the intense blue color normally associated with cobalt-doped synthetic spinel. Photo by Michael Havstad.

nels in our study agree with the values previously reported for similar material (Liddicoat, 1981; Webster, 1983). Those of the flame-fusion synthetics are slightly higher than those of the natural stones. The specific gravity ranges, however, overlap almost completely and thus appear to be unreliable indicators of origin. The refractive index and specific gravity values of the two flux synthetics lie well within the ranges for natural spinels (see figure 3).

The observation of strain patterns in our specimens through crossed polarizing filters revealed generally more strain in the flame-fusion synthetics than in either the flux synthetics or the natural spinels. However, all three groups displayed a variety of strain patterns that provided no clear indication of stone origin.

Inclusions. When present, inclusions can be excellent indicators of spinel origin (Gübelin, 1974; Liddicoat, 1981; Webster, 1983). Most of the natural specimens in this study contain one or more of the common inclusions considered diagnostic of natural spinel, including stringers of minute octahedra, either in straight lines or as "fingerprints" (figure 4), individual octahedra of spinel group minerals or negative octahedra filled with other minerals (figures 5 and 6), and iron-stained healing planes (figure 7). One of the more intense blue specimens from our study collection also contains octahedra with lily-pad inclusions around them (figure 8), and another contains natural-appearing intersecting needles (figure 9).

The synthetic flame-fusion specimens that we examined were remarkably inclusion-free. One stone contains stringers of minute gas bubbles (figure 10) accompanied by thread-like gas inclusions, both of which are typical of synthetic spinel (op. cit.). In addition, flame-fusion synthetic spinel may include gas bubbles with negative crystal faces (figure 11) that appear deceptively natural.

No typical or diagnostic inclusions have heretofore been observed in flux synthetic blue spinels (Fryer, 1982), but we did note the presence of cross-hatched growth lines parallel to the crystal faces of both samples that we studied. Considerably more material of this type must be examined, however,

Figure 2. Top = seven of the natural blue spinels studied which represent a range of greenish blue to violetish blue colors (1.40 ct–7.52 ct). Bottom = seven of the flame-fusion synthetic spinels studied which represent a range of blue colors (1.88 ct–10.64 ct). Photos by Michael Havstad.

Figure 3. Graph of refractive index versus specific gravity for 22 of the spinels examined.
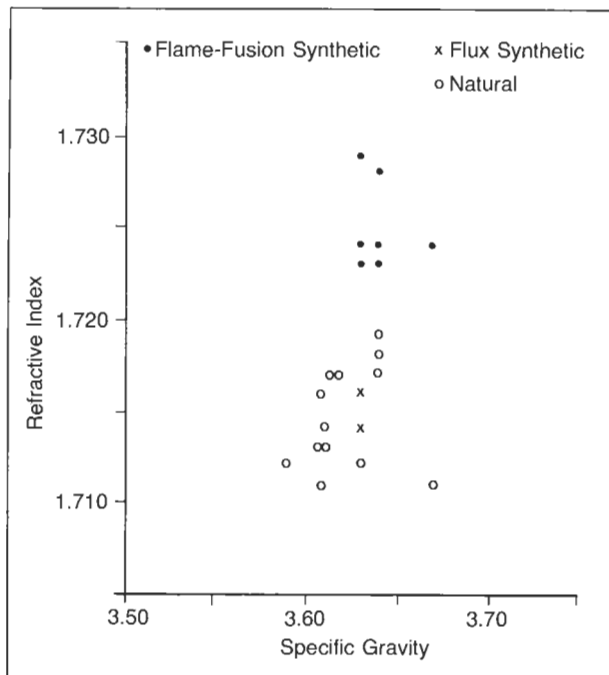
before the significance of this feature can be evaluated.

Absorption Spectra. Eleven absorption bands, here labeled "A" through "K" for convenience, were observed with the spectrophotometer at approximately 429.5, 434, 460, 480, 510, 544, 552, 559, 575, 595, and 622 nm. Bands I + J and K correspond to two bands at about 585 and 635 nm that have been attributed to cobalt in synthetic blue spinels but to iron in natural blue spinels (Anderson and Payne, 1937; Webster, 1983).

As shown in figure 12, we recognized four representative spectral patterns among our suite of blue spinels: two for the natural stones (types I and II) and two for the synthetics (types III and IV). The key identifying feature visible with the hand spectroscope in the spectra of both types of the natural blue spinels (again, see figure 12) is the C band. In addition, type I stones reveal strong G, I, J, and K bands, with the I and J bands merging
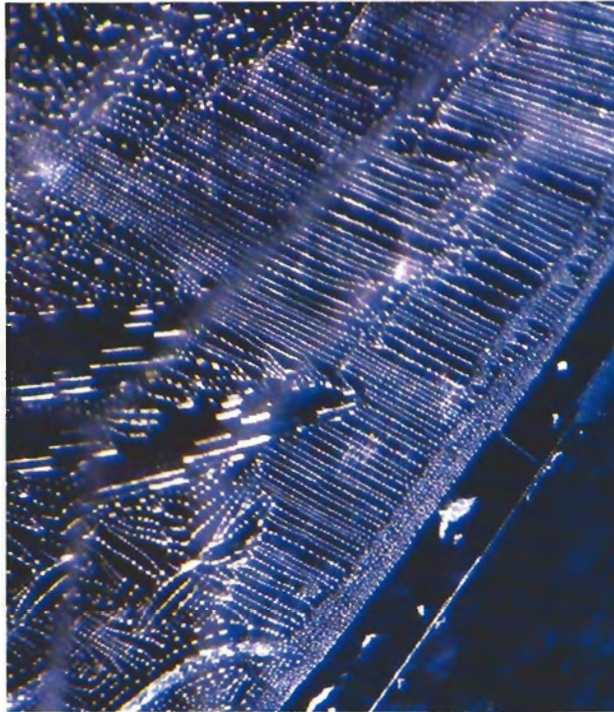
Figure 4. Stringers of minute spinel octahedra such as these are probably the most common type of inclusion seen in natural spinels. Magnified 35×.

Figure 5. Negative octahedron filled with calcite in a natural blue spinel. Magnified 55×.

somewhat to form a single region of absorption. Type II stones have a strong H band, but less frequently display the other bands above 500 nm. Type III spectra (flame-fusion synthetics) invari-

ably have strong F, I, J, and K bands, but no others that can be resolved with a hand spectroscope. Type IV spectra (flux synthetics) differ from type III spectra principally in that the D band is of sufficient intensity that it is sometimes visible in the hand spectroscope. Moreover, the F, I, J, and K bands are so strong in the flux spinel spectra that they usually cannot be resolved into separate bands.

Chemistry. The mineralogical species spinel (ideal formula $MgAl_2O_4$) is a member of a chemically interrelated group of minerals and thus can have other elements (such as Fe, Zn, or Cr) that substitute for Mg or Al (Lindsley, 1976). These sub-

Figure 6. A distorted negative octahedron (left) in one of the intense-blue natural spinels loaned to us for this study. Microprobe analysis of the mineral contained in this inclusion revealed a composition primarily of calcium, aluminum, and silicon, and confirmed the natural origin of the host spinel. Magnified 40×.
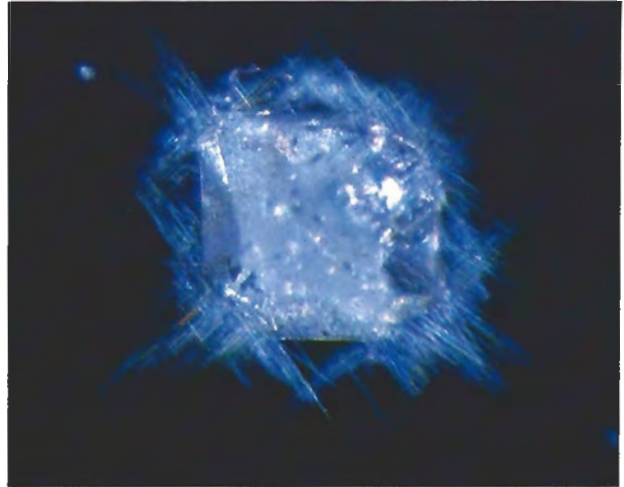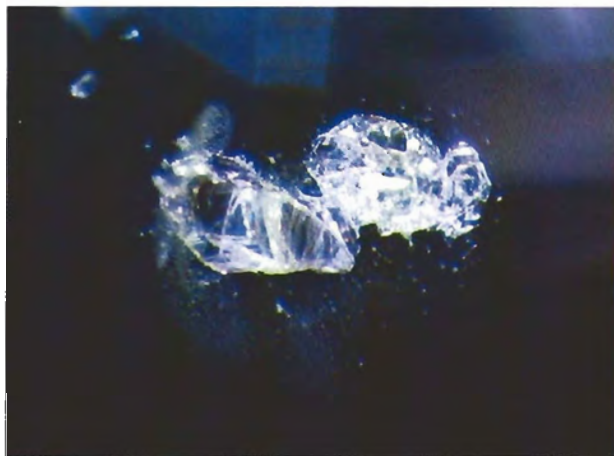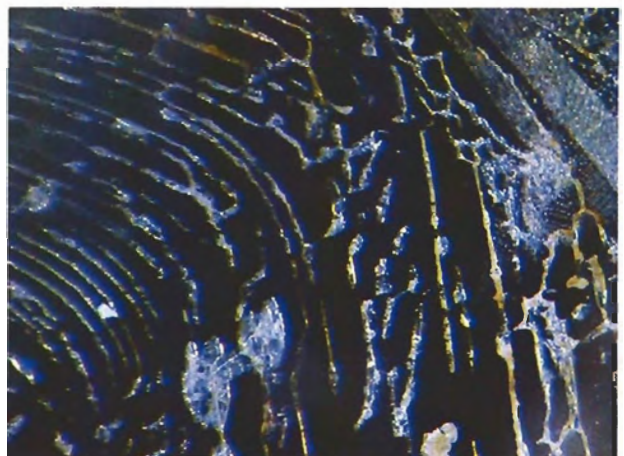
Figure 7. Thin films, some stained by iron, along a healing plane are also diagnostic of the natural origin of a blue spinel. Magnified 30×.
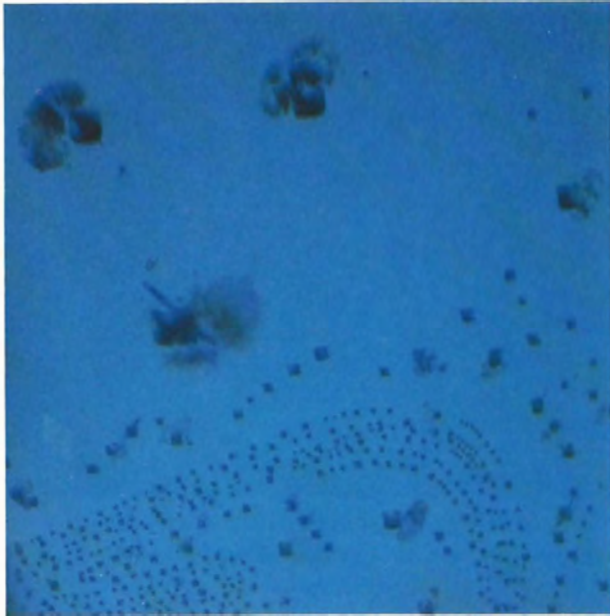
Figure 8. One of the intense-blue natural spinels studied contains numerous octahedra, some of which are surrounded by lily pads that probably contain a thin film of liquid. Magnified 50×.

Figure 9. Another of the intense-blue natural spinels contains these intersecting needles. Magnified 45×.

stitutions are responsible for much of the variability that can be observed in the physical properties of this gem mineral (Winchell, 1941).

Table 1 summarizes our chemical data, from which compositional differences between natural and synthetic blue spinels are apparent. Flame-fusion synthetic stones have excess alumina and thus can easily be distinguished chemically from natural spinels on the basis of the ratio Al:(Mg + Fe + Zn) (Rinne, 1928; Tromnau, 1934).

Flux spinels, however, resemble the natural gem material more closely in this respect.

The iron content in the natural blue spinels studied considerably exceeds that in the synthetics, and trace levels of both gallium and zinc were always present in the former but never in the latter. Nickel and vanadium was found to occur in some of the natural stones, but in none of the synthetics; conversely, titanium was found in most of the flame-fusion synthetics but in none of the natural stones. Small amounts of cobalt were found by microprobe and/or XRF in spinels of all three groups. However, we confirmed the presence of cobalt in several of our spinels (including samples

Figure 10. These stringers of minute gas bubbles are characteristic of flame-fusion synthetic spinel. Magnified 45×.

Figure 11. Gas bubbles with crystal forms, such as this cuboctahedral one, are occasionally seen in flame-fusion synthetic blue spinel. Such negative crystals can be very deceptive and should not be regarded as diagnostic of natural or synthetic origin. Magnified 50×.
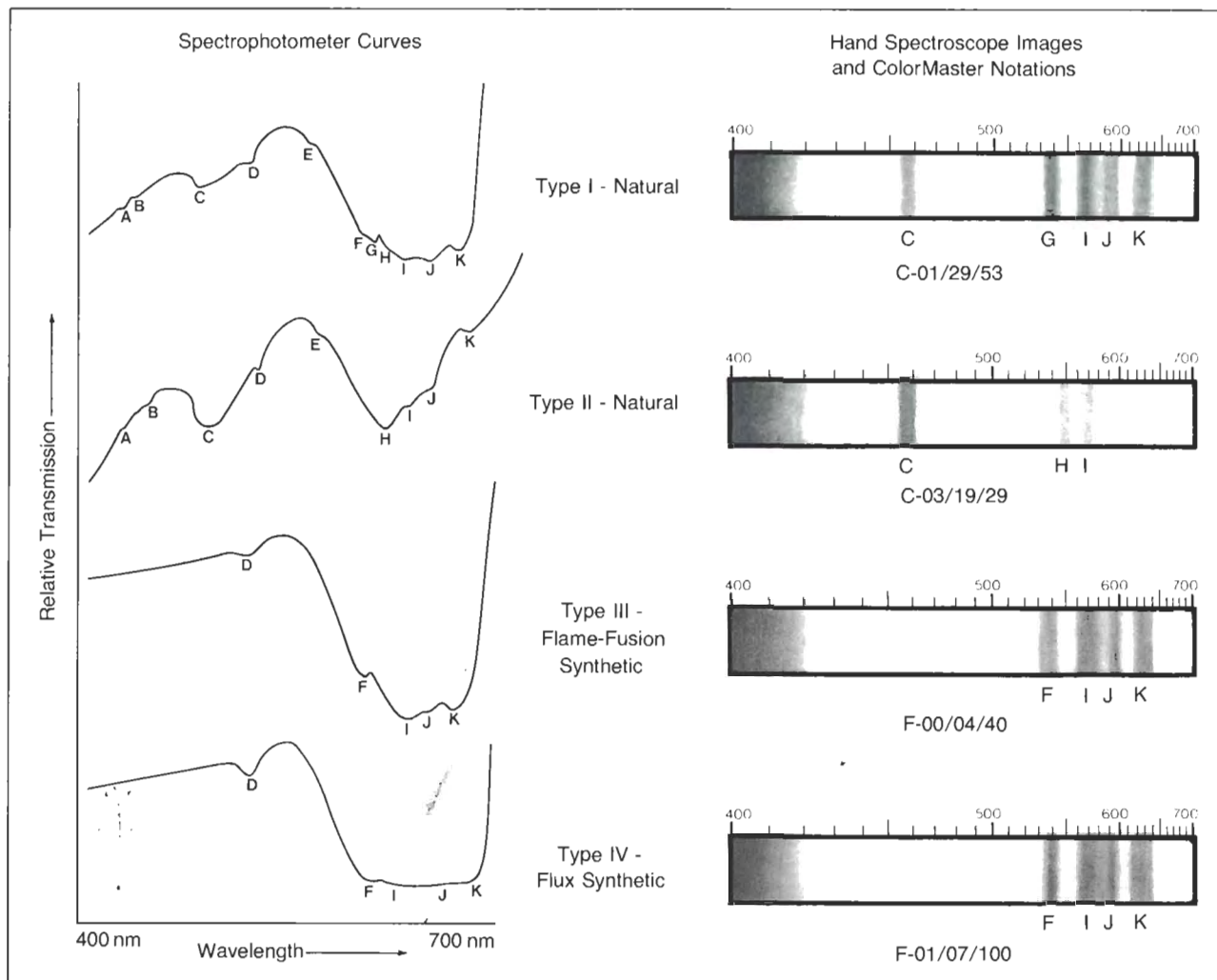
Figure 12. Illustrations of representative spectral curves and hand spectroscope images of the four types of spectra noted in the natural and synthetic blue spinels studied. The ColorMaster notations for each type are given below the hand spectroscope images.

of flux, flame-fusion, and natural intense-blue stones) by infrared spectrophotometry. Furthermore, a light, slightly gray-blue natural spinel was submitted for trace analysis of cobalt by instrumental neutron activation analysis (INAA) and proved to contain 5.3 ppm of cobalt.

INTERPRETATION

Several of the natural spinels we examined are the very intense blue commonly associated with synthetic spinels (figure 13). A case of mistaken identification could easily result in such instances. However, the spectral features and chemistry of spinel are closely interrelated. Thus, absorption bands may provide clues to chemical composition that will serve to distinguish natural and synthetic spinels of this color.

From a comparison of our data with the work of other investigators on spinel absorption spectra (Shigley and Stockton, in preparation), we suggest that bands A, B, C, E, G, and H are due to iron. Almost all of these bands were observed in the spectra of all our natural blue spinels, but none was evident in the spectra of any of the synthetics. Of the six bands, the C band at about 460 nm is perhaps the most useful for the gemologist working with a hand spectroscope because it is distinct in terms of its relative intensity and its isolation from other strong absorption features.

Cobalt is the primary coloring agent in synthetic blue spinels (Rinne, 1928; Tromnau, 1934), while the blue in natural spinels has been attributed solely to iron (Anderson and Payne, 1956). However, our data suggest that cobalt may con-

Figure 13. Two spinels of a similar, intense blue. The 1.88-ct stone on the left is a flame-fusion synthetic, while the 1.40-ct one on the right is natural. The spectral curves for these stones (types III and I, respectively; see figure 12) show similarity in the positions and strengths of their absorption bands in the region above 500 nm. However, recognition of the A, B, and particularly the C bands at shorter wavelengths in the natural stone provides a means for distinguishing it from its synthetic counterpart. Photo by Michael Havstad.

tribute to the color of natural blue spinels as well. With one exception (Mitchell, 1977), cobalt has not been considered a coloring agent in natural blue spinels. In fact, it has generally been accepted in gemology that cobalt cannot cause a blue coloration in any natural gem mineral, and thus that cobalt-related spectral features are proof of a synthetic origin (Anderson and Payne, 1956; Webster, 1983). However, cobalt has been found in other blue-colored minerals (Shannon, 1923), and both it and iron are capable of producing a blue color in materials, although considerably less cobalt than iron is required to produce an equally intense blue (Marfunin, 1979).

The D, F, I, J, and K bands are clearly due to cobalt in synthetic blue spinels; yet in natural blue stones, bands that appear in about the same locations as the I + J and K bands have traditionally been associated with iron. All five bands are strongest in intensity in the flux synthetics, which contain more cobalt than any of the other samples, and are present as well in all of our flame-fusion samples. We suggest, however, that these bands are due to cobalt in both natural and synthetic blue spinels.

The grayish blue natural spinel found to contain 5.3 ppm (0.00053%) cobalt when analyzed by INAA has the nine absorption bands from C through K that can be detected by the spectrophotometer (only C, H, and I can be seen with a hand spectroscope). According to our correlations, then, both iron (present at 1.43 wt. % FeO) and cobalt are represented in the spectrum of this stone, although bands associated with the latter are generally weaker than those attributed to the former. It would thus be reasonable to assume that natural intense-

blue spinels that display even stronger cobalt-associated bands would contain even more of this element. In fact, a number of our natural specimens have amounts of cobalt detectable by microprobe (Shigley and Stockton, in preparation), and all of these exhibit stronger D, F, I, J, and K bands than does the stone with 5.3 ppm cobalt.

Other minor or trace elements found in our specimens do not appear to have a significant influence on the spectra of either the natural or the synthetic blue spinels examined in this study.

CONCLUSIONS

The presence of the iron-induced C band (about 460 nm) in the spectrum of a blue spinel is positive proof of natural origin, since neither flux nor flame-fusion synthetic spinels have sufficient iron to produce a detectable band at this wavelength. This spectral band will be especially useful to the gemologist if at some future date flux-grown synthetic spinels (indistinguishable from natural blue spinels by refractive index) become commercially available. Separation of natural from flame-fusion blue spinels can still be achieved by the use of refractive index: below 1.720 in all the natural stones we examined, and above that in all our flame-fusion synthetics. It is theoretically possible that, since additional iron raises the refractive index of spinel, a natural stone could contain enough of that element to produce a refractive index over 1.720 (i.e., within the range of the flame-fusion synthetics), but in this event the corresponding C band would be even stronger.

We know of no natural blue spinels without an observable C band, and thus it seems likely that this band will be present in the spectra of all

TABLE 1. Summary of chemical data for the 18 natural and 10 synthetic (8 flame-fusion and 2 flux-grown) blue spinels studied (ranges of oxide components in wt. %).

Oxide composition	Natural	Flame-fusion	Flux
MgO	25.45 – 27.88	9.55 – 11.87	26.35 – 26.76
Al_2O_3	70.20 – 71.61	87.99 – 90.41	72.67 – 73.37
TiO_2	n.d.[a]	n.d. – *[b]	n.d.
V_2O_3	n.d. – 0.06	n.d.	n.d.
Cr_2O_3	n.d – *	n.d. – 0.07	n.d.
Ga_2O_3	*	n.d.	n.d.
MnO	n.d. – 0.07	n.d. – *	n.d.
FeO	0.69 – 3.53	*	*
CoO	n.d. – 0.05	n.d. – 0.06	0.18 – 0.19
NiO	n.d. – 0.14	n.d.	n.d.
ZnO	* – 0.44	n.d.	n.d.
Total	99.19 – 100.73	99.86 – 100.59	99.20 – 100.32
Refractive index	1.711 – 1.719	1.723 – 1.729	1.714 – 1.716
Specific gravity	3.59 – 3.67	3.63 – 3.67	3.63

[a] n.d. = below the detection limits of X-ray fluorescence (as low as 0.002 wt. %, depending on elements present).
[b] * = detected by nonquantitative X-ray fluorescence, but below the reliable detection limits of the microprobe (about 0.04 wt. %).

natural blue gem spinels. The virtual absence of iron in synthetic spinels is evident in the lack of a C band in their spectra (see table 1). While iron-doped flux synthetic blue spinels could quite possibly be grown at some future date, our data show that other features of their chemical composition would still provide a positive means of identifying them as distinct from natural blue spinels (Shigley and Stockton, in preparation).

Our data establish the presence of cobalt in natural blue gem spinels and its role as a coloring agent in some of them. It thus becomes unreasonable to consider the use of anything termed *cobalt absorption bands* as a criterion for the separation of natural from synthetic blue spinels. Our observations suggest that both iron and cobalt can give rise to absorption bands in the 500–650 nm region of the visible spectrum. Since we have been able to distinguish only very slight differences in the locations of some of these bands with the use of the spectrophotometer, it would be hopeless to expect to do so with a hand spectroscope. With careful and judicious use, however, the hand spectroscope can be of value, as with the detection of the C and D bands to identify, respectively, natural and flux-grown synthetic blue spinels.

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LEPIDOLITE WITH SIMULATED MATRIX

By John I. Koivula and C. W. Fryer

This article describes a crystal of gem-quality lepidolite (a lithium mica) with a simulated matrix. Under magnification, numerous gas bubbles were observed in the glue that was used to attach the crystal to the matrix. The main crystal was identified as lepidolite by means of X-ray diffraction.

The authors recently examined an unusual crystal in matrix (figure 1). The crystal specimen, which measured approximately 6.0 cm × 1.7 cm, reportedly came from Brazil. At first glance it looked very much like a fine pink tourmaline in matrix, complete with typical surface striations parallel to the length of the crystal. However, the specimen was much too lightweight to be tourmaline. It was obvious that a more detailed examination and some tests were needed to correctly identify the material.

TESTING PROCEDURE

The specimen was first examined carefully under the microscope. It was immediately apparent that the "matrix" was not natural, but had been glued to the crystal. As illustrated in figure 2, the "matrix" contained several areas of an epoxy-like glue in which gas bubbles were trapped. A thermal reaction test carried out on both the "matrix" and the crystal showed that the material simulating matrix was indeed glued on and that some of the glue had been smeared onto the surface of the main crystal, giving it a plastic-coated appearance in a number of areas. A slightly acrid odor and a small puff of white smoke were produced when the hot point was applied to the glue.

Figure 1. The test subject: a translucent crystal of lepidolite, a lithium mica, with applied matrix, 6.0 cm long × 1.7 cm wide.

We also noted that the "matrix" was composed of numerous small, rounded pebble-like grains that suggested extensive alluvial transport. However, a pink and a green crystal fragment (figure 3) attached at either end of the "matrix" showed very few signs of abrasion. In addition, the large
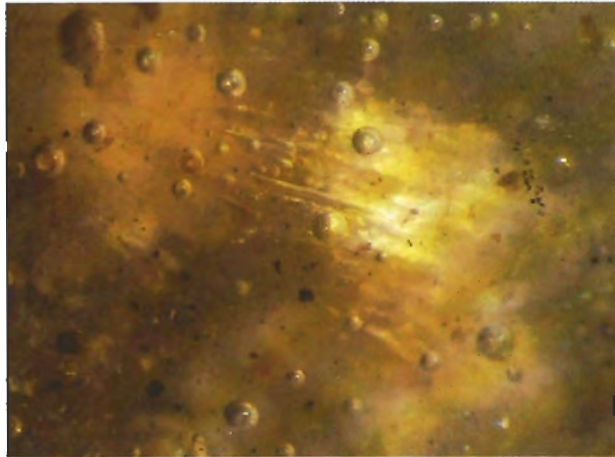
Figure 2. These gas bubbles trapped in the epoxy-like glue used to affix the matrix provided clear evidence that the specimen had been constructed. Oblique illumination, magnified 30×.

pink crystal did not show any signs of alluvial abrasion. Gross inconsistencies, to say the least.

Under magnification, the natural-appearing surface striations running lengthwise on the crystal indicated a lamellar internal structure. There was no question now that the pink crystal was natural; it also appeared to be micaceous (figure 4).

Figure 3. This small green crystal fragment was attached to one end of the applied matrix. Unlike the "matrix," it showed few signs of abrasion. Magnified 6×.
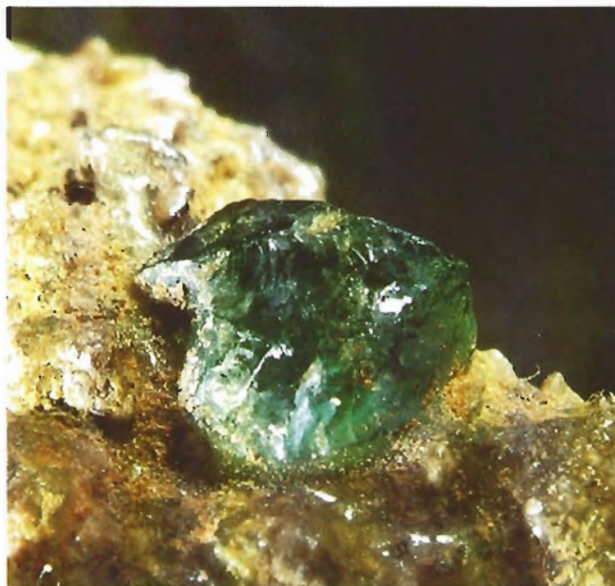
Since the large pinkish crystal was translucent, the specimen was checked with a spectroscope, polariscope, and dichroscope. No absorption spectrum was observed using a Beck spectroscope. The polariscope reaction was inconclusive, but the dichroscope showed definite lighter and darker shades of pink, proving the stone to be doubly refractive. During testing with ultraviolet radiation, only the glue reacted, fluorescing a pale whitish yellow. Because of the micaceous structure observed in the main pink crystal and the similarity of this specimen to a specimen of lepidolite that was pictured in a recent book (Sauer, 1982), lepidolite was next suspected.

We decided to use X-ray powder diffraction to conclusively identify the specimen. A spindle was prepared from a minute powder sample obtained from an inconspicuous area of the crystal. The

Figure 4. The micaceous habit of the lepidolite crystal is evident in this photomicrograph. Magnified 6×.

spindle was then mounted in a Debye-Scherrer powder camera and exposed for 4.2 hours to X-rays generated at 48 KV and 18 MA from a copper target tube. The pattern was measured for d spacing with a Nies overlay corrected for film shrinkage. The intensities of the lines were estimated visually. This pattern was then compared with five known lepidolite patterns. It matched the ASTM 14-11 pattern—a two-layered, monoclinic $(2M_2)$ structure—almost exactly.

CONCLUSION

Lepidolite cabochons are sometimes encountered by the jeweler, but a large, gemmy crystal such as this is quite rare. Although the crystal examined proved to be a beautiful example of gem-quality lepidolite, the matrix was not genuine. Just as gemologists must cope with synthetic, treated, and assembled gemstones, they must also sometimes deal with gem mineral specimens with simulated matrix, many of which are not as easy to identify as the one reported here. Some specimens may show virtually no evidence of assembly or alteration. In these cases, subtle signs such as inconsistencies in matrix texture or color are often useful clues. Readers interested in additional information are referred to an excellent paper on mineral chicanery written by Dunn, Bentley, and Wilson (1981).

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Sauer J.R. (1982) *Brazil, Paradise of Gemstones*. AGGS Industrias Gráficas S.A., Brazil.

Gem Trade
LAB NOTES

BERYL, with Iridescent Coating

The Los Angeles laboratory received a lady's yellow metal ring set with a transparent, light blue, oval mixed-cut stone. Subsequent testing proved the stone to be an aquamarine. The client explained that the stone had an iridescent coating on the crown (figure 1), which was not present when the ring was originally sold. Our client had attempted to remove the coating using several different methods—alcohol, an ultrasonic cleaner, and sulphuric acid—but when none was successful, he brought the stone to the lab for advice.

The effect observed on this aquamarine is similar to the iridescent oxidation seen on some glass. Although we have also observed this type of coating, or "tarnish," on emeralds (*Gems & Gemology*, Fall 1960, p. 70) as well as on golden beryl (*Gems & Gemology*, Summer 1977, pp. 310–311), this was the first time we had seen it on aquamarine. We still do not know the exact cause of this type of coating, but we have found that it can usually be removed by light polishing with rouge or cerium oxide. In the case of this aquamarine, an ordinary ink eraser easily removed the coating.

Sometime later, the Los Angeles laboratory received a synthetic emerald with a similar appearance. In this case, the iridescent coating was so heavy that it caused the refractive index reading to be somewhat vague. As with the previously examined aquamarine, the coating on this synthetic emerald was confined
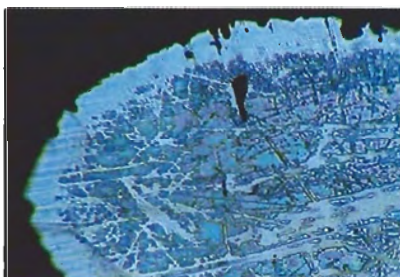
Figure 1. Iridescent coating on the table of a 2-ct aquamarine. Magnified 63×.
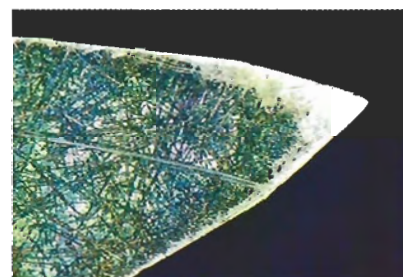
Figure 2. Iridescent coating on the table of a synthetic emerald. Magnified 35×.

entirely to the crown and almost appeared as if the surface had been very poorly polished. Figure 2 shows the table of this stone in reflected light; note the portion on the right of the table where we easily removed a small amount of the coating with an eraser.

CORAL, Dyed Blue with Plastic Coating

An opaque, variegated, blue, 17-mm, round drilled bead, represented to be blue coral (figure 3), was recently submitted to the Los Angeles laboratory for identification. Examination under the microscope showed that the bead consisted of a mottled blue core covered by a transparent, near-colorless coating that contained numerous gas bubbles. The coating was fairly soft and could easily be indented with the point of a pin. Testing with a hot point produced an acrid odor, proving that the coating was plastic.

Figure 3. A 17-mm coral bead that was dyed blue and then plastic coated.

One can also see, in the center of the bead illustrated in figure 3, a small area where the coating had been removed to expose an almost colorless to light blue area with structure typical of coralline growth. A small drop of hydrochloric acid on this area

caused the material to effervesce, proving that it was indeed coral. The blue color, however, was easily removed with a cotton swab soaked with nail polish remover, which indicates that the coral had been artificially colored to simulate natural blue coral before it was coated with plastic.

DIAMOND

Unusually Large Laser Holes

By now laser holes are a common sight to diamond graders and buyers. Occasionally, however, one sees unexpected examples. Usually, the holes are very fine—about the diameter of a human hair. The staff of the New York laboratory was therefore puzzled when we saw what at first appeared to be a stubby, conical "negative crystal" extending into a double disc-shaped inclusion in a 6.88-ct pear-shaped diamond. At the surface, the hole was fully ten times larger than the usual drill hole. We were convinced that it was a laser hole and not a natural inclusion when we found a similar conical hole (figure 4) in another area of the stone.

For comparison, a normal-size drill hole is illustrated in figure 5. Note also the stress fractures around the reddish brown crystal reached by the drill hole.

Figure 4. A large, conical laser drill hole seen in a 6.88-ct pear-shaped diamond. Magnified 34×.
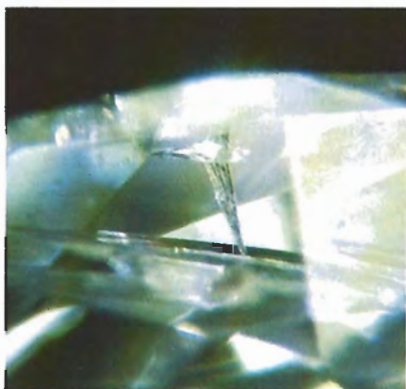
A Successful Laser Experiment

We recently had the opportunity to study a 1.09-ct pear-shaped diamond in which a single laser drill hole reached three separate dark inclusions, allowing them to be treated to remove the color. In figure 6 one can see that the laser drill operator has succeeded in directing the laser beam to take a stepped path from inclusion to inclusion. *Gems & Gemology* readers may recall illustrations of stones with multiple drill holes—as many as 17 in one diamond. This new process, by which neighboring inclusions can be reached with a single drill hole, promises to be much better for the clarity and appearance of the stone.

EMERALD, Oiled

A client recently brought a group of emeralds into the New York laboratory for examination after many fractures had become visible to the unaided eye while the stones were being set into rings. It was not certain whether the stones had somehow been damaged during manufacturing, or if they had been oiled and the oil had subsequently dried out.

Most of the fractures in these emeralds fluoresced yellow when exposed to ultraviolet radiation, an indication that the stones had indeed

Figure 5. This normal-size laser drill hole has caused stress fractures around the inclusion to which it extends. Magnified 50×.
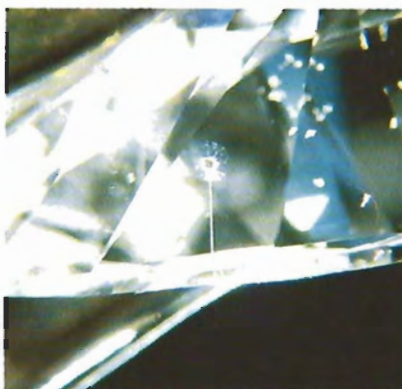
been treated with oil. In addition, whitish dendritic deposits were observed in several fractures (figure 7). Such deposits can occur when oiled stones are cleaned ultrasonically or, as in this case, when exposure to very high temperatures, such as those encountered during the manufacturing process, causes the oil to dry out.

HEMATITE, Magnetic

Generations of gemology students have used a magnet to separate hematite from "Hemetine," a trademarked imitation. A further test was to observe the fracture. Hematite, which is usually not magnetic, generally has a splintery fracture (figure 8), while Hemetine, which is magnetic, has a granular fracture. Hemetine usually produces a black streak, in contrast to the reddish brown streak of hematite. In recent months, however, a plentiful supply of a new type of hematite has reached the market. This new type is confusing because, although it produces a red streak, it also has a granular fracture and is magnetic. Figure 9 shows a bead of this material with a granular fracture suspended from an ordinary small magnet. Only after X-ray diffraction analysis and observation of some of the rough material were we able to positively identify it as hematite. Figure 10 shows a section

Figure 6. Step-like laser drill hole. Magnified 39×.
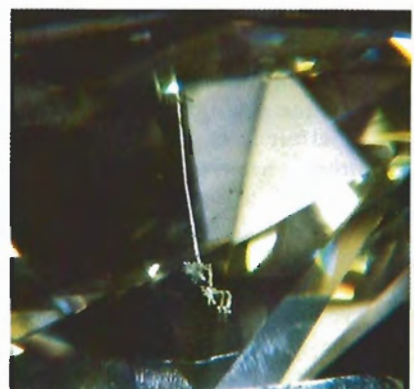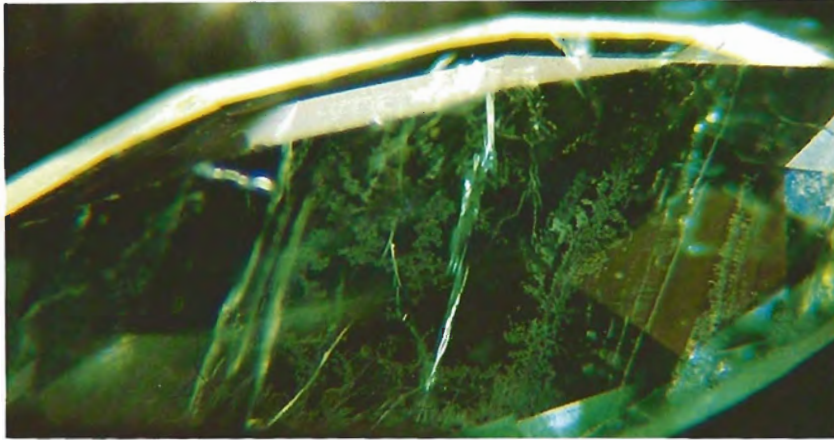
Figure 7. These fractures containing dendritic deposits became visible after the oiled emerald was heated during manufacturing. Magnified 33×.

of a necklace of 4-mm magnetic hematite beads; note the reddish pits on some of the beads and the banded structure of others.

In the *Textbook of Mineralogy*, Dana mentions that specular hematite is sometimes micaceous (granular fracture) and magnetic, probably due to an admixture of magnetite. X-ray diffraction analysis of this material did not reveal magnetite, but we did learn that upon heating hematite becomes magnetic. Possibly this new material is specular hematite, or is a type of hematite that became magnetic with naturally or artificially applied heat. Whatever the cause, a number of competent gemologists have been submitting samples of this new hematite to the laboratory, unable to believe their suppliers' assurances that it is indeed natural and not an imitation.

JADE

Dyed Jadeite

A report with an unusual twist comes from Yoshiko Doi of the Association of Japan Gem Trust in Tokyo. It seems that a quantity of small green jadeite cabochons that recently reached the Japanese market have been represented as being dyed. However, testing by Japanese gemologists revealed no evidence of dyeing. Believing that

a new treatment method might have been developed, Ms. Doi sent some of the stones to the Santa Monica Gem Trade Laboratory for further testing.
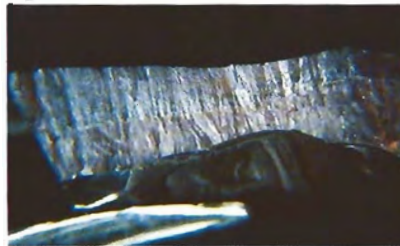
Figure 8. The splintery fracture commonly seen in hematite.

Figure 9. This hematite bead, 4 mm in diameter, not only adheres to the red magnet but also displays granular fracture.
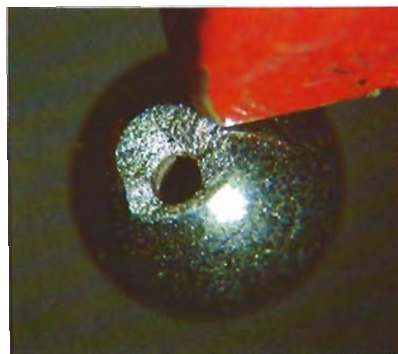
A refractive index of 1.66 and specific gravity of 3.33 confirmed that the material was jadeite. As was expected, the stones were inert to ultraviolet radiation. Absorption lines in the red were consistent with the spectrum of a natural-color green jadeite. There was no evidence of any dye in the cracks when viewed with a microscope (see figure 11). All tests indicated natural-color green jadeite.

As further confirmation, a piece of the jadeite was sent to Dr. George Rossman at the California Institute of Technology. A thin section of the stone was prepared and run on their Cary spectrophotometer. An absorption spectrum run from 350 nm to 1500 nm revealed a slight trace of Fe^{3+}, with minor peaks at 434 and 439 nm and predominant peaks at approximately 638, 656, and 688 nm that were attributed to Cr^{3+}. No extraneous features were present. This analysis is entirely consistent with natural-color green jadeite.

It is still a mystery why anyone would want to represent natural-color jadeite as being dyed, but there is no doubt that the material tested was indeed natural color. Our thanks to

Figure 10. Pitted surface and banded structure on 4-mm magnetic hematite beads.

Dr. Rossman for the detailed absorption spectrum.

Dyed Nephrite

Both the Los Angeles and the New York labs recently had the opportunity to study a flat, green 1.06-ct cabochon (figure 12) that had been presented as dyed nephrite jade. The client claimed that this material had retained its color better than the dyed jadeite he had. The cabochon was fairly translucent and, although slightly mottled, resembled fine green jadeite in color. However, the refractive index and specific gravity proved that the material was nephrite jade. The translucent crystalline aggregate structure was visible under magnification, with the green color concentrated within and around the fire cracks (see figure 13). Spectroscopic examination showed a broad absorption band (figure 14) in the red portion of the visible spectrum from 6600 to 7000 Å, which undoubtedly can be attributed to the green dye. However, only the faintest brownish color was seen under the color filter. This contrasts with the red color usually associated with dyed jadeite, or serpentine. We have observed dyed nephrite only once or twice in the past (see, for example, the mottled carving pictured in the Winter 1965–1966 issue of *Gems & Gemology*). One theory about why there is not more dyed nephrite is that possibly the structure of nephrite resists the crackling necessary to take dye.

Figure 11. Even coloration in a jadeite cabochon. Magnified 63×.

Figure 12. Dyed nephrite cabochon, 1.06 ct.
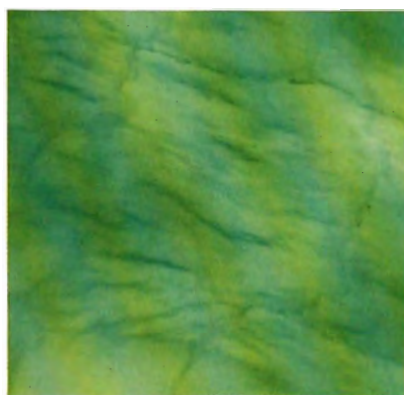
Figure 13. Concentration of dye in the cracks of the dyed nephrite shown in figure 12. Magnified 50×.

Figure 14. Absorption spectrum of the dyed nephrite illustrated in figures 12 and 13.
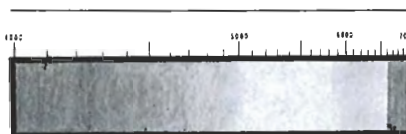
PEARL, Hollow Natural

With the increased production of tissue-nucleated cultured pearls, both freshwater and saltwater, we have had more occasion to study X-radiographs showing the void caused by the tissue nucleus. Prior to the experience described in this report, we had not seen any radiographs of tissue-nucleated pearls in which such a void represented more than half the area of the pearl.

Recently, however, in conjunction with an ongoing exchange of common problems with the London Chamber of Commerce and Industry Laboratory, the New York laboratory examined an attractive hollow button pearl (figure 15). An X-radiograph of the pearl is shown in figure 16. As is evident in figure 15, the hollow appears to be lined with dark-appearing conchiolin, a layer of which surrounds the rather large "drill hole." One explanation for such a hollow might be that originally the pearl had an unconsolidated conchiolin or "mud" center that may have disintegrated when the pearl was drilled, leaving a void. A thin section of such a pearl is illustrated on page 446 of the third edition of *Gems*, by Robert Webster.

By coincidence, while we still had the hollow button pearl in the lab, we received a round half-drilled pearl for testing (figure 17). The X-radiograph of this pearl (figure 18) shows

a solid center that is very transparent to X-rays, with an indistinct drill hole. The dark central core could be rotated within the pearl with the tip of a pin. A touch with the thermal reaction tester produced a medicinal plastic odor. This pearl probably had either a conchiolin or "mud" center, similar to the pearl mentioned above, but in this case the void has been replaced with a filler.

On the same day that the round half-drilled pearl was brought into the lab, we also received a bar pin with 12 pegged pearls. The X-radiograph (figure 19) shows 10 hollow (and probably filled) natural pearls, one solid natural pearl (fourth from the right), and one imitation pearl (on the extreme right).

RUBY, "Manufactured" Mineral Specimen

The Los Angeles laboratory recently received the transparent red crystal illustrated in figure 20. In his attempts to identify the material, our client had removed the stone from a light brown sedimentary rock "matrix" and polished a flat on it. Feeling that his results were inconclusive, he subsequently submitted the crystal to our laboratory for identification.

The easily visible curved striae and gas bubbles, in conjunction with the refractive indices of 1.762–1.770, proved the material to be a flame-fusion synthetic ruby. The material had been cleverly fashioned into a hexagon measuring 10.96 × 6.32 × 5.10 mm, similar in appearance to a red beryl crystal. Even the surface of the 5.03-ct "crystal" had been either etched or abraded to resemble the surface characteristics that a natural crystal might have.

Figure 15. Hollow button pearl showing a brown conchiolin layer around the drill hole. Magnified 12×.

Figure 17. Drill hole in a hollow round pearl.
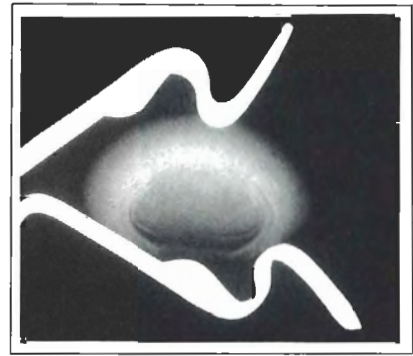
Figure 16. X-radiograph of the hollow button pearl in figure 15.
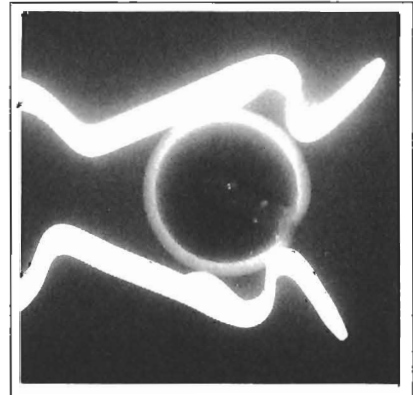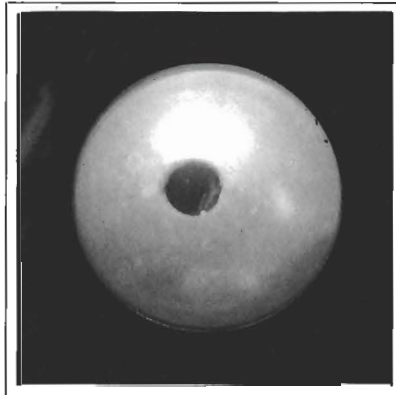
Figure 18. X-radiograph showing the solid central core and drill hole of the pearl shown in figure 17.
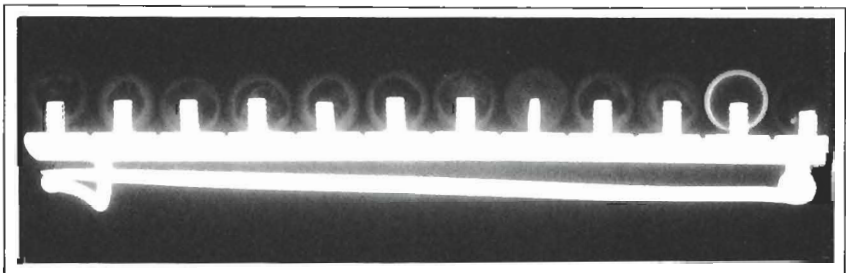
Figure 19. X-radiograph of a pearl bar pin; all but two of the pearls appear to have been hollow and subsequently filled.

SCAPOLITE, A New Cat's-Eye From Kenya

Figure 21 illustrates a heretofore undescribed reddish brown cat's-eye scapolite that is reportedly from an area of Kenya north of Nairobi. Although both colorless and pale yellow scapolite from Kenya and Sri Lanka have been reported by K. Schmetzer and H. Bank (Gems & Gemology, Summer 1983, p. 108), and reddish brown, chatoyant scapolites from Tanzania have been reported by E. Gübelin, G. Graziani, and S. Lucchesi (Journal of Gemmology, April 1981 and January 1983), this is the first time the Tanzanian chatoyant
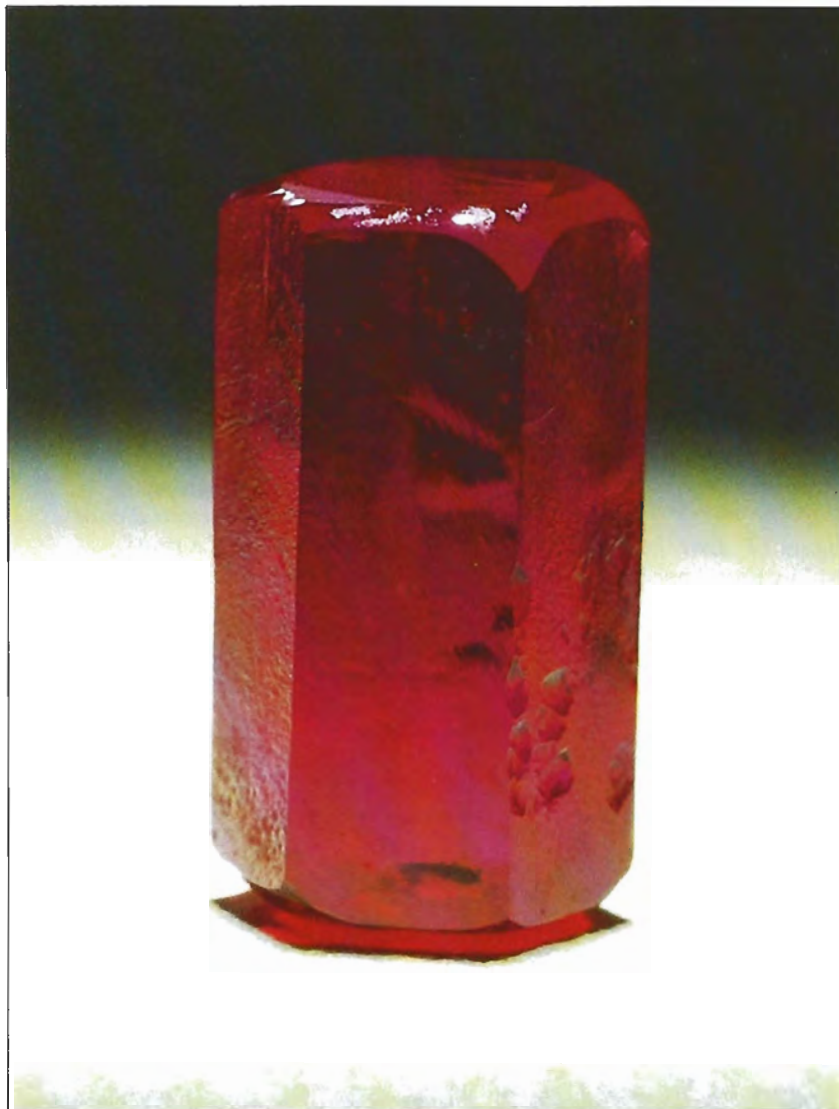
Figure 20. Synthetic ruby imitating a crystal, 10.96 × 6.32 × 5.10 mm. Notice the curved striae running vertically.

type has been reported from Kenya. We determined that the attractive color of this stone, which resembles some coppery colored cat's-eye beryl seen in recent years, is derived from the inclusions (figure 22), rather than from the bulk crystal. This phenomenon also occurs in the Tanzanian material mentioned above.

The gemological properties of this stone are: R.I. 1.57 (spot); specific gravity, 2.73; long-wave ultraviolet, inert; short-wave ultraviolet, strong red; and no absorption spectrum. Further testing, including X-ray diffraction, proved that the stone was a scapolite of the mizzonite species, identical to the Tanzanian material. The Sri Lankan material is 69% meionite. Scapolite has been determined to be a group of related species that, to the jeweler/gemologist, may resemble members of the feldspar group, and routine gem testing methods may not always determine the exact species to which a given stone belongs.

This new chatoyant scapolite differs from the fibrous, semitransparent, pink Burmese cat's-eye scapolites in relative transparency, in the nature of the inclusions causing both color and chatoyancy and, undoubtedly, in the species of the scapolite group to which it belongs. Although it is not visible in the photograph, there is another, much weaker chatoyant ray at right angles to the dominant ray, and a distorted six-ray star near the girdle. This indicates that the needles and other inclusions are aligned in more than one direction in this tetragonal material.

Figure 21. Cat's-eye scapolite reportedly from Kenya. Magnified 6×.

Figure 22. Concentration of color in inclusions in the scapolite shown in figure 21. Magnified 50×.

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Exsolution of copper from labradorite phenocrysts of Steens Mountain basalts, Lake County, Oregon (abstract). A. M. Hofmeister and G. R. Rossman, *Geological Society of America Abstracts with Programs,* Vol. 15, No. 6, 1983, p. 597.

Large phenocrysts of colorless and pale yellow labradorite are found in Rabbit Basin, Oregon. Occasionally, they exhibit a pink schiller effect and are transparent red or green. Gemologists have labeled these latter variations sunstones, and attribute the effect to hematite or goethite inclusions. The authors analyzed a

number of samples with microprobe and X-ray fluorescence, and conclude that copper and lead are responsible for the odd colors. The schiller flakes are copper. Hofmeister and Rossman propose that the copper (Cu^{1+}) and lead (Pb^{2+}), respectively, reduce and oxidize in pairs. Thus, Pb^{3+} gives green color, and Cu^0 (colloidal copper) produces the red and ultimately the schiller effect. It appears that the composition of the megacrysts changed with the increasing copper content in the melt as the labradorite crystallized. *DMD*

Gemstones of Canada. W.F. Boyd and W. Wight, *Journal of Gemmology,* Vol. 18, No. 6, 1983, pp. 544–562.

This paper was originally presented at the 18th International Gemmological Conference at Kashikojima, Japan, in November 1981. The authors review the gemstones that have been produced in Canada, including the relative amount of production and the mines or areas from which the gems were recovered. Major stones in Canadian mineral collections are also noted.

Nephrite is produced on a commercial scale, while quartz, ammolite (ammonite), labradorite, amazonite, sodalite, and rhodonite have had limited production success. Other gemstones included in this article are diamond, sapphire, beryl, grossular garnet, almandine garnet, apatite, cordierite, vesuvianite, amber, oligoclase, and lapis lazuli. Six maps have location indicators for these gems. *GSH*

Materiales gemológicos españoles, minerales, perspectivas generales (Spanish gemological materials, minerals, general perspectives). J. García Guinea, *Boletín del Instituto Gemológico Español,* No. 24, 1983, pp. 9–18.

The author laments the lack of a comprehensive guide to the gemological materials of Spain. He discusses the need for a study that would take into account sociological, economic, and artistic considerations, as well as technical data. He lists areas of inquiry and potential sources of information for such a study. There is a bibliography of Spanish literature in the field, dating from 1910, as well as six color photographs of gems from Spain. *SLD*

Natural coral and some substitutes. R. Aliprandi, F. Burragato, and G. Guidi, *Journal of Gemmology,* Vol. 18, No. 5, 1983, pp. 401–410.

This article reports on the examination of natural untreated coral, two types of treated material, and Gilson imitation coral.

A dark red untreated natural coral bead was tested with a transmitted, concentrated beam from a fiber-optic illuminator. This and all the other specimens of coral tested exhibited a degree of translucency not shown by either pressed calcite substitutes or resin-impregnated coral, both of which appear opaque. Fiber-optic examination also revealed the characteristic striped structure of natural coral. Examination using SEM techniques revealed distribution of both Ca and Si.

The second specimen was a pink-white dyed coral bead. When the bead was exposed to long-wave ultraviolet radiation, a weak purplish red fluorescence was observed along minute veins, apparently due to dye concentrating in surface fractures. Immersion of this material in ether or acetone caused a discoloration of the liquid and bleaching of the specimen. SEM examination revealed nothing to help distinguish the stained coral from natural material.

The third specimen was a porous natural coral stabilized for use as jewelry with epoxy-esters resin. In this treatment, colorless resin fills cavities in the material, giving it compactness. A drop of hydrochloric acid on this specimen caused effervescence and left behind a porous, spongy, semitransparent aggregate that proved to be epichlorhydrin. SEM examination revealed its porous nature, with specks of resin of a different consistency breaking the uniform surface. Unlike the natural, untreated coral, this specimen lacked Ca in some surface areas.

The final specimen was an oxblood-red Gilson imitation coral bead. When tested with hydrochloric acid, the bead effervesced and left behind some residual red pigment. SEM examination revealed a grainy structure composed of particles of different shapes and sizes; Ca was evenly distributed while Si was irregularly distrib-

uted. The authors conclude that it is possible to distinguish between natural, treated, and simulated coral without resorting to destructive tests. Twenty photomicrographs relating to the SEM investigations are included in this article. *RCK*

Natural etch pits in beryl related with the structure. J. A. Medina, M. Morante, and S. Leguey, *Bulletin de Minéralogie,* Vol. 106, 1983, pp. 293–297.

Etch pits are small geometrically shaped cavities occasionally seen on certain outer surfaces of crystals. They represent the locations where selective dissolution of the crystal has taken place at a time subsequent to its formation. Their geometrical shape arises from the fact that the rate of dissolution is influenced in part by the underlying internal structural symmetry of the crystal. Thus, etch pits with different shapes develop on different crystal faces. The authors of this article investigated beryls from Minas Gerais, Brazil, and from Muzo and Yacopi, Colombia, to further relate etch pits to the beryl crystal structure. Taking each type of face in turn (basal, prismatic, pyramidal), they have related the shape of etch pits (triangular, hexagonal, rhombic, etc.) to the structural arrangement of constituent atoms in the beryl. In particular, they identified the importance of the relative orientation of "chains" of bonded -Al-0-Be-atoms with respect to each crystal face. *JES*

The petrogenesis of topaz rhyolites from the western United States. E. H. Christiansen, D. M. Burt, M. F. Sheridan, and R. T. Wilson, *Contributions to Mineralogy and Petrology,* Vol. 83, No. 1, 1983, pp. 16–30.

Fluorine-rich rhyolites containing gem-quality crystals of topaz, garnet, and beryl are widely distributed in various parts of the western United States and Mexico. These rhyolites, which characteristically contain topaz, were emplaced throughout most of the Cenozoic era as volcanic domes, lava flows, and shallow intrusives. They are mineralogically and geochemically distinct from other rhyolites. From a survey of major localities, this paper summarizes current ideas on the petrogenesis of these rocks and presents a model to account for their origin. Available evidence suggests that topaz rhyolites evolved from the partial melting of a residual granulitic source rock in the lower crust. An extensional tectonic setting in this region allowed small batches of these rhyolitic magmas to rise to the surface without substantial mixing with contemporaneous mafic magmas. Crystal/liquid differentiation and possibly liquid-state fractionation appear to have been important processes that took place within these magmas following their generation. After emplacement on or near the surface, crystals of gem minerals such as topaz and beryl resulted from crystallization of a vapor phase released by the magmas during their cooling and devitrification. *JES*

Tiger eye gems machined by diamond. P. Daniel, *Industrial Diamond Review*, Vol. 43, No. 497, 1983, pp. 184–185.

Daniel begins by noting that, only a short time ago, tiger-eye was considered too difficult to work by machine. However, recent advances in diamond tool technology have expanded the capabilities of lapidaries. The author credits a German geologist, Lichtenstein, with discovering tiger-eye in the Kuruman Hills of the Northern Cape around 1803. Today, seams of tiger-eye are found among ironstone and jasper where blue asbestos (crocidolite) is also mined. Oxidation of the iron as the asbestos silicified produced the golden yellow and brown bands of tiger-eye. When the blue color has not changed, the material is called hawk-eye or falcon-eye, as well as blue tiger-eye. *Bull's-eye* is the term applied to the red material produced by heating tiger-eye.

Daniel then turns to a discussion of the equipment used by the Max Hart Co. in Cape Town, South Africa, to work tiger-eye, from slabbing machines to cabbing machines. He includes the addresses of seven companies that produce the equipment as he notes how versatile tiger-eye can be in jewelry. *DMD*

A trapped-hole center causing rose coloration of natural quartz. D. Maschmeyer and G. Lehmann, *Zeitschrift für Kristallographie*, Vol. 163, 1983, pp. 181–196.

Atomic-scale structural defects in crystals, collectively referred to as color centers, are important in the coloration of several gemstones (i.e., some diamond, quartz, and topaz). Such defects frequently involve a displaced electron. In its new site where it becomes trapped in the crystal structure (an electron center), or in the old site from which it was removed (a hole center), selective absorption of visible light can occur, producing color. These centers are often associated with impurities, and may be produced by ionizing radiation. The resulting colors differ in their thermal stability.

Maschmeyer and Lehmann suggest that such color centers are responsible for the coloration of some rose quartz. Rose quartz is generally a massive, translucent material; its color has a high thermal stability due to trace amounts of titanium. In contrast, the small, transparent crystals of rose quartz from Brazil have a color that can be bleached by heating and then made to reappear by gamma irradiation. In this instance, electron paramagnetic resonance (EPR) measurements indicate that the rose color is due to a trapped-hole center. This center is associated with an oxygen atom bridging between a substitutional aluminum atom and a phosphorus atom in the quartz crystal structure. Thus, the authors suggest that more than one cause of color may occur in any given specimen of rose quartz. *JES*

DIAMONDS

Metastable crystallization of natural diamond from the fluid phase. N. S. Nikol'skiy, *Doklady Akademii Nauk SSSR*, Vol. 236, No. 4, 1981, pp. 954–958.

Published reviews indicate that an overwhelming majority of researchers believe that all natural diamonds, without exception, form under stable conditions at high temperatures and pressures. However, according to Nikol'skiy, there is evidence suggesting that natural diamonds can form under metastable conditions at low pressures and temperatures. This evidence is to some extent confirmed by diamond's synthesis from the gaseous phase in the region of graphite stability. An appropriate composition of the diamond-forming fluid, the presence of suitable seed crystals, and optimal thermodynamic conditions in the system are required for such epitaxial growth of diamond crystals.

Nikol'skiy, working with the system $H-O-C$, compares experimental and theoretical data supporting his estimation of the best thermodynamic conditions required for the formation of metastable diamond. The author's technical discussions focus on the reaction rates and processes that occur during the evolutionary stages of the melt under various temperatures and pressures. Nikol'skiy concludes that diamond-formation processes are not uniquely specific to kimberlite-bearing rocks, and that we should expand the range of rocks perceived as diamond bearing to include other igneous rocks. *SCH*

Miscellaneous diamond mining news. Manchete, *Indiaqua*, Vol. 36, No. 3, 1983, pp. 27–28.

In this section, Manchete presents a short account of the current diamond mining activities in Mato Grosso, Brazil, which produced the 261.88-ct Star of the South diamond in 1853.

Today a flurry of activity occurs in and around Poxoreu, located 680 km west of Brasilia. Not only are diamonds being "panned from the black waters" of nearby rivers, but some streets have also been turned into mini-diamond fields. Since the main activity of the townspeople is searching for diamonds, there are few complaints. The skills of diamond digging are passed along family lines, from father to son. Two of Poxoreu's citizens are highlighted as we learn how diamonds have changed their lives. *DMD*

GEM LOCALITIES

Un gisement d'emeraudes à Madagascar (An emerald vein in Madagascar). H. A. Hänni and H. H. Klein, *Revue de Gemmologie a.f.g.*, No. 74, 1983, pp. 3–5.

The authors present a study of emeralds from a new mine at Ankadilalana, Madagascar. The mine is located in the south-central portion of Madagascar's eastern

coast, an area that consists primarily of Precambrian rocks intruded by pegmatites. These pegmatites have reacted with the surrounding rock, and the displacement of elements from this reaction has resulted in the formation of emerald crystals in the biotite schists adjacent to the pegmatites.

The authors examined small blue-green emerald crystals found at the mine site and noted that they bore a striking resemblance to the emeralds from Miku, Zambia. Chemical and spectrographic analyses of these Madagascar emeralds were performed, and their inclusions identified. These data are provided in a table, which also lists the corresponding data from comparable African emeralds. Hänni and Klein conclude on the basis of their comparisons that the mine at Ankadilalana is capable of producing gem-quality emeralds similar to those from Africa.

The authors also discovered in the course of their research that some cut stones reputed to be from Zambia and Zaire were in fact from Madagascar. This article is the first published study of the new Madagascar emeralds, and should prove very helpful to those gemologists who have dealt with African emeralds and who will need to identify emeralds from this new source. *JMB*

Harts Range hessionite. H. Bracewell and G. Brown, *Australian Gemmologist,* Vol. 15, No. 1, 1983, pp. 6–10.

In this gemology study-club report, the authors describe a specimen of hessonite (*hessionite* is the spelling used by the authors) garnet from an as-yet-undisclosed location in the Harts Range region of the Northern Territory, Australia. The optical and physical properties of the specimen were found to be consistent with those previously reported in the literature for this gem variety.

However, the results of the authors' microscopic examination are significant, revealing epigenetic cracks; syngenetic healed cracks which contained black, iridescent grains of an unidentified, though apparently iron-bearing, mineral; irregular masses of an unidentified black, iridescent-surfaced mineral; small two-phase, liquid-and-gas, inclusions in planes; and pyrite crystals surrounded by planar stress cracks and occurring in lines. Conspicuously absent were any indications of either a treacly internal structure or a granular internal appearance caused by numerous included apatite (and possibly diopside) crystals, both considered of notable diagnostic value for hessonite garnet.

These results led the authors to conclude that the "classical" pattern of inclusions reported in the literature for hessonite may only be of value for identifying material from the better-known Sri Lankan source (it is also noted that inclusions in hessonite from a third source—the Jeffrey Mine in Asbestos, Quebec—differ from those in Sri Lankan stones). They also conclude that it is possible that the examined hessonite crystallized in the presence of an excess of iron, some of which

contributed to the color while the rest precipitated out in the form of various iron minerals. Finally, it appears that the hessonite from the Harts Range and hessonite from Sri Lanka formed under somewhat different geological conditions. The article is accompanied by six photomicrographs. *RCK*

La mine de "topaze" de la Fazenda Serra do Salto (Bahia-Bresil) (The "topaz" mine of Fazenda Serra do Salto [Bahia-Brazil]). J. Cassedanne, *Revue de Gemmologie a.f.g.,* No. 75, 1983, pp. 3–6.

Cassedanne begins with a discussion of the term *topaze* (topaz) noting that, in Brazil, it has several meanings. It can actually be the mineral topaz, or imperial topaz, or it can also denote quartz. Topaz da Bahia (topaz of Bahia) refers to citrine, amethyst, or a pale green or pale violet quartz that is heat treated to a brown-orange and called *lambreu.* These different types of quartz and their characteristic features are the subject of Cassedanne's article. He first describes in detail the geographic setting before turning to a discussion of the deposit workings. He then provides a detailed description of the appearance of the rough: transparent and translucent fragments of quartz with inclusions of long, recrystallized needles.

In the section on rough and finished gems, the author states that the color before heating is variable, even in one sample. The properties fit what one expects for quartz. Cassedanne notes an important absorption pattern in the 5200–5500 Å region that is present in both the amethyst and the lambreu.

The deposit has a long history. It was first worked by the Dutch from 1870 to 1890. The most recent intensive period of mining occurred in the early 1970s. Annual production at that time was 8–15 kg of amethyst and 60–110 kg of citrine, which includes the heat-treated lambreu. Only about 10 kg of quartz per metric ton of rock was recovered.

The raw material is sent to Brejinho das Ametistas, where it is heat treated and re-sorted. It then goes to Rio de Janeiro and from there to Germany for cutting. *Brigitte Alzerra-Lehat*

Precious opal from New Zealand. R. A. Ball, *Australian Gemmologist,* Vol. 15, No. 1, 1983, pp. 12–15.

Ball examined three types of opal from the Coromandel Valley area of New Zealand using scanning electron microscopy. The first was a jelly/crystal type with fairly good color patches; SEM examination revealed a spherical structure typical of sedimentary opal but with no evidence of the spheres being etched out as is common in much volcanic opal. The second type was a jelly opal with some violet iridescence and a green "sunflash"; SEM revealed regular and irregular sphere sizes with the intersphere vacuities showing infilling.

Milk opal with a rolling flash of color in only some directions was the third type studied. One specimen

showed a flattened sphere to large disc-like structure with clearly visible open spaces; another had a "wafer biscuit" structure reminiscent of some synthetic opal. A third exhibited both large discs that appeared warped and flaking at higher magnification, and areas of conventional sphere structure. The author concludes that the flattened structure was responsible for the flaky composition and peculiar iridescence of this material (which he compares to some sea shells). Accompanying this article is a map and 10 photographs, two of which are in color. *RCK*

INSTRUMENTS AND TECHNIQUES

Seismic gem prospecting. G. Pearson, *Australian Gemmologist*, Vol, 15, No. 1, 1983, pp. 17–18.

Many gems occur in localized alluvial deposits that are, by nature, often patchy, consisting of rich but discontinuous gemmiferous pockets. Australian sapphire and Sri Lankan gem gravels are two examples. The mining of such deposits is inherently speculative because of the inability to predict yields.

In this article, the author proposes the use of seismic analysis to prospect for such deposits. Basically, the seismograph measures the time of propagation of a surface-applied acoustic signal; the time elapsed is graphed against the distance between impact points to determine acoustic velocity. This velocity can, in turn, provide strong indications as to the possible composition and degree of compaction of strata and, therefore, the ease of excavation. Depressions in which heavy minerals have concentrated may also be located.

The author has used seismology in Victoria, Australia, to accurately detect auriferous beds to a depth of about 15 m. While admitting that tests in the opal fields of New South Wales met with mixed success, Pearson argues that the technique has potential for locating opal deposits, as well as alluvial sapphire, cassiterite, zircon, tantalite, and perhaps diamond. *RCK*

JEWELRY ARTS

Antique jewelry. K. Moline, *Robb Report*, Vol. 7, No. 12, 1983, pp. 66–78.

The best parts in this general article on the pleasures and pitfalls of buying antique jewelry are quotes from the most authoritative dealers in the high-end New York market: Edward Munves of James Robinson Antiques, Raizel Halpin of Ares Antiques, Fernanda Gilligan of Cartier, Sarah Kutas of Christie's East, and Jackie Saye of Sotheby's. With these experts commenting on how and what to buy, the article cannot go wrong. In addition, the pros and cons of auction house vs. dealer purchases are discussed, and some light is shed on exactly what makes a piece of jewelry "antique" (and duty free) according to the U.S. Customs Department.

The serious buyer is urged to consider good design,

style, wearability, workmanship, and condition. All buyers are cautioned to patronize dealers who guarantee what they sell and are straightforward about prices. The author suggests that, in collecting high-quality antique jewelry, "money doesn't matter if you enjoy what it is (sic)." This interesting point of view is reflected in the beautiful and numerous photographs, with no item under $1200 being worthy of illustration, and prices going up to $360,000 for the 19th-century brooch with 9 ct of pink diamonds. This article, in a first-rate financial publication, would be useful to jewelers who are asked to provide "suggested reading" to potential clients. It is aimed at an investment-oriented audience and provides sufficient information to stimulate interest, yet is brief enough to forestall ennui. *NL*

Assaying in antiquity. A. Oddy, *Gold Bulletin*, Vol. 16, No. 2, 1983, pp. 52–59.

Coin forgery was common in the ancient world. The two basic methods used were the gold- or silver-plating of base metals and the alloying of precious metals with base metals. Naturally, governments were concerned with this counterfeiting and resorted to a number of methods to detect it. Modern methods of chemical analysis have, in large measure, developed from three ancient methods of quantitatively analyzing gold which Oddy traces in this article.

The first method is that of fire assay, in which an excess of lead is added to the gold. The mixture is then melted in a crucible in an oxidizing atmosphere, causing everything but the silver in the alloy to oxidize and be absorbed by the crucible, leaving behind the gold and silver. Any one of a number of chemical separations is then used to part the gold from the silver. The earliest technical description of this general process is found in an Indian Sanskrit document dating to the third century B.C.

The second method, associated with the name of Archimedes, is based on the fact that gold has a specific gravity almost twice that of silver, and more than twice that of copper. Therefore, as gold is alloyed with these metals, its specific gravity is progressively reduced, giving an indication of the extent of alloying. There are indications that this method was used as a quantitative tool as early as the sixth century A.D., when both pans of a balance were immersed in water with the gold-silver alloy weighed against pure silver weights. Accurate assaying with this method, however, dates to relatively modern times in the analysis of gold coins.

The third is the touching or touchstone method, which involves rubbing the alloy onto the surface of a fine-grained, slightly abrasive, smooth black stone. The color of the streak left by the unknown alloy is then compared to those from standard alloys. Here, accuracy depends on knowing whether the alloying element is silver or copper, and on having an adequate range of standard alloys for comparison. Earliest references to

this method date to the sixth century B.C., although the earliest detailed description of touchstones does not appear until the time of Theophrastus (372–287 B.C.). Unlike the fire assay and Archimedes methods, physical evidence of this method is found early in the archaeological record—as early as the sixth/fifth century B.C. in the ancient city of Taxila in what is now Pakistan.

This well-researched article is documented with 65 references and accompanied by 11 photographs and diagrams. *RCK*

Carved gem pendants. J. Culp Zeitner, *Lapidary Journal*, Vol. 37, No. 10, 1984, pp. 1396–1408.

This excellent article provides a comprehensive overview of carved gem pendants. It focuses on the well-known carver Hing Wa Lee and his son, David, and includes photos of their fine carvings.

Pendants may be the oldest carved gems used as jewelry. The article begins with a complete history of pendants and continues with the materials used and the meanings of the particular carvings. A discussion of contemporary carved gem pendants follows. The author states that pendants carved of jade and other materials are popular today for many reasons. First is the intrinsic value of the material (which is often fine quality); second, the pendant is not only an attractive piece of jewelry, but also a portable work of art; and third, these original works of art are "investments." The value of each pendant is determined by the material used and the artistry with which it is worked.

Other sections of the article deal with the Oriental influence in carved pendants, as well as the types of carvings used for pendants. The author concludes with Lee's advice to beginning carvers. Lee states that a beginner can gain a feeling for the stone and the tools used, and an attitude of self-confidence, if he keeps his first work simple and proceeds slowly, step by step. *WEB*

Focus: a jewel in his crown. H. Novas, *Connoisseur*, Vol. 213, No. 860, 1983, pp. 134–140.

Whose crown? Louis Tiffany's. The jewel: Julia Munson, 1875–1971, who for a decade and a half at the turn of the century created for Tiffany & Co. enameled vases, trays, lamp bases, inkwells, and silver boxes. She also created the LCT enameled jewelry, called "little missionaries of art," that was sold in a separate department of Tiffany & Co.

This tribute to Munson (a student of Lalique and of the teachings of William Morris) flashes and gleams as it recalls an era full of aesthetic ideals that will never go out of style. Color photographs by Theodore Flagg of the front and back of Munson's "peacock necklace," as well as those by Toby Sanford of other pieces, excite wonder and delight. A few quotations will convey the tone:

When he [Louis Tiffany] decided . . . to experiment in ceramics, he found it expedient to let Julia Munson

buy the materials under her own name. She would take the blame if the project failed; he would take the credit and praise for its success.

"Every piece," she [Julia] once said, "was made to stand perfectly on its own and last and even improve with time. Our idea was to take an inexpensive stone and bring out its natural beauty and luster by echoing its feeling in its treatment. Each piece had a name and a personality. Only a few hundred were made, and I still have a personal feeling for each one."

She left no children, and her legacy is buried among the few who knew her work. *FS*

Forever adamant: a Renaissance diamond ring. D. Scarisbrick, *Journal of The Walters Art Gallery*, Vol. 40, No. 1, 1982, pp. 57–64.

With the highest measure of scholarship and consistent with the range and quality of the collections, the *Journal of The Walters Art Gallery* frequently publishes distinguished articles which add significantly to the large body of jewelry literature. The present article draws attention to a 16th-century diamond ring in the Walters collection that is thought to have been manufactured about 1546 in one of the south German jewelry centers of Augsburg or Nuremberg. The author discusses and documents the design sources of the several elements of the ring, and points out that jewelry of this quality resulted from progress in the cutting, setting, and marketing of precious stones in the late Middle Ages. The desire for magnificence in dress and jewelry stimulated developments in diamond technology, revealing the true brilliance of the stone and allowing a departure from the practice of mounting diamonds in the pointed form (displaying only the upper half of the natural octahedral crystal). Emphasis is given to the talismanic importance of the diamond, which was believed to possess the power to repel demons and poisons while holding the wearer chaste and invincible. This belief ultimately led to the adoption of the diamond by royalty for weddings and coronations, and as an emblem of sovereignty.

Diana Scarisbrick is in the vanguard of 20th-century jewelry historians, and her research at the Ashmolean and British museums is well known. She bridges the gap between historian and gemologist with erudition and style, and this article contributes an important *tessera* to the complex mosaic of Renaissance iconography. *NL*

RETAILING

Lettuce leaves and diamonds. H. C. Schonberg, *Connoisseur*, Vol. 213, No. 862, 1983, pp. 84–91.

This colorful article derives its incongruous title from the work of Gene Moore, America's preeminent designer of window displays. This celebrated window

dresser, now 73, has become famous for his flamboyant designs for Tiffany's New York City storefront windows.

In the article, Schonberg provides an introduction to some of Moore's most arresting designs—which comprise a body of work that has earned Moore a reputation as "the Picasso of window dressers." The author focuses on Moore's penchant for the surreal, which has resulted in fanciful window displays that juxtapose chicken eggs with sapphires, and diamonds with blocks of ice.

Schonberg praises Moore's ability to "double the glamour of expensive jewelry by surrounding it with the shock of the unexpected." Once Moore displayed a large diamond on a piece of lettuce, causing a revolution in the jewelry trade.

This brief article is illustrated with many full-color photographs of Moore's work, and is an inspiration for retail jewelers as well as anyone with an appreciation for commercial design.   *JMB*

SYNTHETICS AND SIMULANTS

Identification of the new synthetic and treated sapphires. E. Gübelin, *Journal of Gemmology*, Vol. 18, No. 8, 1983, pp. 677–706.

Gübelin discusses ways to identify some of the flux-grown sapphires recently synthesized by Chatham. The new synthetic blue sapphires have several diagnostic features—irregular color zoning, pronounced tabular crystal habit, pale-to-dull green fluorescence, straight color zones, platinum platelets, and fingerprint-type flux inclusions—which help to distinguish them from natural stones and other kinds of synthetics. The new synthetic orange sapphires have patchy fluorescence, several distinct absorption features, platinum platelets, and flux inclusions. Thirty-eight color photomicrographs illustrate many of these features. Gübelin concludes his article with several remarks on the recognition of treated natural sapphires.   *JES*

MISCELLANEOUS

El color de las gemas (Color in gems). J. Garzon Jiménez, *Boletín del Instituto Gemológico Español*, No. 24, 1983, pp. 24–47.

Using published material as well as the results of his own experimentation, the author presents various principles relating to considerations of color in gem materials. The three parts of the article deal with atomic configurations, the origin of color, and color changes produced by irradiation and heat.

The first section outlines atomic theories of matter and includes pertinent equations. The second introduces the electromagnetic spectrum and discusses the natures and examples of idiochromatic and allochro-matic materials. Color centers are explained, and molecular orbits and band theory are touched upon. The final section covers the processes, both natural and constructed, through which color change is affected, concluding with heat- and diffusion-treated corundum. There are numerous charts, illustrations, and photographs.   *SLD*

Oyster farming. S. Aletti, *American Jewelry Manufacturer*, Vol. 31, No. 7, 1983, pp. 24–38.

Steffan Aletti, editor of AJM, toured Ago Bay, a major pearl-growing region of Japan. Beginning with a review of the history of cultured pearls, he focuses on the efforts of Kokichi Mikimoto from his first oyster farm in the Shenmei Inlet in Shima, Ago Bay. Then the author describes oyster farming today. Photographs are included from his trip to a small oyster farm. The author also visited the National Pearl Laboratory in Kashikojima. The director, Dr. Koji Wada, is shown with a scanning electron microscope, one of the pieces of research equipment at the lab. Government-supported research is conducted on all aspects of pearl cultivation. The remainder of the article features Pearl Island, "a shrine to Mikimoto," from the pearl-diving demonstration to the Mikimoto Museum. Eight color photographs, including the magazine's cover, highlight the topics discussed.   *DMD*

Sequence of mineral assemblages in differentiated granitic pegmatites. J. J. Norton, *Economic Geology*, Vol. 78, No. 5, 1983, pp. 854–874.

In 1949, Cameron and his coworkers (*Economic Geology*, Monograph 2) suggested that the internal structure of complex granitic pegmatites could be interpreted as a general sequence of mineral assemblages proceeding from the outer contact of the pegmatite to its core. No pegmatites are known to have all assemblages in this generalized sequence, but the Cameron group was able to demonstrate the existence of a portion of this sequence in numerous pegmatite localities. Since that time, this sequence has become firmly established in the geologic literature on pegmatites. Here the sequence is modified on the basis of newer information as well as on the reevaluation of certain past observations. This revised sequence takes into account not only the contact-to-core zonal pattern, but also a vertical component of this mineral arrangement. The observed internal structure of 11 well-known granitic pegmatites, many of them rich in lithium minerals and some gem species, is shown to be consistent with this revised sequence. The crystallization history of complex granitic pegmatites, especially the zonal formation of these various mineral assemblages, is described in general terms using the results of field observations and experiments.   *JES*

GEM NEWS

John I. Koivula, *Editor*

DIAMONDS

Africa

Diamonds from Guinea. Bridge Oil, an Australian oil and gas exploration and mining company, has joined with the Aredor-Guinea Joint Venture to explore for and mine diamonds in Guinea, in the Kissidongon, Banankourn region, abutting the diamondiferous areas of Sierra Leone.

Exploration for diamond off Namaqualand. Golden Dumps, a small independent South African company, will be exploring the Dawn Diamonds prospecting lease off the Namaqualand coast in South Africa. The area to be studied as a potential diamond producer is near Kleinzee, and consists of a 30 km × 4 km block running north and south of the Buffels River. The seabed will be examined first, both to determine its profile and to locate any sand and gravel deposits.

Diamond exploration in Swaziland. The government of Swaziland has issued a diamond-mining license to Trans-Hex, of South Africa, for exploration of an area near the industrial center of Manzini. No indication of the potential size or grade of the deposit has been revealed as yet. In the mid-1970s, De Beers sampled a deposit of diamonds located at Ehlane to the north, and also explored the adjacent Dokolwayo kimberlite. Because of the small size of the stones recovered, they eventually rejected both prospects as uneconomic.

Australia

Diamonds found at Limestone Creek, Western Australia. Freeport of Australia and Gem Exploration and Minerals, having entered into a partnership called the Bow River Joint Venture, reported the recovery of 2,177 diamonds with a total weight of 367 ct from 2,250 tons of mined and processed ore. The diamonds were recovered at Limestone Creek in the Kimberley region of Western Australia, not far from the Argyle diamond locality. Most of the diamonds recovered so far are thought to be small and of industrial quality, although no evaluation has yet been made. Freeport and Gem Exploration have equal rights in the Bow River Joint Venture, but Freeport retains the option to earn an additional 30% in the project by funding future diamond exploration.

First Argyle diamonds sold in Antwerp. Northern Mining, holder of a 5% interest in the Australian Argyle Diamond Mining Operations, has marketed its share of production, a total of 44,600 ct of rough, through Arslanian Frères. The entire lot was sold within a week, with some of the stones going to local Antwerp firms, some to Americans, and some to Israel. Although the diamonds recovered from the Argyle mine have generally been characterized as tending toward brown and of low quality, some finer stones were noted in this first lot. A mixed parcel of white and brown stones was sold in the United States, so Australian diamonds should be available soon to jewelers in the U.S.

India

Diamonds from India. The Geological Survey of India reports that Andhra Pradesh continues to yield a steady supply of gem-quality diamonds. The producing area is Munimadugu in the Kurnool District. Exploratory drilling in the Majhgawan Block, Panna Diamond Belt, Madhya Pradesh, showed a 4-cm to 34-cm-thick potentially diamond-bearing conglomerate zone. A hard-rock treatment plant was built in the Panna District to recover diamonds.

News of the Famous Eureka Diamond. Mr. Walter Neil Letson has supplied *Gems & Gemology* with the following report on the Eureka Diamond:

The Eureka diamond, often identified as the first diamond discovered in South Africa, has been placed on permanent loan in the De Beers Mine Museum in Kimberley.

Authorities differ on the "first diamond" claim, citing references to diamonds in southern Africa which appeared as early as the mid-18th century and to a find in 1859, whose authenticity has recently been documented. It was the Eureka, however, that first attracted wide public attention to the area; the prediction that it would be the rock "on which the future of South Africa would be built" has proved to be extremely accurate.

The 10.73-ct stone, cut from a 21.25-ct yellow rough, was found by Erasmus Jacobs on the banks of the Orange River, near Hopetown, Cape Province, in 1860 (or 1866). It was shown at the Paris Exhibition of 1867–1868 and owned for many years by a private collector in England. The Eureka was a prominent feature of "The Ageless Diamond" exhibition in London in 1959. It was purchased by De Beers in 1966 and presented to the South African Parliament. The Government now believes the

Kimberley Mine Museum to be the most fitting place for its public display; an estimated 35,000 visitors saw it during the 1983 Christmas holiday period.

The Kimberley Mine Museum has also recently received a collection of more than 1,000 diamonds of exceptional technical importance from the estate of Alpheus Fuller Williams, who was a De Beers general manager for 26 years, author of *The Genesis of the Diamond* (London: 1932), and a distinguished student of the geology of the diamond. He was the son of Gardner Fuller Williams, the American mining engineer who was the first De Beers general manager and whose monumental work *The Diamond Mines of South Africa* (London: 1905) set a standard in its field.

The stones were purchased by the South African Diamond Producers Association and presented to the museum on the condition that they be exhibited and made available for study and research.

COLORED STONES

Correction: Brazilian amethyst. In the Gem News column of the Fall 1983 issue it was reported that a new find of amethyst was from Para, Minas Gerais, Brazil, which is of course impossible since Para is a separate state in Brazil, some 1,500 km north of the state of Minas Gerais. This error was brought to our attention both by Michael Ridding of Silverhorn Designers and Goldsmiths in Banff, Alberta, Canada, and by Jack Lowell of the Colorado Gem and Mineral Company, Tempe, Arizona, who was the source of the original news item. According to Mr. Ridding, the lighter material described by Jack Lowell is found near the town of Maraba in Para, and the dark material is found farther south, near the town of Pan d'Arco, also in Para.

Gem Exploration in Southern India. Karnataka, India's southern state, may prove very interesting gemologically. To date, the Geological Survey of India, in cooperation with Karnataka's Department of Mines and Geology, has identified three gem tracts in the southern part of the state: in the areas of Haggadadevankote, Holenarsipur, and Pavagada Taluk. During the current field season, the gem potential of the Bangerpet, Osahunda, and Kamasamndram areas in the Kolar District is also being explored.

Heat treatment in Sri Lanka. Mr. Joe Segera, of the *Daily News* in Colombo, Sri Lanka, reports that Sri Lanka's government-owned State Gem Corporation is promoting the formation of a Sri Lanka–Thai joint stock company to handle the treatment of poor-quality corundum, here known as geudas, in Sri Lanka. Gem dealers from Thailand have been visiting Sri Lanka regularly to purchase these stones at attractive prices and then have been taking them back to Thailand for of heat treatment to enhance the color. The projected company will also handle the export of these treated gems.

Korean amethyst. Choong Hyun Kim, of the Gemological Institute of Korea, reports on Korean amethysts of a very attractive violetish purple color. The gems this editor examined ranged in weight from 2.35 ct to 4.54 ct and were of excellent jewelry quality, containing just enough inclusions to prove their natural origin. For further information on the new Korean amethyst, please contact: Choong Hyun Kim, Gemological Institute of Korea, 24 Sogong-Dong, Sam Jim Bldg. #300-302, Choong-Ku, Seoul, Korea.

PRECIOUS METALS

Lady Bountiful looks promising. Consolidated Exploration Limited recently announced that it has obtained very high gold assay results from several diamond drill holes at the Lady Bountiful prospect in Western Australia, at depths betwen 108 and 110 m. The highest assay value in this depth interval was 2668 grams of gold per ton of ore over 0.51 m from one of the drill holes. Since there are 31.103 grams per troy ounce, this converts to 85.77 troy ounces of gold per ton of ore. With gold at $400 per ounce, this half-meter section promises $34,308 per ton of ore mined. (Homestake Mine, the richest in America, operated for many years at $8 per ton gold recovery.)

Rich Gulch California gold. Inca Resources Inc. released results from three drill holes completed at its Rich Gulch gold property in Plumas County, California. The holes were drilled in the near-surface high-grade extension of the Virginia zone. The assay values ranged from 42 to 16.4 grams/ton gold (1.35 to 0.52 ounces per ton of ore), over widths from 2.7 m to 12.5 m. The maximum depth of the intersections was no more than 50 m. A feasibility study on the property is being completed; indications suggest that a 3,000-ton-per-day operation, with a grade in excess of 3.8 grams/ton, and operating costs in the $150-$160 per ounce range, might be developed in the near future.

Soviets recover gold from industrial waste. According to Soviet press reports, the Siberian Institute of Chemistry has discovered a new process for recovering greater amounts of gold from waste waters used in industrial processes involving the use of gold. The new process involves the use of carbon fiber electrodes.

French study of worldwide gold deposits now available. A technical study of worldwide gold deposits, now available in book form, is the result of three years of research by a French team from the Bureau de Recherches Géologiques et Minières and the Ecole Nationale Supérieure des Mines de Paris. The team was led by Jean-Jacques Bache, who is also editor of the book. Accompanying the text are a number of detailed maps, diagrams, and tables. The book is available only in French.

For further information, write to: Bureau de Recherches Géologiques et Minières, Avenue de Concyr, Orléans-La-Source (Loiret), BP 6009, 45060 Orléans Cedex, France.

SYNTHETICS

Seiko growing synthetic gemstones by the floating-zone method. Floating-zone crystal growth was first developed in 1953 to produce high-purity silicon as a semiconductor. It has since been used to produce refractory metals, alloys, and other semiconducting compounds. Although colorless synthetic sapphire has been grown by this method in the past, it was not until the Suwa Seikosha (Seiko Watch) Company Ltd. of Japan, became involved, as part of their efforts to make a better electronic crystal for their watches, that this technique was developed to produce synthetic gems.

In the floating-zone crystal growth process, a sintered rod, composed of a uniform mixture of all of the components necessary to produce the desired gem material, is held vertically at both the top and bottom. An infrared radiation convergence heater, using a halogen lamp and an ellipsoidal reflector with its inner surface gold plated, heats a small region near the top of the rod until it melts. The two holders then begin to rotate while at the same time the heat source begins dropping down the rod at an even rate. Eventually, the sintered rod is consumed and a single crystal results.

The floating-zone synthetics examined to date are a 0.35-ct ruby, a 0.49-ct pinkish orange sapphire, and a 0.51-ct alexandrite chrysoberyl. The three stones showed no unusual characteristics during testing. Their reactions to long-wave and short-wave ultraviolet radiation and their refractive indices are as follows:

Floating-zone synthetic	LWUV	SWUV	R.I.
Ruby	Very strong red	Strong red	1.762–1.770
Orange sapphire	Strong red	Strong red	1.762–1.770
Alexandrite	Weak red	Very weak red	1.740–1.749

The internal characteristics visible in all three of the stones were swirled and curving to subangular growth as well as color zoning and gas bubbles. Since November 1983, Seiko has been marketing, under the trade name Bijoreve, a synthetic ruby, orange and blue sapphires, and an alexandrite chrysoberyl — all grown by the floating-zone method. They have also started to market a flux emerald as well, but this material was not available for examination.

ANNOUNCEMENTS

Smithsonian devises gemstone donation procedures. As reported in the American Gem Society's *Gem and Jewelry Fact Sheets*, the Smithsonian Institution has revised its regulations covering gemstone donations because of the Internal Revenue Service's close scrutiny of such tax exemptions. The museum now requires an appraisal which is then evaluated in writing by the curator. The appraisal, together with the curator's evaluation, is then studied by individuals of higher authority at the National Museum. John S. White, curator of gems and minerals at the Smithsonian, suggests that in preparing appraisals of gemstones for museum donation the following procedure be used:

1. Give a range of value
2. Be objective in pricing

3. Select a value that will hold over a period of time
4. Never use the country of origin in the description without supporting evidence

The Fifth Annual Course in Antique Jewelry and Gemstones will be held at the University of Maine, in Orono, July 9–11. For further information, please contact: Helen Thomas at (213) 735-0205.

Jewelry competition. "Jewelry USA," a national competitive exhibition, is being cosponsored by the American Craft Museum in New York City and the Society for North American Goldsmiths. The event, which will be juried, is to be held at the museum from June

3 through August 31, 1984. The exhibition will encompass all aspects of contemporary jewelry design and is open to all residents of the United States. Entry forms are available from the Society for North American Goldsmiths, 2849 St. Ann Drive, Green Bay, WI 54301.

The AFMS/CFMS National Gem and Mineral Show will be held July 12–15, 1984, in the Convention and Performing Arts Center, San Diego, California. Among the guest speakers will be noted *Gems & Gemology* authors Peter Keller, John Koivula, and D. Vincent Manson. For further information, please contact: Shirley Leeson, Co-Chairman, 6155 Haas, La Mesa, CA 92041.

CROWN JEWELS OF EUROPE

By Prince Michael of Greece, 144 pp., illus., publ. by Harper & Row, New York, NY, 1983. US$19.95*

When a distinguished, titled member of one of Europe's most ancient royal houses, who has authored six previous books, writes on the crown jewels of Europe, readers might expect an accurate, well-researched volume. Unfortunately, Prince Michael's *Crown Jewels of Europe* is a disappointment. He has produced a selection of beautiful photographs accompanied by a text filled with inaccuracies and misinformation written in a convoluted style that lacks both charm and consistency.

To his credit, Prince Michael has provided illustrations of many splendid jewels that are seldom seen: notably, the Cameo of Noah, the remarkable half-black – half-white Pearl of the Palatinate, the great ruby-and-diamond parure of the Queens of Bavaria, the enamel lily that forms the sceptre of King Frederick III of Denmark, and the remarkable sapphire-and-diamond parure of Marie Antoinette, worn by three separate ruling dynasties of France. While many of the celebrated pieces included may be found in standard museum photographs, those shown from private collections are extremely interesting.

The text, however, fails to measure up to the art. The author skitters nonchalantly through history, consistently annoying this reviewer by referring to objects that have both religious significance and intrinsic importance as "knick-knacks" or "trinkets," shifting his tone from reverent awe to cavalier disdain and airily dismissing collections of crown jewels that proved inaccessible or which he judged to be of "mediocre artistic interest" as being a "jumble of precious objects" or "an unbelievable muddle"—words that might accurately describe this book.

How can he expect to be taken seriously when he describes the coronation of Charlemagne by telling his readers that " . . . the Pope tiptoed up behind Charlemagne and rammed

BOOK REVIEWS

a crown on his head"? Prince Michael seems unfamiliar with jewelry terminology, and his editors have done him a disservice by not improving his style or providing him with adequate proofreading and research assistance.

In the chapter on the British Crown Jewels, the Prince says that "most of the instruments of Coronation [in the Tower of London] were made in the 20th Century and are not distinguished by their elegance." Elegance means different things to different people, but it is patently untrue to say that "most" of the British regalia dates from the 20th century. Three important crowns have been added in this century, but *most* of the regalia dates from the late 1600s, with substantial additions having been made in the following centuries.

The Prince tells his readers that the British Imperial State Crown was "fashioned for the Coronation of Elizabeth II in 1953." It was, in fact, made for Queen Victoria in 1838. He misses the correct weight of the uncut Cullinan diamond by a whopping 495 carats, stating 3601 ct rather than the 3106-ct actual weight, and he cites the Cullinan II as weighing 319 ct instead of the correct weight of 317.40 ct. In describing an emerald carved with a portrait of Catherine the Great, sold recently by a major European auction house, the Prince says there is a "twin" in the Kremlin. Actually, the engraved emerald that remains in the Russian State Collection does bear a portrait of Catherine, but the profile faces to the right rather than the left, is signed by the engraver (Elger), and is oval rather than rectangular. In discussing the Stone of Scone, he fails to mention its removal from Westminster Abbey in 1950 by

Scottish nationalists, surely the most exciting event in the recent history of this venerable relic.

The list of errors and omissions goes on and on: "Queen Alexandra of Denmark" was actually Queen of England; the Queen of Portugal is identified as the Queen of France; in discussing the Hope diamond, no mention is made of Evalyn Walsh McLean, owner of the stone for 35 years.

The pictures are beautiful and some of the pieces are rarely seen, but after so many errors, the few anecdotes provided by the author are insufficient to encourage this reviewer to recommend the book beyond saying that, while it is a pretty thing, it can only be considered an inconsequential "knick-knack."

NEIL LETSON
Anniston, Alabama

IGNEOUS ROCKS

By Daniel S. Baker, 417 pp., illus., publ. by Prentice-Hall, Englewood Cliffs, NJ, 1983. US$34.95

As indicated by Dr. Baker in the preface, this book was written as a text for undergraduate geology majors, beginning graduate students, and geologists wanting an update of the technical literature now available on igneous petrology. In order to use this book, the reader should know general physical geology as well as college-level chemistry and mineralogy.

The book can be divided into four main parts comprising a total of 16 chapters. The first part reviews physical geology and mineralogy and relates them to igneous petrology. The second part, the main portion, presents traditional igneous petrology. It uses phase diagrams to relate the phases of matter with pressure, temperature, and composition. Next, rock compositions and classifications are discussed and related to the formation of magmas and the rock form after emplacement. The chapter dealing with volatile components contains a brief section on peg-

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**This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404.*

matites with information useful for any gemologist.

The third part discusses the types of igneous rocks. Of importance to the gemologist concerned with diamond formation are the sections on eclogites and kimberlites. The last part contains miscellaneous chapters such as an introduction to metasomatism and tectonics.

This is not an easily read book — but no book addressing this detailed subject ever is. Additionally, the value of this book to most gemologists is severely limited by the background knowledge necessary and the lack of specific gemological subjects. However, for the intended audience, this is an *outstanding* publication. The text is well organized, with each chapter using the knowledge gained in previous chapters. The fine illustrations—black-and-white photographs of thin sections and geological occurrences, line drawings, diagrams and maps—make it easier to assimilate the information. This book should become a standard college text on igneous petrology.

GARY HILL
Resident Instructor, GIA

NATURE OF EARTH MINERALS

By Anthony C. Tennissen, 415 pp., illus., publ. by Prentice-Hall, Englewood Cliffs, NJ, 1983. US$21.95*

This book is an introductory college text intended for students who are not majoring in a scientific field, but who want to gain a basic understanding of the nature and properties of the materials that make up the earth. By *earth materials,* the author refers to the more important minerals and major rock types. A unique feature of this book, and of the author's intent, is that the discussion is divorced from a consideration of the broader-scope topics of earth processes that are often the main interest of most introductory geology courses.

The book can be divided into four parts. The first describes the nature of atoms and how they are bound together to form crystals. This section also includes a brief introduction to crystallography and deals with topics such as crystal growth and symmetry and the six crystal systems. In this and other chapters, frequent illustrations emphasize key ideas and clarify the text.

The second part deals with minerals. A summary of several aspects of crystal chemistry helps the reader understand something of the chemical nature of minerals, and discussion of the important physical properties of minerals also deals with how these properties are perceived or measured. The 110 most common minerals are described in terms of their key features and mode of occurrence. There is a photograph of each mineral, but there is no specific information on localities of occurrence. Mineral identification tables are also presented.

The third and longest part of the book comprises three chapters on igneous, sedimentary, and metamorphic rocks, respectively. Each chapter discusses origin, chemical and mineralogical nature, important textural features, and classification. Each also includes descriptions of major rock types and photographs. Large- and small-scale features exhibited by each general rock type are described as well.

The final part of the book presents summary information on the occurrence of mineral deposits, including something about their geographic distribution and how they formed in the earth's crust. There is a classification of commercially valuable earth materials and a discussion of how these materials are used.

This book is useful to the jeweler-gemologist because it focuses on the properties of minerals and rocks rather than on geological processes and features, which is usually the case with most general geology textbooks. In each chapter, there is an effort to define key terms and to illustrate important points. The book is well organized, and it provides valuable introductory information in a concise and interesting manner. For those readers who wish to gain a more complete knowledge of the "nature of earth materials" so that they can better understand certain basic concepts of mineralogy and geology, this readable and informative book bears consideration.

JAMES E. SHIGLEY
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