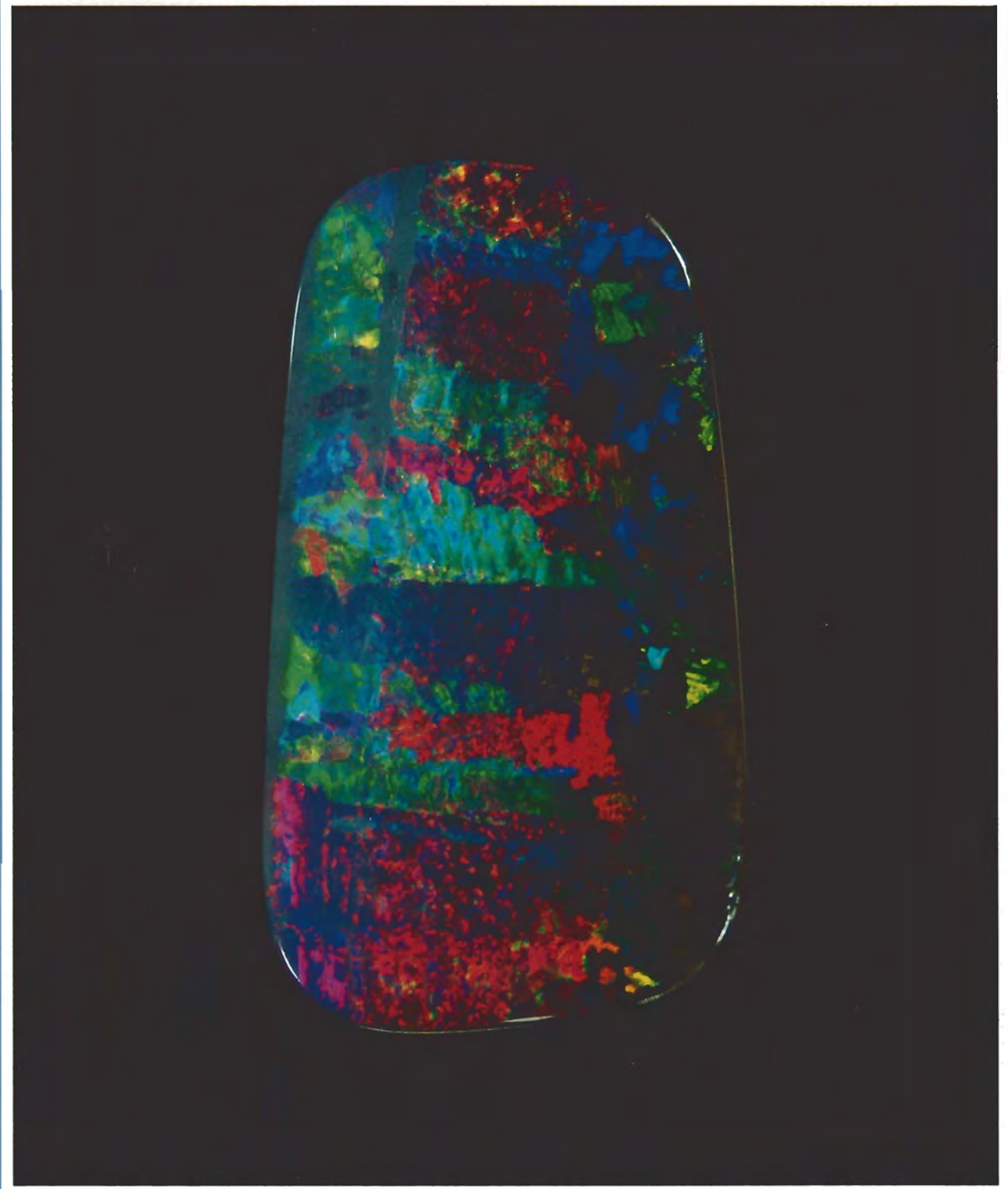


# Gems & Gemology

VOLUME XXIV

SUMMER 1988



The quarterly journal of the Gemological Institute of America

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# Gems & Gemology

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*ABOUT THE COVER: The extraordinary play-of-color seen here in the 26-ct "Jason" boulder opal arises from diffraction of light on symmetrically stacked layers of silica spheres. Diffraction, one of the less common causes of color in gem materials, is described in this issue in the third part of the series by Drs. Fritsch and Rossman on the origins of color in gems. This final installment also discusses other optical phenomena and band theory, and includes an extensive listing of the known origins of color in gem materials. The opal, from the Ditto Collection, is courtesy of "Jayson" Traurig Bros. Pty. Ltd. (Dallas, TX office). Photo © Harold & Erica Van Pelt—Photographers, Los Angeles, CA.*

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# THE DIAMOND DEPOSITS OF KALIMANTAN, BORNEO

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By L. K. Spencer, S. David Dikinis, Peter C. Keller, and Robert E. Kane

*The island of Borneo is one of the oldest known—and least reported on—sources of diamonds. Although diamond mining historically was concentrated in the western area of what is now Kalimantan, recent activity has focused on the alluvial deposits in the southeast. A progress report on the first bulk sample pit in this area found that significant amounts of diamonds appear to be concentrated beneath the center of the Danau Seran swamp. The traditional hand-mining methods contrast greatly with the sophisticated techniques used to mine the first bulk sample pit. Virtually all of the diamonds recovered are gem quality, although most are relatively small, averaging about 0.30 ct. Future potential for southeastern Kalimantan appears excellent.*

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#### ABOUT THE AUTHORS

Mr. Spencer is a consulting geologist based in Inverell, New South Wales, Australia; Mr. Dikinis is a gemologist and independent importer of diamonds and colored stones based in Sonoma, CA; Dr. Keller, a geologist and gemologist, is associate director of the Los Angeles County Museum of Natural History, Los Angeles, CA; and Mr. Kane is senior staff gemologist at the GIA Gem Trade Laboratory, Inc., Santa Monica, CA.

Acknowledgments: L. Spencer would like to thank W. W. Shaw, Charles Watson, Acorn Securities, P. T. Aneka Tambang, and Keymead Pty., Ltd., for their cooperation. S. D. Dikinis wishes to thank Tom Altgelt, and Chris Johnston for sponsoring his trip; Daum and Vyga Dikinis, Janet Montgomery, Albert Johnston, Cheryl Kremkow, Rosaline Chow, Colin Curtis, Michael Horovitz, and Phillip Freeman for their support; and Mrs. Helly and Mr. and Mrs. Kuntadi for their guidance.

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Borneo is an island of the Indonesian Archipelago located in the western Pacific Ocean. It is divided into the Malaysian states of Sarawak and Sabah and the British-protected, oil-rich sultanate of Brunei to the north, and the Indonesian state of Kalimantan to the south. The coastal areas of Kalimantan are relatively accessible and well known. However, the interior, which comprises approximately two-thirds of the island, is still very remote, and little has been published on its potentially vast mineral resources. Yet, along with India, Kalimantan has historically been one of the world's oldest sources of fine diamonds (figure 1). Renewed interest in the diamonds of the area has prompted a great deal of geologic investigation. The purpose of this article is to review what little is known of these remote deposits and to report on recent geologic exploration of, and development activity in, the Banjarmasin-Martapura area of southeastern Kalimantan (the province of Kalimantan Selatan). The gemological characteristics of diamonds recovered from this area will also be discussed.

In December 1985, Acorn Securities (an Australian public company) together with Keymead Pty. Ltd. (a British private concern) executed a joint exploration and production agreement with the firm P. T. Aneka Tambang (representing the Indonesian government) to explore for diamonds in the Banjarmasin-Martapura area of southeastern Kalimantan (figure 2). The areas subject to the agreement have had a long history of gem-quality diamond production.

During the 1970s, P. T. Aneka Tambang conducted extensive exploration on the conglomerate gravels (i.e., those materials that were originally deposited as an alluvial fan) of the Riam Kanan River, with generally negative results. Little exploration was conducted beneath the extensive swamps in the area, however, even though local residents have recovered diamonds for several hun-





Figure 1. Two recently found crystals (0.76 and 0.68 ct, respectively) flank three older faceted examples of fancy-color diamonds found in Borneo. The three faceted diamonds, 0.20–0.34 ct, were recovered from the Cempaka diamond fields early in this century and subsequently faceted in Martapura. Photo © Harold & Erica Van Pelt.

dred years on the flanks and margins of the swamps by sinking shafts to the gravel horizon. Deep water and extensive overburden precluded extending the workings to the center of these swamps. Exploration and development work by Acorn in this area has shown that these swamps do indeed contain significant diamond deposits. The information presented here is based largely on a geologic exploration progress report on the Banjarmasin area that was prepared by the senior author (L. K. Spencer) in October 1987, on the visit of S. D. Dikinis to Banjarmasin and other areas of Kalimantan in the summer of 1987, and on geologic research and gemological testing performed by P. C. Keller and R. E. Kane.

## HISTORY

The diamond deposits of Borneo are believed to share with India the distinction of being the earliest worked diamond mines in the world (see box), although researchers have not been able to pinpoint the exact date that mining began. For example, Webster (1983) believes that mining may have started on the island as early as 600 A.D., and that mining was certainly carried out since the 14th century. Bruton (1978) does not believe that mining in Borneo started until the 16th century. Schubnel (1980), however, provides strong evidence that the area on the Sungai Landak (Landak River) in western Kalimantan was worked by the Malays and Chinese as early as the Sung period

(960–1279 A.D.). Numerous fragments of Chinese pottery traced to this period have been found in the diamond workings. In the 16th century, the Portuguese reached Borneo and noted the workings on the Landak River. Cutting, probably learned from India, was done in shops in Ngabang and Pontianak. In the early 17th century, the Dutch colonized Borneo and began exploiting the diamonds through the Dutch East India Company. Tavernier (1676) reported that in the 17th century, Borneo paid annual tributes to the Chinese emperor and that part of each tribute was in diamonds.

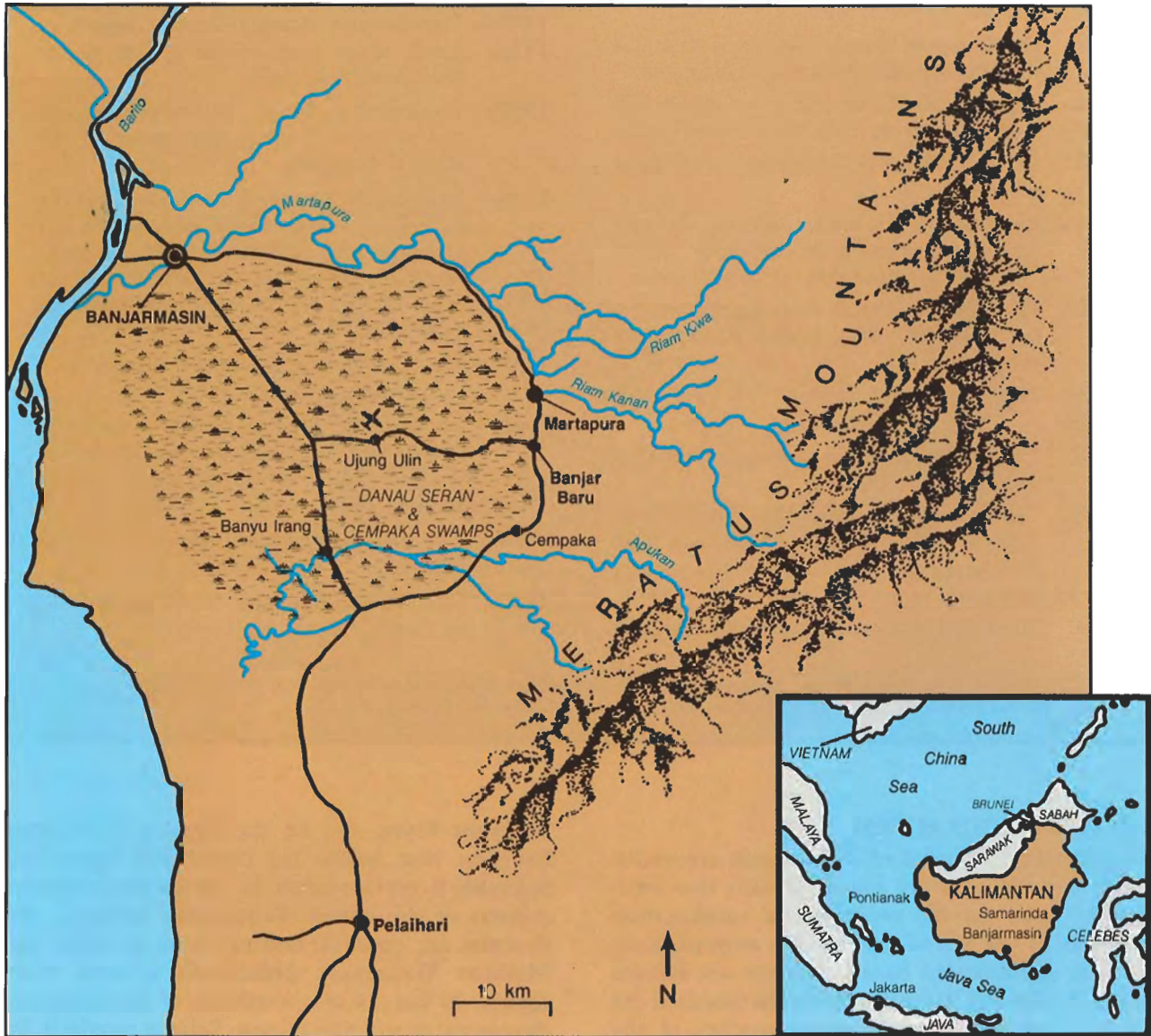
For the most part, early production records appear to be unreliable. Although several thousand workers were reported in Tanah Laut, near Martapura, in 1836, the Dutch government listed a total diamond production of only 29,857 ct between 1836 and 1843 (Bauer, 1904). These figures do not differ significantly, however, from the 25,378 ct estimated by merchants at Ngabang for production between 1876 and 1880. Bauer reported that "in 1880 the mines on the Sekayam River were worked by about 40 Chinese only, those in Landak gave employment to about 350 workers." With the discovery of diamonds in South Africa in the late 19th century, Borneo's diamond production became insignificant. Whereas an estimated 6,673 ct of diamonds were produced in western Kalimantan in 1879, that number dropped steadily to only 600 ct in 1907 and minor amounts subsequently.

During the period 1913–1936, diamond production in southeastern Kalimantan fluctuated between 236 and 2,152 ct, but started a significant upward rise from 907 ct in 1937 to 3,292 ct in 1939 (Van

Bemmelen, 1939). Today, production in western Kalimantan is minimal, and mining activity and exploration are concentrated in the southeast, near Banjarmasin and Martapura.



Figure 2. This map shows the two major areas (left = the Landak district of western Kalimantan, below = the Banjarmasin-Martapura area of southeastern Kalimantan) where diamonds have been found in the Indonesian state of Kalimantan, on the island of Borneo. Artwork by Jan Newell.





## A Brief History of Diamond Mining in Kalimantan.<sup>a</sup>

- |   |   |
|---|---|
| <p><b>600</b> Hindus are probably the first to discover diamonds (Webster, 1983).</p> <p><b>700–1000</b> The Malays vanquish the Hindus and initiate the first diamond mining.</p> <p><b>960–1279</b> Chinese miners work the Landak area for gold and diamonds (Schubnel, 1980).</p> <p><b>1518</b> Duarte Barbosa, of Portugal, provides the first written reference to diamond mining in Borneo.</p> <p><b>1540</b> Feran Mindez Pinto, of Portugal, provides the first description of diamond mining.</p> <p><b>1565</b> Garcias ab Horto, of Portugal (Goa), provides the first description of the quality, shape, and other characteristics of Borneo diamonds.</p> <p><b>1598</b> De Moraga, of Spain (Philippines), mentions the first Portuguese trading in diamonds.</p> <p><b>1604–1609</b> Captains Middleton and Sare are the first Englishmen to describe the diamond mines.</p> <p><b>1608</b> The first Dutch trading posts are set up at Pontianak.</p> <p><b>1631–1689</b> Jean Baptiste Tavernier provides the first detailed description of diamonds and of flourishing trade at Batavia (now Jakarta).</p> <p><b>1650s</b> The Dutch East India Company exercises a full monopoly on diamond trading from Borneo.</p> <p><b>Late 1600s</b> The Martapura diamond field is discovered.</p> <p><b>1698</b> The first British trading post in Borneo is set up at Banjarmasin.</p> <p><b>1738</b> The Dutch East India Company exports 300,000 guilders worth of diamonds from the Landak district in what is now western Kalimantan.</p> <p><b>1789</b> The 367-ct Matan diamond (which may have</p> | <p>been quartz) is reportedly found in the area of the Landak River.</p> <p><b>1780–1800</b> The Dutch East India Company experiences a decline in its trade monopoly and diamond mining.</p> <p><b>1810–1830</b> Stamford Raffles, governor of Java, writes an extensive history of the diamond fields.</p> <p><b>1823</b> Englishman George Windsor Earl reports the Dutch purchase of the Sukadana diamond fields for the equivalent of US\$50,000.</p> <p><b>1828</b> Earl reports the blockading of Pontianak by Dutch gunboats to stop diamond smuggling by the Chinese.</p> <p><b>1842</b> Chinese miners are massacred at Landak.</p> <p><b>1880s–1920s</b> The discovery of major diamond deposits in South Africa leads to the decline of the Borneo diamond fields.</p> <p><b>1930s</b> The Dutch undertake mining at Cempaka and attempt to trace the source of the alluvial diamonds.</p> <p><b>1940s</b> Production (unrecorded) continues after the Japanese invasion. Many Japanese vessels carry gems during the occupation. The cargo carried by the cruiser Ashigara when it was sunk off the coast of Sumatra is valued at £4,000,000.</p> <p><b>1949</b> The Netherlands transfers sovereignty to an independent Indonesia.</p> <p><b>1965</b> 166.85-ct Tri Sakti diamond is found in Kalimantan and subsequently faceted to produce a 50.53-ct emerald cut ("Petrified Tears," 1977).</p> <p><b>1970s</b> P. T. Aneka Tambang initiates exploration at Cempaka.</p> <p><b>1985</b> The Aneka Tambang–Acorn Securities–Keymead joint venture is signed.</p> |
|---|---|

<sup>a</sup>Unless otherwise indicated, the information in this table was derived primarily from Ball (1931) and discussions with local residents and officials at the Banjar Baru Museum.

### LOCATION AND ACCESS

The diamond deposits of Kalimantan are exclusively alluvial and are clustered into two well-defined areas on the western and southeastern portions of the island. In extreme western Kalimantan (Kalimantan Barat), deposits are known along the Landak River near Serimbu (north of the city of Ngabang), on the upper reaches of the

Sekayam River, and on the Kapuas River near Sanggau just below its confluence with the Sekayam River (see figure 2). On the southeastern portion of the island (Kalimantan Selatan), the deposits are concentrated in rivers draining the Meratus Mountains, principally around Martapura, 39 km (24 mi.) southeast of Banjarmasin, the capital city of Kalimantan Selatan province. In

this area, workings are found near Cempaka (the *c* is pronounced as *ch*), on the Apukan River, and also along the Riam Kanan and Riam Kiwa Rivers.

The Acorn Securities exploration project, the most extensive currently being undertaken, has concentrated activities in the districts of Cempaka, Banyu Irang, and Ujung Ulin (again, see figure 2). The project area is centered around longitude 114°45' east and latitude 3°30' south. The project can be reached from Jakarta by jet to Syamsuddin Noor airport, which is located adjacent to, and immediately north of, the concession boundary. A paved road is also available from Banjarmasin to Banjar Baru, where the company's camp is located, a distance of about 45 km (28 mi.). As in all parts of Kalimantan, access to areas away from the main road is difficult, especially during the rainy season, which lasts from October through March in southeastern Kalimantan.

The Meratus Mountains, which form the dominant geographic feature adjacent to the project area, are characterized by rugged topography and narrow, sharp ridges with well-developed V-shaped valleys. Two major rivers—the Riam Kanan and the Riam Kiwa—drain the Meratus Mountains.

Flanking the Meratus Range is a series of low, undulating hills. These grade into grass-covered swamps, at or slightly below sea level, which dominate the Banjar Baru area. The water level in the swamps ranges from 1 to 3 m during the rainy season, but during the peak of the dry season (August to September) it is possible to walk over some of the upstream areas. Elevated laterized sediments (i.e., red, iron- and aluminum-rich products of rock decay) flank the northern and southern boundaries of the swamp area, with a tongue of slightly elevated ground dividing the swamp in the center of the study area. This tongue defines the Danau Seran swamp to the northeast and the Cempaka swamp to the south. The major drainage within the project area is the Apukan River, which defines the course of the Cempaka swamp along its southern margin. No active watercourse exists in Danau Seran, but several small drainages discharge their flow directly into the swamp. Parts of both swamps—although more commonly the Cempaka—are irregularly cultivated for rice.

Inasmuch as the region is close to the equator, the climate is characterized by high temperatures (up to 35°C—95°F—from July to October) and humidity. The driest months are May to October; December and January have the greatest rainfall.

The island of Borneo has an average rainfall of approximately 500 cm (200 in.) per year.

## GEOLOGY OF THE KALIMANTAN DIAMOND DEPOSITS

**Previous Work.** The Indonesian Geological Survey published the most comprehensive compilation of available geologic mapping for Kalimantan (Hamilton, 1970). This report presents the general geology and tectonic history of this area, although it does not discuss the diamond occurrences. The earliest geologic report on diamonds in Borneo was written by R. D. M. Verbeek, an early director of the Geological Survey of the Dutch East Indies. His report, which appeared in *Boutan* (1886), remains one of the few published descriptions of the geologic occurrence of Borneo's diamond deposits.

**Diamond Occurrences.** From the 1930s into the 1980s, the "Pamali Breccia" was believed to be a possible primary source of at least some of the diamonds in Kalimantan. However, recent work has shown that this breccia may be a sedimentary rock with no primary kimberlitic affinities. To date, no kimberlites or related lamproites have been located in Kalimantan. Nixon and Bergman (1987) suggest that the primary source of the Kalimantan diamonds are ophiolites—a suite of mafic and ultramafic rocks which are believed to represent mantle material that has been thrust up onto the earth's surface when continental plates collide. Kalimantan underwent significant plate collision during Cretaceous time, and ophiolites have been found in Kalimantan. It is important to note that this theory is untested, and while the mantle peridotites may contain diamonds, it is questionable that diamonds could survive the relatively slow 150-km trip to the earth's surface without converting to graphite. Diamond-bearing alluvial deposits at Cempaka, downstream from the Meratus Mountains (which include ophiolites), do not contain any classic diamond indicators or large amounts of bort; only one piece of bort was found among the 6,766 diamonds recovered at Acorn Securities' first bulk sample pit. Percussion fractures, the lack of cleavages, and the relatively clean nature of the material indicate that the diamond source is probably far removed, lesser-quality material having been eliminated over the distance traveled.

Within the Meratus Mountains, diamonds have been found in the Upper Cretaceous con-



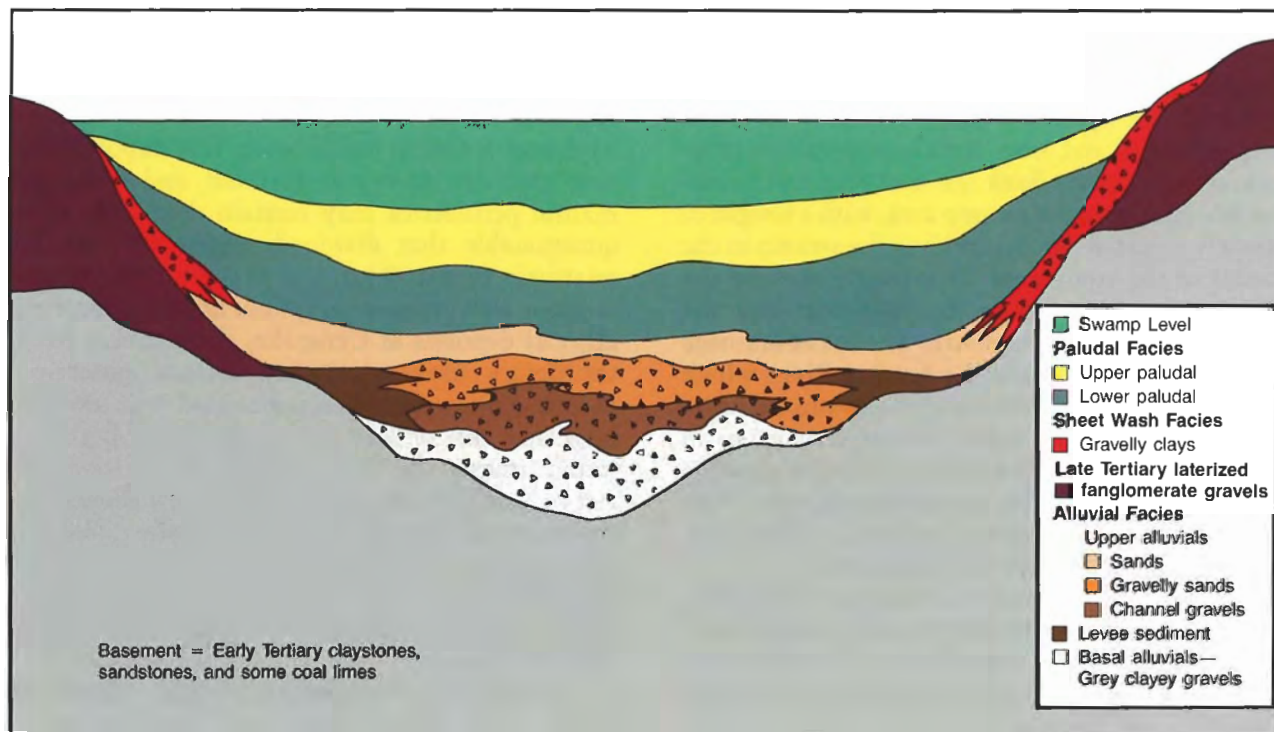
glomerates of the basal layers of the Manunggul Formation (one of the main stratigraphic formations in the area) and have been mined from these rocks at the Pinang River, a tributary of the Riam Kiwa. This same formation is believed to be the source of the Cempaka deposits. The continual emergence of the Meratus Mountains has ensured a constant supply of diamondiferous material to the major drainages of the Riam Kanan and Riam Kiwa. Several periods of uplift, erosion, and re-sedimentation are evident in the late Tertiary and Quaternary sediments flanking the Meratus. Such multiple erosion and sedimentation cycles are considered important in the formation of economic placer deposits.

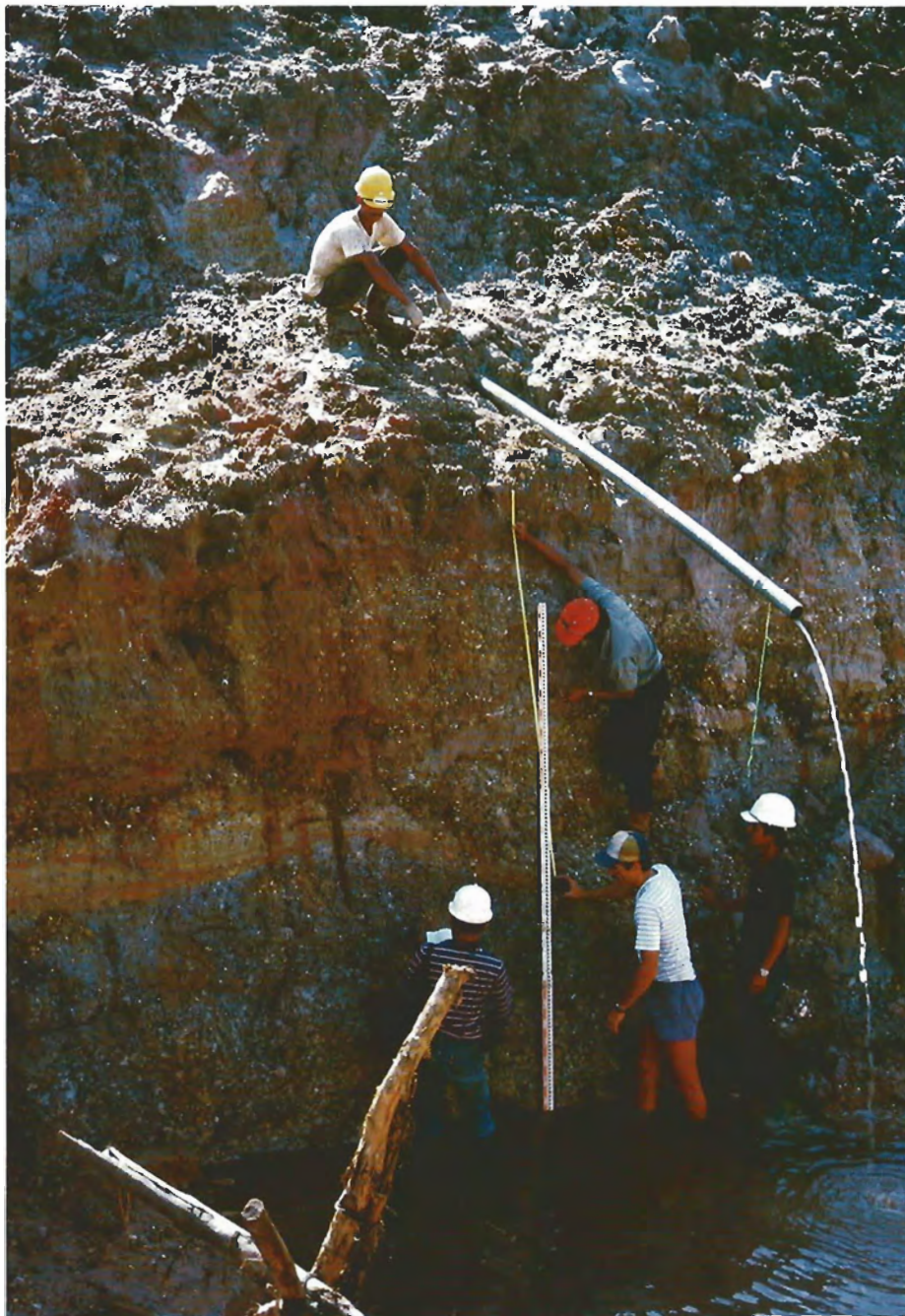
The exploration concept applied by Acorn geologists at the Banjar Baru project is that weathering of the late Tertiary laterized gravels by tectonic uplift would result in their erosion and deposition into surrounding swamps. Deposition of reworked gravels would occur as paleochannels (ancient riverbeds) and lag deposits on previously scoured basement irregularities. It was suspected that reworking would result in higher in-situ

diamond grades within the paleochannels beneath the swamps than in the laterized sediments. It was Acorn's task to identify the location of these ancient riverbeds and to bulk sample them with a view to probable exploitation.

Acorn's work at the Danau Seran test pit readily proved this hypothesis of an ancient riverbed beneath the swamp. Geologists have identified three main sediment facies (stratigraphic bodies): paludal (swamp), sheet wash, and alluvial (figure 3). Diamonds are found principally in the alluvial facies. The (upper and lower) paludal sediments generally constitute the bulk of overburden that covers the diamond-bearing channel gravels. The thickness of this overburden varies from less than 2 m near the headwaters of Danau Seran to 10 m downstream. The sheet-wash facies consist of sediments that have been derived from erosion and subsequent re-sedimentation of laterite gravels and sediments. They usually occur around the margins of the swamps, but have also been found beneath paludal sediments and on the flanks of eroded valleys away from the swamp altogether. These sediments are usually red to brownish red

Figure 3. This diagram shows the schematic relationship of the main sediment types (the trigons indicate the diamondiferous layers) at the Danau Seran sample pit in southeastern Kalimantan. Note that the relative thicknesses of the various types and the swamp level are not exact. Artwork by Jan Newell.





*Figure 4. In this view of the wall of one of the sample pits dug by Acorn Securities at the Danau Seran swamp, the upper alluvial gravels (the yellowish brown sediments that are the principal source of diamonds) can be seen lying above the basal alluvial layer. Gravel thicknesses were measured at 1-m intervals all around the inside walls of the pit. Photo courtesy of Acorn Securities.*

but may be mottled white; characteristically, they contain abundant iron oxide nodules. Sheet-wash sediments are invariably clay rich and may contain diamonds in addition to other heavy minerals. A large percentage of native workings on the periphery of the swamp involve these sediments. The third main facies, the alluvial diamond-bearing gravels, are derived from river action and sedimentation. The alluvial gravels have three main subdivisions: the upper alluvial (peripheral and channel), the levee, and the basal alluvial sediments.

The bulk of the diamondiferous sediments occur in the upper alluvials, which are characterized by coarse gravels, sandy gravels, gravelly sands, and coarse gritty sands; these upper gravels are often yellowish brown to white or grayish white (figure 4). The diamonds are usually associated with gravel lithologies of quartz, schist, intrusives, and fragments of volcanics of broad composition. Corundum, rutile, and gold are considered good indicators for diamonds.

In summary, the Acorn Securities project has





*Figure 5. The Cempaka mining area is a jumble of shafts and tailings. When a pit is exhausted, the miners move a small distance to continue extracting the gem-bearing gravels. Because the upper gem gravels have been largely worked out, mining is more difficult and the miners are more likely to work as a team. Photo by David Dikinis.*

suggested that the principal source of the diamonds found in southeastern Kalimantan is associated with erosion of the late Cretaceous Manunggul Formation. These diamonds were subsequently deposited and re-eroded several times before being finally deposited in later Tertiary and Quaternary sediments. Two of the three main sedimentary facies identified at Banjar Baru are known to contain diamonds: the sheet wash and the upper sections of the alluvial gravels. The majority of diamonds occur in the upper alluvial materials, the distribution of which corresponds to the outline of paleochannels emanating from the Danau Seran and Cempaka swamps, and represents the reworking of previously eroded diamondiferous sediments.

In the western area of Kalimantan, around Ngabang, diamonds also occur in ancient stream channels of probable Eocene age, and in recent stream beds that drain exposed areas of these ancient stream channels, usually near the flanks of mountains (see Bauer, 1904). The Eocene gravels exhibit no bedding, and diamonds appear to be evenly distributed. The gravels consist of moder-

ately to well-rounded metamorphic and igneous rock fragments and quartz pebbles. As in southeastern Kalimantan, fragments of corundum are found in the gravels and are used by the miners as a good indicator of diamonds. The corundum, which is not gem quality, is commonly accompanied by magnetite, muscovite, and economically important amounts of gold and platinum. The gravels of the Eocene-age stream channels typically occur only sporadically throughout the region and are always well above sea level (Bauer, 1904).

#### **MINING METHODS**

**Traditional Mining.** Near the town of Cempaka are found traditional mining sites. The mines have been slowly moved as old workings have been depleted. In recent years, however, many of the local miners have left the area for the alluvial gold fields west of Samarinda in the eastern and central parts of Kalimantan. In July 1987, fewer than 500 miners were actively using traditional methods in Cempaka. Because the upper gem-bearing gravels have largely been worked out, mining is more difficult now than in the past. The gem-bearing



gravels are as much as 10 m below the surface of the swamp, with the water table lying just underground. The miners now usually work together in a communal mining association (figure 5). It is interesting to note that women are involved in every element of the work except the strenuous lifting of equipment.

Toiling under the hot equatorial sun, the miners first start digging a shaft at the chosen site. They soon bring in lumber for supports and also construct a lean-to to shield the workers from the sun. A four-cylinder car engine is connected to a 10-cm-diameter pump to remove the constant inflow of water (figure 6). The sides of the shaft are well supported, and swamp grass is woven together and shoved between the timbers to staunch the constant oozing of the swamp. The miners work

*Figure 6. A car engine is commonly used to pump water from the mine shafts at Cempaka. Photo by David Dikinis.*



*Figure 7. The black ironwood dulang (pan) and clove cigarette are trademarks of the diamond panner at Cempaka. Photo by David Dikinis.*

from near sunup to sunset every day except Friday, which is the Moslem holy day. They break for coffee and lunch at one of the many "snack bars" that are set up in the gem fields by enterprising "members of the family."

The camp is in continual activity, with pumps running, miners (including the women) digging, and young boys hauling baskets of gem-bearing gravel to the stream bank, where yet another team of workers washes it. The washers clean and concentrate the gravel in long hollowed-out logs set into the stream. The gravel is poured into one end of the log and then worked by the washers first with their feet to clean off silt and later by hand to remove the lighter gravel and larger rocks. The concentrate is then divided among the panners, who squat waist deep in the stream with a *dulang* (pan) made of black ironwood which they swish relentlessly in search of that large white diamond that will make them all rich (figure 7). When a stone is found, it is presented to the group's leader,

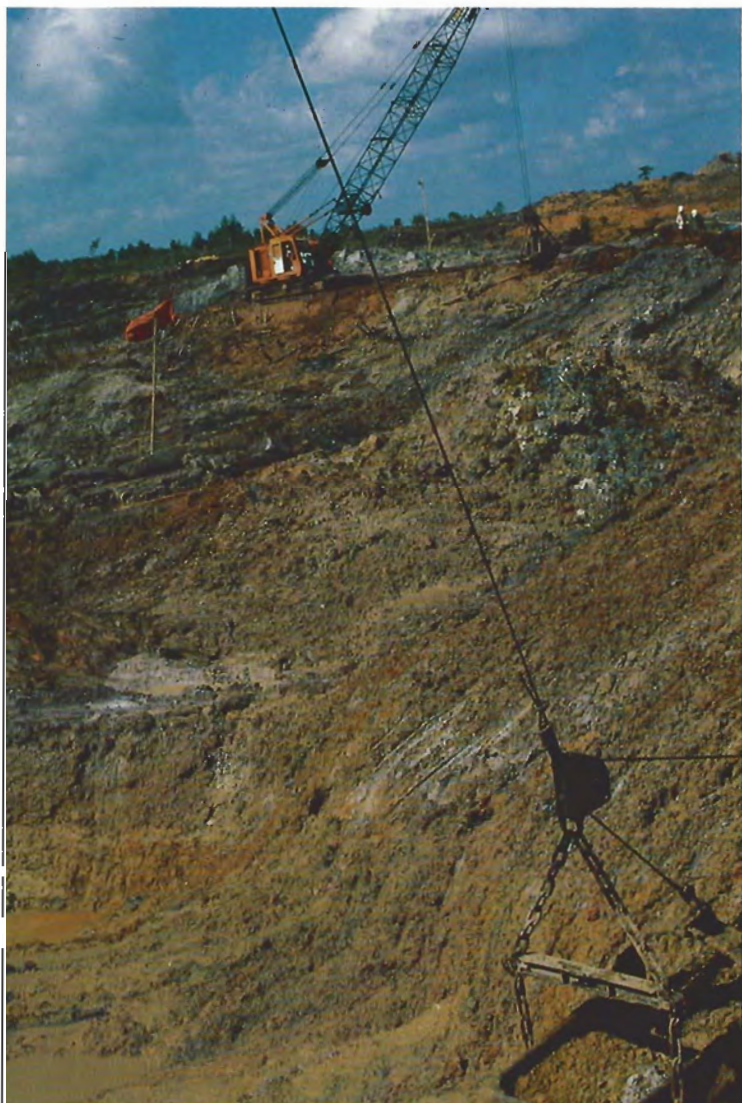


who will be in charge of selling it in Martapura on the traditional Tuesday or Saturday market day.

**The Sampling Project at Banjar Baru.** In contrast to the manual digging, washing, and sorting of the gem gravels at Cempaka, the most sophisticated equipment available was used to mine the gravels for bulk sampling at Banjar Baru. The aim of the bulk sampling was to determine the diamond-bearing potential of the gravels beneath the swamp and to recover at least 1,000 ct of diamonds for quality and manufacturing evaluation.

The first pit was sited at Danau Seran because of the occurrence of significant indicator mineral grain counts as well as the recovery of a number of small diamonds from the preliminary drill holes. The pit was laid out with an initial length of 40 m and a width of 8 m, the overburden was stripped, and then the gravels were excavated by 35T Link-belt clamshells (figure 8). To stop slumping and the

*Figure 8. Clamshells are used to remove gravels from the first sample pit at Danau Seran. Photo by David Dikinis.*



inflow of surface water, a retainer wall was constructed from loose material excavated around the perimeter of the pit; in addition, a slurry pump was installed to remove water. To determine accurate in-situ volumes of diamond-bearing gravels, the internal dimensions of the excavated pit were accurately surveyed, and gravel thicknesses were measured at 1-m intervals around the interior (again, see figure 4).

The excavated gravels were loaded onto 6-ton haul trucks and delivered to the sampling plant some 5 km away (figure 9). The sampling plant is a standard alluvial plant of 10 m<sup>3</sup> per hour capacity that uses a trommel-scrubber unit and primary and secondary jigs (figure 10). A spiral concentrator was added to improve the recovery of black sand (a mixture of ilmenite, chromite, rutile, gold, and platinum). The plant was constructed in Inverell, Australia, and is basically the same as that used to separate sapphire at Inverell (see Coldham, 1985). The recovery procedure was found to be highly effective, with virtually all diamonds recovered from the first two (of three) screens in both the primary and secondary jigs.

The jig screens were removed after three or four days' production and the concentrate processed in the laboratory. The 5–7 mm and the 3–5 mm concentrates were fed into a Plietz jig, which delivers a high-grade diamond concentrate in the center of a flat screen. This screen is then placed upside down on a white cloth on a rubber sorting deck, and the diamonds are hand picked under strong white light in a shallow water bath. The Plietz jig tailings were panned by hand again to check for diamonds that may have escaped initial inspection. The <1.5-mm black sand concentrate was first dehumidified, put through a magnetic separator, and then tabled with the super-concentrate amalgamated to recover gold and hand washed to recover platinum. Considerable amounts of gold and platinum were recovered in this way (figure 11). A total of 5345.9 m<sup>3</sup> of gravels were taken from the bulk sample pit. From these gravels, 1050.96 ct of diamonds, 470 grams of gold, and 178 grams of platinum were recovered.

The authors are not aware of any major sophisticated diamond mining operations being undertaken in western Kalimantan at this time. Local inhabitants continue to mine by traditional methods in the area of Ngabang, following procedures similar to those described above for south-eastern Kalimantan.





Figure 9. This sampling plant, located 5 km from the Danau Seran sample pit, is basically the same as that used to separate sapphire at Inverell, Australia. Photo courtesy of Acorn Securities.



Figure 10. Material emitted from the jigs at the Acorn Securities sampling plant will be further examined by hand for diamond rough. Photo by David Dikinis.



Figure 11. In addition to over 1,000 ct of diamonds (some of which are shown here in the center), 470 grams of gold and 178 grams of platinum were recovered from the first bulk-sample pit at Danau Seran. Photo by David Dikinis.

## DESCRIPTION OF THE KALIMANTAN DIAMONDS

### Quality Analysis of Diamonds from Banjarmasin.

Acorn Securities reports that the great bulk of the diamonds they recovered are of gem quality, with only one piece of bort recovered from 6,766 individual stones found in the bulk sample pit. The

diamonds occur as stones and shapes with uncommon cleavages, as well as some macles and, rarely, ballas (figure 12). The dominant crystal forms of the stones and shapes are the dodecahedron and tetrahexahedron (58%; C. E. Watson, pers. comm.,





Figure 12. A variety of colors and shapes of diamonds (here, 1–3 ct) were found in the first bulk sample recovered from Danau Seran. Photo courtesy of Acorn Securities.

1988) followed by the octahedron (22%). The goods generally show low amounts of inclusions. White (46%) and yellow (33%) stones are the dominant color groupings, although brown (15%, including cognac and champagne colors), green (5%), and other colors (1%) were also recovered. Of the larger stones cut, that is, stones greater than 2 ct, the highest color rating was a J. Because of the shapes in which the diamonds occur and their overall quality, independent valuers in both London and Antwerp have deemed the material eminently "sawable."

The largest stone recovered from this area in recent months is a 33-ct octahedron found by a local miner. The largest stone recovered during the Acorn sampling was an 8.53-ct octahedron (figure 13) that cut a 3.50-ct stone of J color. Twenty percent of the stones by weight are larger than 0.8 ct, with 48% of the stones larger than 0.30 ct. Approximately 15% of the stones are larger than 1 ct.



Figure 13. This 8.53-ct diamond from the first bulk sampling pit at Danau Seran cut a 3.5-ct stone of J color. Photo courtesy of Acorn Securities.

**Gemological Properties.** Comprehensive gemological testing of the three fancy-color faceted stones shown in figure 1 and the near-colorless crystal shown in figure 14 confirmed that the properties of these Kalimantan diamonds are the same as diamonds of similar hues from other localities (see table 1). With regard to internal characteristics, no mineral inclusions were observed in the grayish blue diamond when it was examined with the microscope. However, a cloud of pinpoint inclusions was evident throughout the light pinkish brown stone, and numerous black crystal inclusions (which could not be identified without damaging the stone) were noted under the crown and table of the greenish yellow diamond. Both of these characteristics, however, have been observed in diamonds from other localities. Also observed in the greenish yellow diamond was the strong green graining that is typical of this color type from various sources.

**Famous Diamonds.** Although diamonds over 5 ct from Kalimantan are rare, this does not preclude the occasional discovery of a significant stone. The Jakarta Museum has many diamonds that weigh 10 ct or more. Bauer (1904) reported that several stones over 100 ct once belonged to the Malay Prince of Landak. Since the Landak district was the major producer of diamonds in Kalimantan into

the early 20th century, it would have been appropriate for the ruling prince to retain the largest stones. Bauer also reported that the Rajah of Matan had several significant diamonds, including a 70 ct named the Segima and an unnamed 54-ct stone. The Rajah of Matan was reported also to have a 367-ct diamond, but it is generally thought that the stone was actually quartz.

In 1965, a diamond weighing 166.85 ct was found in southeastern Kalimantan and named the Tri Sakti, or "Three Principles," after the three watchwords of the new Indonesian republic—nationalism, religion, and unity ("Petrified Tears," 1977; Schubnel, 1980). The rough was sent to Asscher's Diamond Company, Ltd., an Amsterdam firm that is renowned for having cut the Cullinan, and a 50.53-ct emerald-cut was produced in 1966. The stone was subsequently sold to an undisclosed buyer in Europe and, unfortunately, its current whereabouts are not known.

#### THE MARTAPURA DIAMOND INDUSTRY TODAY

Martapura is the largest diamond-cutting center in Indonesia. In the town square of Martapura, one is immediately aware that this is a gem-trading town. Small jewelry shops are found around the square, and open-front cutting shops predominate in the alleyways. Purchasing diamonds as a tourist



Figure 14. This near-colorless 0.96-ct octahedral diamond crystal from Cempaka is set in an 18K gold pendant designed by Diane Allen. Photo © Tino Hammid.

TABLE 1. Gemological properties of four diamonds from Borneo.

Property	0.34-ct fancy light pinkish brown	0.20-ct fancy grayish blue	0.28-ct fancy greenish yellow	0.96-ct near-colorless octahedral crystal
Absorption spectrum <sup>a</sup> (400–700 nm)	Strong 415.5-nm line	No lines or bands	Moderate lines at 498 and 504 nm	None at room temperature; very weak 415.5-nm line when stone cooled to –54°C
Transmission luminescence	None	None	Strong green	None
Fluorescence to U.V. radiation				
Long-wave	Very strong chalky blue	None	Very strong chalky yellow	Very weak yellowish orange
Short-wave	Moderate chalky blue	None	Moderate chalky yellow	None
Phosphorescence	Very weak dull chalky yellow, long-wave U.V.	None	None	None
Electrical conductivity	Nonconductive	Conductive	Nonconductive	Nonconductive

<sup>a</sup>As observed through a GIA GEM Instruments spectroscopy unit with a Beck prism spectroscopy, with the diamonds cooled with an aerosol refrigerant.

for personal use is perfectly legal in Indonesia, but there are special requirements for obtaining a business visa. The jewelry is both made locally and also imported as halfmounts from Hong Kong and Bangkok. The round brilliant is virtually the exclusive cut in Martapura. A marquise-cut diamond shown to one of the coauthors was described as a "very unusual fancy cut." The faceting machines used are typical of those found in India, with heavy bronze wheels attached by a spindle with bearings on the top and bottom. One electric motor will run from one to six cutting wheels by means of a belt.

The grading of diamonds in Kalimantan is reminiscent of the grading in existence around the turn of the century. Color is graded as blue-white (*biru*), white (*putih*), yellowish (*kuning*), brownish (*coklat*), and, of course, the fancy colors. Clarity is divided into "loupe clean," "slightly imperfect," etc. No microscopes or modern diamond-grading equipment (or terminology) were in evidence during Dikinis's 1987 visit. Some fine cut stones in 3- to 5-ct sizes, as well as one 10-ct, were available at that time. The prices for rough were based on what kind of a finished round stone the rough should produce. The largest consumers of the finished cut stones are the jewelry stores in Jakarta, so the prices are fairly consistent with the international market.

#### RECENT PRODUCTION AND FUTURE POTENTIAL

Schubnel (1980) estimated that annual diamond production from southeastern Kalimantan ranged between 20,000 and 30,000 ct. In 1984, however, *Diamond World Review* gave production estimates for Borneo of 15,000 ct per year. During Dikinis's visit in the summer of 1987, only about five rough stones (over 0.50 ct) a day came on the open market in Martapura (although a somewhat greater number were undoubtedly sent directly to the local cutting facilities). During a subsequent visit to the mining town of Cempaka, Dikinis also observed that a full day of prospecting produced only three gem-quality stones. These figures are low enough that the government and the international community pay little attention to the native workings of southeastern Kalimantan.

The best hope for increasing diamond production in Kalimantan is through large-scale, mechanized mining. Several corporations are actively exploring for both alluvial diamonds and possible

kimberlite pipes in the Meratus Mountains and elsewhere. The most advanced of these diamond projects in Kalimantan is that of the Aneka Tambang-Acorn Securities-Keymead joint venture in the Cempaka district.

At the time of printing, Acorn has completed an additional large bulk sample as well as several smaller bulk samples using sheet pile caisson techniques driven by crane-mounted vibro-hammers. The Cempaka swamp, as well as Danau Seran, has now been sampled. A detailed feasibility study prepared in conjunction with Alluvial Dredges Ltd. of Scotland proposes a 16-ft<sup>3</sup> bucket-ladder dredge for the Danau Seran paleochannel that would remove the overburden and some 800,000 m<sup>3</sup> of diamondiferous gravel per annum for five years to produce approximately 100,000 ct per annum of gem-quality diamonds. The proposal also calls for an additional two 36-ft<sup>3</sup> bucket-line dredges to mine the deeper Cempaka paleochannel at an annual production of 200,000 ct.

The high unit value of the diamonds enables the relatively low in-situ grades to be profitably mined using these sophisticated high-volume extraction techniques. With the success of this project, it is hoped that Indonesia will become a small but consistent producer of high-quality gem diamonds.

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# AN UPDATE ON COLOR IN GEMS. PART 3: COLORS CAUSED BY BAND GAPS AND PHYSICAL PHENOMENA

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By Emmanuel Fritsch and George R. Rossman

The previous two articles in this series described the origins of color in gems that derive from isolated structures of atomic dimensions—an atom (chromium in emerald), a small molecule (the carbonate group in Maxixe beryl), or particular groupings of atoms ( $\text{Fe}^{2+}-\text{O}-\text{Fe}^{3+}$  units in cordierite). The final part of this series is concerned with colors explained by band theory, such as canary yellow diamonds, or by physical optics, such as play-of-color in opal. In the case of band theory, the color-causing entity is the very structure of the entire crystal; in the case of physical phenomena, it is of microscopic dimension, but considerably larger than the clusters of a few atoms previously discussed.

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All of the colors discussed in parts 1 and 2 of this series (Fritsch and Rossman, 1987 and 1988) arise from processes in which electrons are localized on a single atom or are delocalized over no more than a few atoms. The colors that arise from these processes depend on the presence of specific minor components or defects in the host crystal. However, colors can arise, though less commonly, from processes that involve the entire crystal, through either its electronic structure (band theory) or its internal texture (physical phenomena such as interference effects, diffraction effects, scattering, and inclusions; see figure 1). These, the most unusual causes of color in gems, are covered in this last article of our series.

## BAND THEORY

In contrast to the processes described in the first two parts of this series, the electrons in some gem minerals can be delocalized over the entire crystal, and produce color through their interaction with visible light. Such delocalization is a characteristic property of most metals and semiconductors. The physical theory that describes the cause of color in such materials is called *band theory*. Examples of the various gem colors explained by this theory are presented in table 1.

In numerous solid materials, billions of atoms contribute to the possible energy levels, which are so numerous and so close together that they are considered collectively as an energy *band*. This is of particular interest in the case of some semiconducting and metallic minerals (Marfunin, 1979a). There are two bands in these solids: a low-energy valence band that is fully populated with electrons, and a high-energy conduction band that is generally empty (figure 2). The energy that separates these bands is well defined and is called a "band gap." This energy separation is of dramatic importance to the optical properties of certain types of gemstones.



Figure 1. Colors in gem materials can be caused by a wide variety of processes. This article explains color-producing mechanisms related to band theory and physical phenomena. Examples of the latter include diffraction in opal (in the center top and bottom right), scattering of light in “moonstone” feldspar (the necklace), and coloration by inclusions in fire opal (center bottom) and “sunstone” feldspar (bottom left). The necklace is courtesy of Elise Misiorowski; photo by Robert Weldon.

For these gemstones, transitions between bands rather than between energy levels of single atoms are responsible for the color. These “interband transitions” occur when electrons from the valence band receive sufficient energy by absorbing light to “jump” over the band gap and reach the conduction band. As illustrated in figure 2, three different scenarios are possible for interband transitions.

When the energy of the band gap is greater than the maximum energy of the visible range (i.e., the violet light), visible light does not supply enough energy to cause an electron to jump from the lower band to the upper one (figure 2A). Consequently, all of the visible spectrum is transmitted (none is absorbed) and, in the absence of impurities or defects, the mineral is colorless. Such materials—e.g., corundum, beryl, quartz, diamond, and topaz,

**TABLE 1.** Types of gem materials for which color can be explained by the band theory and examples of the colors produced.

Origin of color	Type of material	Color	Examples
<b>Band gap less than the energy of visible light</b>	Conductors and some semiconductors = colored opaque materials with metallic luster	<b>Violet to blue</b>	Covellite (Berry and Vaughan, 1985)
		<b>Yellow</b>	Gold, pyrite (Nassau, 1975; Fritsch, 1985)
		<b>Red</b>	Copper (Nassau, 1975)
		<b>White</b>	Silver, platinum (Nassau, 1975)
<b>Band gap in the visible range</b>	Some semiconductors	<b>Red</b>	Cuprite, cinnabar (Fritsch, 1985)
<b>Band gap greater than the energy of visible light</b>	Some semiconductors and all insulators	<b>Intrinsically colorless</b>	Diamond, corundum, beryl, quartz, topaz, fluorite (Fritsch, 1985)
		<b>Blue</b>	Type IIb diamond, containing dispersed boron atoms (Collins, 1982)
<b>Color modified by minor components</b>	Some semiconductors	<b>Yellow</b>	Type Ib diamond, containing dispersed nitrogen atoms (Collins, 1982)

as well as many other oxides and silicates—are inherently electrical insulators.

When the energy of the gap is less than the energy of violet light (i.e., is *in* the visible range), the most energetic radiations in the visible range (violet to blue to green) are absorbed, leaving the low-energy range unaffected, that is, transmitted (figure 2B). The exact energy of the band gap varies among different materials, so the transmitted color will also vary. Usually band-gap colors range from deep yellow to deep red. Cuprite and cinnabar (figure 3) are colored red by such a process.

The energy in the band gap may be even less than the lowest energy of the visible spectrum (red). In such a situation, all wavelengths of visible light will cause a transition from the valence band to the conduction band, so the whole visible spectrum is absorbed (figure 2C). As a conse-

quence, the mineral usually appears black and opaque. All metals have just such a small band gap or no band gap at all. They appear, however, to be shiny (metallic luster) because their electrons quickly return to their original energy level, emitting the exact same energy (light) that they formerly absorbed (Nassau, 1975b). In some metals, the number of available excited states may vary throughout the conduction band, so that some wavelengths are absorbed and re-emitted more efficiently than others, thus producing color. Although silver and platinum absorb and emit all wavelengths with about the same efficiency and appear white, gold (or pyrite) absorbs and emits more yellow than the other wavelengths and so gets its distinct golden coloration (again, see figure 3).

The band gaps discussed thus far are an intrinsic

Figure 2. The three possible types of intrinsic coloration of gem materials are explained by examining the width of the band gap in relation to the visible range. (A) Band gap greater than the energy of the visible range: All visible radiation is transmitted and the gem is intrinsically colorless. (B) Band gap in the visible range: Only the high-energy part of the spectrum (violet to blue to green) is absorbed, and the gem is yellow to red. (C) Band gap less than the energy of visible light: All visible radiation is absorbed and the material is black, or displays metallic colors due to re-emission. Artwork by Jan Newell.

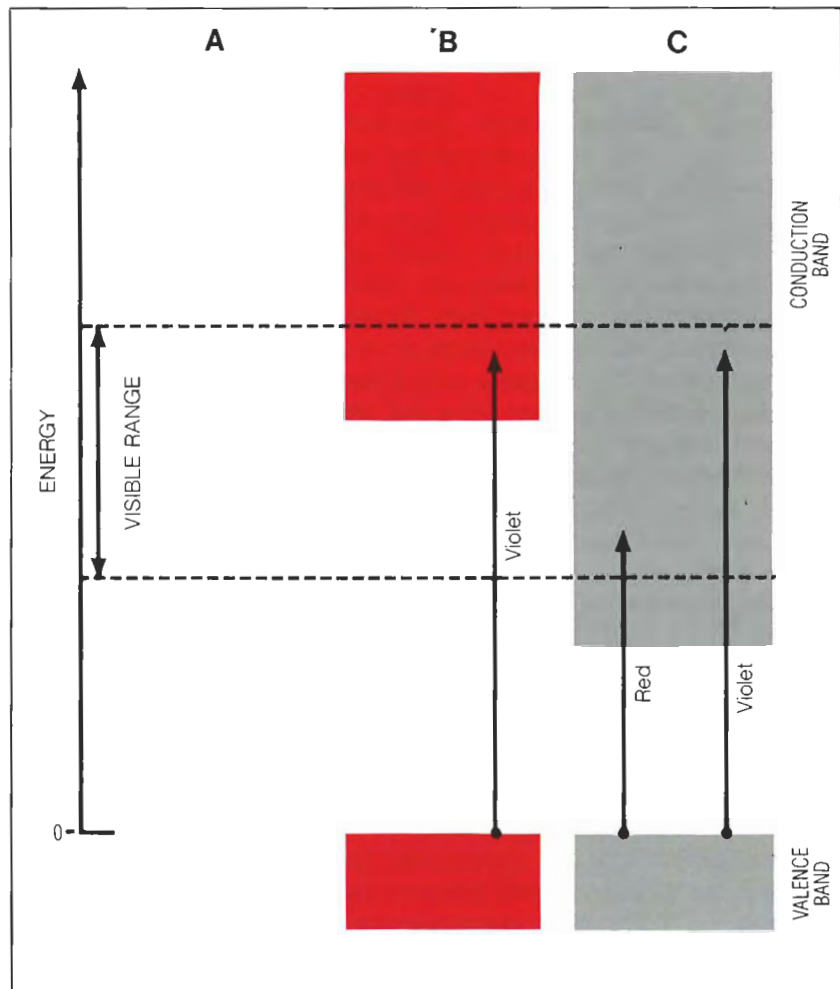






Figure 3. The red color of cuprite (the cushion cut) and cinnabar (the pentagon cut) has little to do with the fact that these gems contain copper and mercury, respectively. The color occurs because the band gap of these minerals is within the visible range: All wavelengths from violet to orange are absorbed, so that only red light is transmitted. The band gap in gold is much smaller than the energy of the visible range: All visible light is absorbed but some wavelengths are re-emitted preferentially, giving gold its yellow color and metallic luster. (Remember that the energy scale is inverse to the wavelength scale.) Photo by Robert Weldon.

sic property of the material; they are ultimately directly related to its chemical composition and atomic structure. In some semiconductors, however, color is caused by small amounts of impurity atoms that normally do not produce color in intrinsically colorless minerals. Specifically, these atoms can introduce electronic energy levels at an energy between the valence band and the conduction band of the host mineral (see figure 4). Some of the most striking examples are canary yellow and fancy blue diamonds, which contain isolated nitrogen and boron atoms, respectively. Although pure (colorless) diamonds are insulators, they may also be considered semiconductors with a band gap so large that they have neither color nor appreciable electrical conductivity (figure 4A). Nitrogen can easily substitute for carbon, which it follows in the periodic table of elements. Because nitrogen possesses one more electron than carbon, however, it becomes an electron "donor" when it substitutes for carbon in diamond. This additional electron contributes an additional energy level situated above the diamond valence band, but below the diamond conduction band (figure 4B). However, because this donor level has a finite width, light of a variety of wavelengths extending from the ultraviolet into the visible range up to 560 nm (green) will be absorbed, creating a strong yellow color. This type of coloration occurs only in type Ib diamonds, in which isolated nitrogen atoms substitute for carbon atoms in the proportion of about 1 to 100,000 (Collins, 1982). This color is distinct from the yellow color commonly caused by the

nitrogen-related N3 color center, which produces the familiar Cape series of absorption lines.

Boron has one less electron than carbon, which follows it in the periodic table of elements. Therefore, boron is an electron "acceptor" when substituting for carbon in diamond. It contributes its own electron energy band, which is situated within the diamond band gap (figure 4C). The excitation of an electron from the diamond valence band to the acceptor level requires only a very low energy, in the infrared range (Collins, 1982). Because the boron energy band is broad, it can cause absorption extending from the infrared up to 500

Figure 4. The band gap in pure diamond is much greater than the visible range (A), so this gem is intrinsically colorless. However, a substitutional nitrogen atom introduces a level that donates electrons to the diamond conduction band (B), creating an absorption in the ultraviolet that extends into the blue end of the visible range (see spectrum); such stones are of an intense yellow color, and are therefore called "canary" (type Ib) diamonds. By contrast, a boron atom substituting for carbon can introduce a broad energy level available for electrons from the diamond valence band (C), which will induce an absorption of the near-infrared and the red end of the visible range (see spectrum), giving a blue hue to such a stone (type IIb diamond). These three mechanisms are illustrated by the colorless, De Beers synthetic type Ib yellow (photo © Tino Hammid), and natural dark blue diamonds shown here. Artwork by Jan Newell.

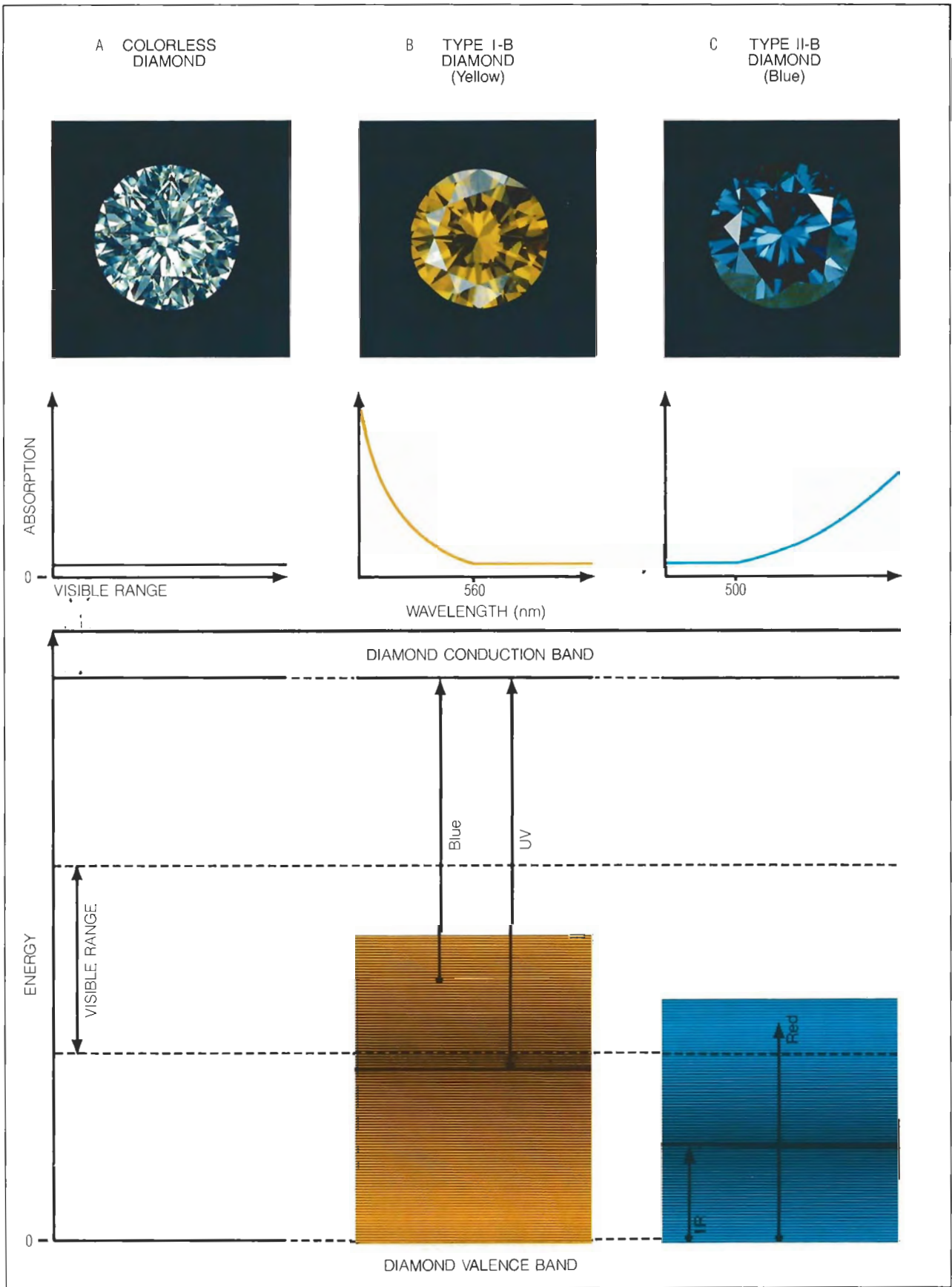






Figure 5. Minute amounts of boron contribute the intense blue color to blue diamonds. Yellow in diamonds can arise from a variety of processes, all of which are related to the presence of nitrogen impurities. The possible origins of color for orange, brown, and pink diamonds are listed in table 4. The blue marquise shown here is 3.88 ct; the intense yellow oval weighs 29.16 cts; the two intense yellow diamonds mounted in earrings weigh a total of 12.26 ct. Jewelry courtesy of Harry Winston, Inc.; photo © Harold & Erica Van Pelt.

nm (the edge of the green). The resulting blue color, which can be produced with boron concentrations as low as one part per million (Nassau, 1975b), may be quite intense (figure 5). The Hope diamond is the most famous example of a blue diamond. There is no known commercial treatment that would affect band-gap coloration.

#### COLORS THAT ARISE FROM PHYSICAL PHENOMENA

All of the colors discussed thus far in this series have been due to the absorption of light. But as the introduction to part 1 pointed out, other causes of color are possible. In some gem materials, physical properties such as inclusions or lamellar texture can influence the hue. In this next section, we will explore how light interference, diffraction, and scattering can interact with these physical features to create colors in gem materials. These processes are rarely related directly to the chemistry of the stone, but rather are connected to the texture or internal arrangement of the mineral. The various colors obtained in gems as a conse-

quence of physical phenomena are summarized in table 2.

**Interference Effects from Thin Films.** Interference phenomena occur when two rays of light travel along the same path or in closely spaced parallel paths. If these rays, or light waves, vibrate in phase, the wave crests reinforce each other to produce bright light (constructive interference). If the light waves vibrate exactly out of phase, they cancel each other to produce darkness (destructive interference).

Iridescence, the most common interference phenomenon, occurs when light passes through a thin transparent film that has a different index of refraction from the surrounding medium (e.g., a thin film of air in "iris quartz"). Rays reflected from the bottom of the film will travel beside waves reflected from the top of the film. At certain wavelengths, dictated by the thickness and the index of refraction of the film, the rays vibrate out of phase and the corresponding colors are removed from the reflected light through destructive inter-



ference. The remaining wavelengths produce the familiar colored effects that appear when a drop of oil expands as a thin film on water. The possible colors in iridescence are illustrated in figure 6. None of these colors is a pure spectral color.

In gemology, examples can be found as interference color in cracks (again, "iris quartz"), or in tarnish films on oxidized cut stones and sulfide crystals, such as pyrite and bornite (Nassau, 1975b). Iridescent cracks are sometimes created by heating and rapidly cooling a stone ("quench crackling"), especially quartz. The color observed in many pearls is also due in part to interference effects (again, see figure 6). Pearls are constructed from concentric alternating layers of aragonite and conchiolin, two substances of different refractive indices. Incoming overhead light is reflected from the surfaces between those successive layers. The reflected light interferes with the incoming light to create delicate iridescent colors, called orient. Mother-of-pearl and some abalone pearls exhibit similar interference effects, but the colors generally are stronger and less subtle (figure 7). In addition to "quench crackling," interference effects can also be generated by coating thin films of various substances on the surface of a gem.

**Diffraction Effects.** Diffraction effects are special types of interference phenomena. The most important of these for gem materials is that caused by a regular stacking of alternating layers that have different indices of refraction. This diffraction effect produces pure spectral colors, in contrast to iridescence, which gives rise to colors that are a combination of several spectral colors (again, see figure 6).

Opal is one of the very few gems that can exhibit all colors of the spectrum in a single stone. It is interesting to note in play-of-color opal that although the pattern may be quite irregular, within each color region the color is homogeneous (see, for example, figure 1 of this article and the cover of this issue). The color of any one patch depends on the orientation of the overhead light source; when the stone moves, the color changes, giving "life" to the opal. If the light emerging from one of the color patches is analyzed, it appears to be a pure spectral color, that is, essentially of only one wavelength. These properties are characteristic of the diffraction effect created by the interaction of white light with a regularly layered structure (figure 8).

**TABLE 2.** Physical phenomena and examples of the colors they cause in various gem materials.

Process	Color and gem material
<b>Interference on a thin film</b>	<b>Various (nonspectral) colors:</b> iris quartz, iridescent coatings and tarnish, "orient" in pearls, mother-of-pearl (Nassau, 1975)
<b>Diffraction</b>	<b>All (spectral) colors:</b> play-of-color opal (Darragh and Sanders, 1965), labradorite/spectrolite (Ribbe, 1972), some rare andradites (Hirai and Nakazawa, 1982)
<b>Scattering</b>	
Rayleigh scattering	<b>Blue:</b> feldspar/moonstone (Lehmann, 1978), some blue quartz (Zolensky et al., 1988), some opal (Lehmann, 1978)
Mie scattering	<b>Violet:</b> fluorite, scattering by calcium microcrystals (Braithwaite et al., 1973) <b>Red:</b> ruby glass, scattering by copper or gold microcrystals (Nassau, 1983)
Scattering from structures larger than visible wavelengths	<b>White:</b> milky quartz (Fritsch, 1985)
<b>Presence of colored inclusions</b>	<b>Blue:</b> dumortierite inclusions in quartz (J. Koivula, pers. comm., 1988) <b>Green:</b> nickel-bearing clays in chrysoprase and prase opal (A. Manceau, pers. comm., 1987; Koivula and Fryer, 1984), chromian mica (fuchsite) in aventurine quartz (Lehmann, 1978) <b>Orange:</b> hydrous iron oxides in carnelian agate and fire opal (J. Koivula, pers. comm., 1988) <b>Red:</b> hematite platelets in orthoclase (Andersen, 1915), hematite or copper platelets in sunstone feldspar (Lehmann, 1978), cordierite/"bloodshot iolite" (Gübelin and Koivula, 1987)

The structure of opal was first revealed with scanning electron microscopy more than 20 years ago (Darragh and Sanders, 1965). It is an extraordinarily regular stacking of parallel layers of small spheres composed of hydrous silica. Color phenomena occur when the diameter of these spheres is less than the wavelengths of visible light. The conditions for diffraction of a given color are met when the distance between two successive layers is approximately equal to the wavelength of that color divided by the index of refraction of the spheres. The exact conditions are described in Nassau (1983). Consequently, the diffracted wavelength is proportional to the size of the particle. For example, the intense red is selected by spheres of about 250 nm in diameter (Darragh and Sanders,

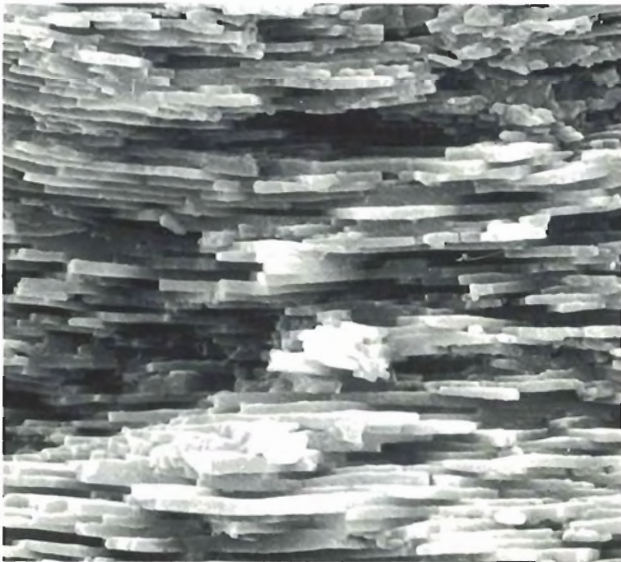
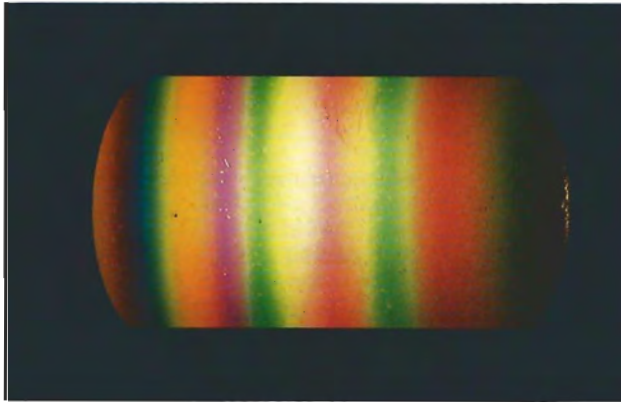


Figure 6. The colors produced by interference on a thin film are the same as those observed on this quartz wedge (top left) in polarized light. None of them is a pure spectral color. Notice that the "higher orders" on the right produce mostly pink and green. Interference colors are caused in pearls by light passing through and reflected back by alternating concentric layers of aragonite and conchiolin, which are readily visible on the electron photomicrograph of a pearl section (left). The resulting "high order" interference colors (mostly green and pink) are called orient and overtone (the latter, when they are stronger and homogeneous all over the pearl). They are readily apparent in these black pearl cufflinks (top right). Photomicrograph courtesy of B. Lasnier, Gemology Laboratory, Nantes University, France. Jewelry courtesy of Harry Winston, Inc. Color photos by Robert Weldon.

1965). The other colors are diffracted by smaller spheres, down to 140 nm in diameter.

As stated earlier, the color of the diffracted light varies with the angle between the direction of illumination and the direction of observation. The observed wavelength is at a maximum (e.g., red) when those two directions are perpendicular. When the stone is rocked away from this position, the observed wavelength decreases (e.g., goes to orange; Lehmann, 1978).

For the more commonplace play-of-color opals, those with mostly blue and green patches, the remainder of the incoming light (i.e., yellow to red) is transmitted so that an orange coloration is seen in transmitted light. Fire opal, however, probably owes its yellow-to-red body color (figure 9) to both diffraction and body absorption by  $Fe^{3+}$ -rich sub-microscopic to microscopic inclusions between the silica spheres (J. Koivula, pers. comm., 1988).

Similar effects are encountered in some feldspars belonging to the plagioclase series. These feldspars display regions of color, often violet to green, against a generally black background. Finnish "Spectrolite," a variety of labradorite, appears to show every color of the spectrum. This phenomenon is called "labradorescence," after the classic occurrence of these stones on the Isle of Paul, Labrador, although varieties of plagioclase feldspars other than labradorite may display this effect. The diffracting objects in labradorescence are alternating layers, known as exsolution lamellae, of two feldspars with different chemical compositions. One layer is calcium rich and the other is calcium poor. The color created by the lamellar structures depends on their respective thicknesses and indices of refraction (figure 10). Another gemstone that occasionally shows diffraction colors is andradite from Hermosillo, Mexico



Figure 7. Pink and green interference colors make a spectacular display in this abalone pearl. Courtesy of Lowell Jones, St. Louis, MO; photo © Tino Hammid.

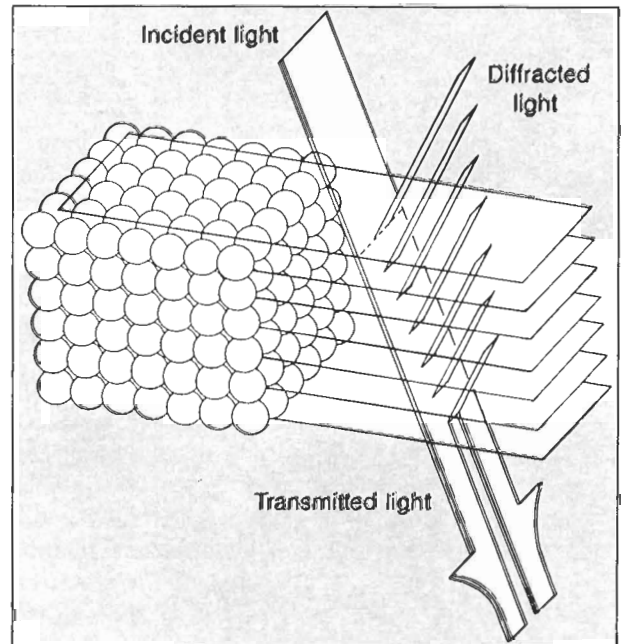
(Koivula, 1987). Similar material from Japan has lamellar structures about 100 nm thick (Hirai and Nakazawa, 1982), which give rise to some very rare crystals with patches of color. Diffraction effects probably account for the color phenomena observed in some varieties of agate (e.g., iris agate, fire agate).

Diffraction cannot be induced by any known commercial treatment. However, an already existing diffraction color can be enhanced by inducing a dark background (sugar and smoke treatment of opals, for example, as well as doublets), or by reducing the scattering of light in the matrix through impregnation with various kinds of polymers.

**Scattering.** When the internal structure of the stone is irregular and/or the size of the components is outside the very narrow range needed for diffraction (approximately 100–400 nm), visible light cannot be diffracted. It can, however, still be scattered, the process by which light entering a stone in a given direction is deflected in different directions through interaction with the scattering centers. This creates both striking color effects and optical phenomena. The exact phenomenon depends on the size and shape of the scattering centers. When the scattering centers are smaller than the wavelength of visible light (including down to molecular dimensions) and not regularly distributed, the process is called *Rayleigh scattering*; when the scattering centers are comparable in size to visible wavelengths, the process is called *Mie scattering*. (The names are derived from the mathematical theories used to describe scattering.) A third type of scattering occurs when the centers are larger than visible wavelengths.

*Rayleigh Scattering.* When the incoming light ray encounters randomly distributed objects smaller

Figure 8. The homogeneous color in a patch of opal arises because light rays entering the stone are diffracted by an orderly array of silica spheres and the holes in between them. The diffracted color depends on the size of the spheres (after Lehmann, 1978).

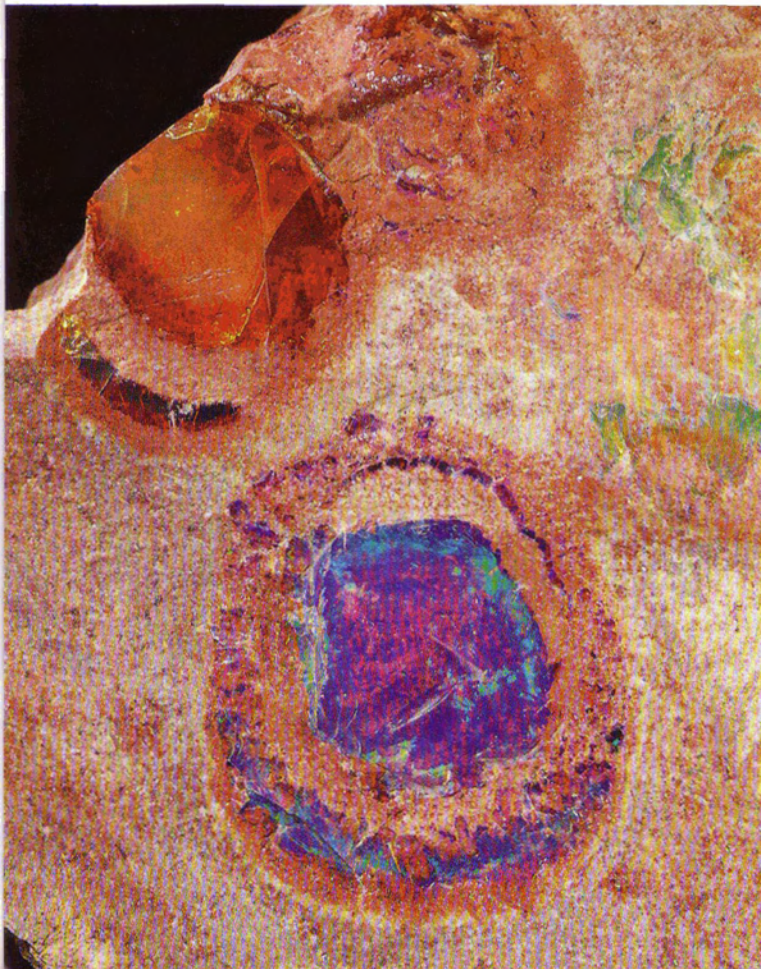




than the wavelengths of visible light, the most energetic radiations—violet and blue—are scattered much more strongly than the others. In fact, violet light is scattered 16 times more efficiently than red. As a result, the majority of the orange-red light passes through the stone and appears as transmitted light, whereas violet and blue light is scattered and can be observed at right angles to the incident beam.

This phenomenon is familiar to all of us as the scattering of sunlight by molecules and molecular aggregates in the upper atmosphere, which causes the sky to appear blue in the daytime (scattered light) and orange-red at dawn and twilight (transmitted light). Examples in gemology are few but well known. Common opal (potch) contains spheres that are too small and too irregularly stacked to diffract. Instead, it has a bluish white appearance called "opalescence," which is due to scattering by the silica spheres. Such an opal indeed also transmits orange light. "Moonstone" is

Figure 9. This extraordinary opal specimen from Mexico shows a diffraction-caused play-of-color zone close to a region of fire opal, which is colored by a combination of diffraction and body absorption by  $Fe^{3+}$ -containing inclusions. Specimen courtesy of the Paris School of Mines; photo © Nelly Bariand.



so called because light scattered from exsolution lamellae creates a bluish white "moon-like" hue (in the best specimens; see figure 1). Moonstone is actually an alkali feldspar, with alternating parallel planes of potassium- and sodium-rich feldspars forming an assemblage called a microperthite. These component layers in moonstone range from 50 to 1000 nm ( $1 \mu\text{m}$ ) thick (Lehmann, 1978). The thinner layers produce the Rayleigh scattering. The same colors from scattering can also occur in plagioclase, and are sometimes called "adularescence." Some blue quartz receives its color from the scattering effect created by dispersed ilmenite inclusions that are approximately 60 nm in diameter (Zolensky et al., 1988).

*Mie Scattering.* When the scattering elements are roughly the size of the visible wavelengths, the scattering is best described by the "Mie theory." This theory has applications in gem materials only in those very special cases in which the color is created by metallic inclusions.

A common example is provided by some varieties of violet fluorite. This color is generated by irradiation, which expels a fluorine atom from the crystal, leaving partially bonded calcium atoms behind. Over time, the calcium atoms coagulate and form small hexagonal platelets about the size of visible wavelengths (Lehmann, 1978). Part of the light is absorbed by the calcium crystals and part is reflected. The combined effect of this absorption and reflection is a strong absorption from the green to the red, which leaves a violet transmission window. The position of the bands, and therefore the hue, varies slightly with the size of the metallic particles. Such an effect has been known for a long time in man-made glasses (which are often used as gemstone simulants). "Ruby" glasses are colored by microscopic particles of copper (or gold), and the brown glass used for beer bottles (and to imitate topaz) is usually tinted by metallic oxysulphide precipitates (J. F. Cottrant, pers. comm., 1987).

*Scattering from Structural Components Larger than Visible Wavelengths.* When the inclusions are larger than the wavelengths of visible light, they scatter light in all directions, including toward the observer's eye. Unlike the case of Rayleigh scattering, all wavelengths are scattered equally and recombine to produce a white light with a translucent milky appearance. This is typical of crystals



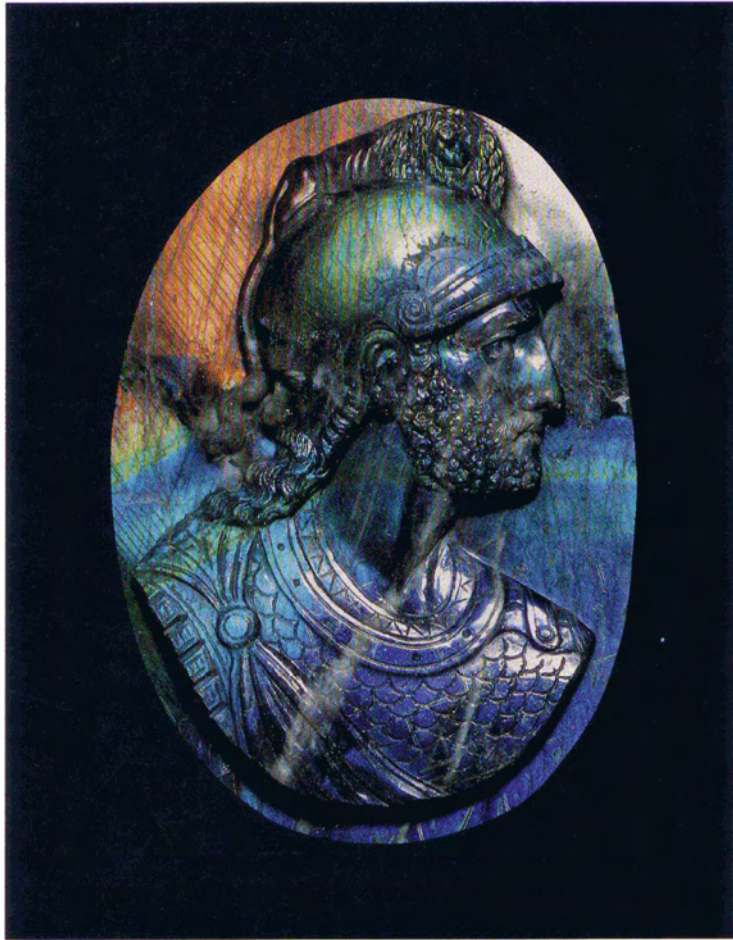
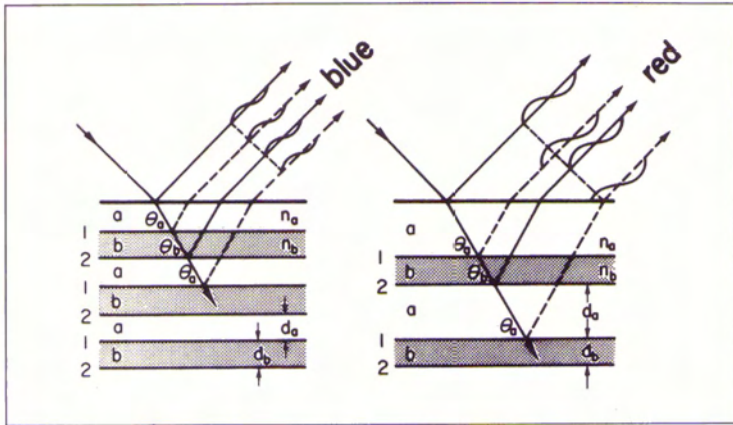


Figure 10. The schematic drawings illustrate why various diffraction colors occur in plagioclase feldspars. The two sets of lamellar feldspars have different thicknesses ( $d_a$  and  $d_b$ ) and indices of refraction ( $n_a$  and  $n_b$ ); therefore, the light beam will go through interfaces 1 and 2 at different angles ( $\theta_a$  and  $\theta_b$ ). As a consequence, the beam at interface 2 is retarded relative to the one at interface 1, although the wavelengths are the same, and generally attenuate each other. For one given combination of thicknesses, refractive index, and incident wavelength, the beam from interface 2 is exactly one wavelength behind the beam of interface 1, so they combine in a coherent monochromatic beam. The color of this beam of light is blue for relatively thin lamellae, red for larger ones. The cameo (by Tiffany & Co.) is a rare example of carved red and blue labradorite. The line drawing is courtesy of the Mineralogical Record; the photo is by Chip Clark, reprinted by permission of Harry N. Abrams, Inc., courtesy of the Smithsonian Institution.



containing pervasive fluid inclusions (such as milky quartz), colorless microcrystals, microfractures, bubbles, and the like.

In some cases, a particular orientation of the scattering elements may produce special optical effects. If they are fibrous, the result is a "white adulescence" or silky sheen, as in gypsum ("satin spar" variety), some malachite, or pectolite. Chatoyancy or asterism arises when the scattering elements are sets of parallel fibers, tubes, or plate-

lets. These effects, beyond the scope of this article, do not affect color. However, for the sake of clarity and completeness, the various kinds of phenomena (in the gemological sense) have been grouped in table 3. With the exception of the alexandrite effect, which was discussed in part 1 of this series (Fritsch and Rossman, 1987), all gemstone phenomena can be understood as the interaction of visible light with particles in a particular size range. The size of the particle can be used as a basis



**TABLE 3.** Descriptions, causes, and examples of phenomena in gem materials and considerations they require in fashioning.<sup>a</sup>

Phenomenon	Description	Cause	Examples	Considerations in fashioning
<b>Iridescence Orient</b>	Interference colors on, or in, a stone, like those produced by a drop of oil on water	Interference of visible light rays, due to the presence of a thin film or thin structure in, or on, a material of different refractive index	Iris quartz, "ammolite," pearls	Thin film or structure oriented to the girdle plane
<b>Play-of-color Labrador-escence</b>	On a given spot, for a given illumination angle, only one pure spectral color is seen; rotating the stone changes the color	Diffraction of visible light by regularly layered structures <i>smaller</i> than the visible wavelengths	Opal, feldspar ("spectrolite")	Diffraction layers oriented parallel to the girdle plane
<b>Adularescence</b>	Floating bluish sheen in a stone	Scattering of visible light by randomly distributed structures <i>smaller</i> than visible wavelengths	Feldspar (moonstone)	No relation
<b>Chatoyancy ("cat's-eye") Asterism</b>	One or more lines of white light appearing on a curved surface (chatoyancy = one ray, like a cat's eye; asterism = several rays—up to 6—building a star)	Scattering of light by oriented parallel needle-like or plate-like inclusions or structures <i>larger</i> than visible wavelengths (chatoyancy = one set of inclusions or structures; asterism = multiple sets)	Chrysoberyl, corundum, quartz, diopside	Curved surface (not well focused on flat surface)
<b>Aventurescence</b>	Colored metallic-like spangles in the stone, especially obvious when the stone is rotated in reflected light	Reflection of light by <i>large</i> eye-visible plate-like inclusions	Aventurine quartz, feldspar (sunstone), goldstone glass	No relation
<b>Change-of-color ("Alexandrite effect")</b>	The stone changes color when the illumination is switched from sunlight or fluorescent light to incandescent light	A major absorption band around 550–600 nm cuts the visible range in two transmission windows: one at the blue end (dominating in daylight), the other at the red end (dominating in incandescent light)	Chrysoberyl (alexandrite), corundum, garnet, spinel, fluorite	Observed in all directions, better colors in some

<sup>a</sup>This table includes all terms used for phenomena in gem materials. It describes each of the phenomena and shows how similar some of them are and how others relate to one another almost in a continuum.

for classification. There is a continuum in the size of the particles between color-creating phenomena (such as adularescence) and phenomena that do not affect color (such as chatoyancy). This continuum is emphasized in table 3.

Some of these phenomena can be induced or enhanced by treatment—especially heat treatment. Basically, the heat precipitates a second phase in the matrix, which creates oriented inclusions, which in turn induce chatoyancy or asterism (Nassau, 1984).

**Presence of Colored Inclusions.** The last type of coloration encountered in gemstones is coloration caused by the body color of inclusions in a near-colorless host crystal. These inclusions can be extremely small, like the nickeliferous clays that color chrysoprase or the small hydrous iron oxide crystals that make carnelian orange (figure 11). Somewhat larger but still microscopic inclusions of hematite cause the color of red orthoclase from

Madagascar (Malagasy Republic) and some cordierites ("bloodshot iolite"). Fire opal is colored by submicroscopic inclusions of iron hydrous oxides (J. Koivula, pers. comm., 1988).

When the platelets are large enough to be distinguished with the naked eye (say, when they reach 1 mm), they can produce "aventurescence." This term is used to describe the reflective powder-like appearance of crystalline flakes disposed *a l'aventurra* (the term refers to a Murano glass—first made in Venice, Italy—in which copper platelets have been dispersed at random). In aventurine quartz, mica crystals colored green by chromium sparkle when the stone is tilted back and forth. "Sunstone" can be either native-copper-included labradorite (most commonly), or oligoclase containing red hematite spangles (again, see figure 1).

## SUMMARY AND CONCLUSION

In most gem materials, color is caused by selective absorption of light by different processes. In a few

instances, phenomenal colors are caused by the interaction of light with certain physical characteristics, such as inclusions, texture, or the structure of component materials.

Absorption processes in gemstones can be divided into four broad categories. First, absorption caused by dispersed metal ions explains how an isolated  $\text{Fe}^{2+}$  metal ion makes peridot green. Second, when certain ions come close enough together, oxygen-to-metal or metal-to-metal charge-transfer transitions are possible, like the  $\text{O}^{2-} \rightarrow \text{Fe}^{3+}$  charge transfer that causes the yellow of citrine, or the  $\text{Fe}^{2+} - \text{O} - \text{Fe}^{3+}$  intervalence charge transfer responsible for the blue in cordierite. Third, color centers represent an extremely varied class of often complex structures or defects that absorb light; for example, carbon vacancies associated with nitrogen aggregates cause an orangy yellow color in diamond. These first three categories give colors that are sometimes easily modified, removed, or enhanced by treatment, usually heat and/or irradiation. In our fourth category, band gaps provide colors that cannot be induced or modified by commercial treatment because they are directly related to the crystal structure of the gem and not to minor amounts of defects or small concentrations of impurities. They could, however, be modified by overriding color-generating processes, but there are no known examples of such a treatment used for gem materials.

It is important to keep in mind, however, that a single color in a given gem can have more than one cause. In emerald, for example, color can be due to  $\text{Cr}^{3+}$ ,  $\text{V}^{3+}$ , or both. Table 4 lists the origins of color in most currently available gem materials and illustrates the variety of potential origins for each. This listing refers only to known studies. Consequently, a common color for a given gem might be absent, because no one has yet investigated its cause, whereas the cause of a very unusual color might be known because it attracted the curiosity of researchers.

Ongoing research in a number of laboratories may lead to results that contradict former origin-of-color assignments. Usually this is because many of our earlier ideas were "educated guesses" that were never proven, but nevertheless were often repeated. This probably is also a consequence of the fact that the exploration of the origin of color in a gem material can be a long, difficult, and expensive process, especially when a color center is involved.



*Figure 11. This magnificent Turkoman bracelet was made in Central Asia in the 18th century. The carnelian is colored by inclusions of hydrous iron oxides. The precious metals owe their white or yellow coloration to preferential re-emission of some visible wavelengths. Photo © Nelly Bariand.*

The origin of color in gem materials is an increasingly important topic as more color-altering treatments are used. A detailed understanding of the origin of color in natural-color gems and the color-inducing processes involved in the various enhancement techniques is necessary to provide a better means of separating natural- from treated-color gem materials. Likewise, the origin of color in some synthetic materials may differ significantly from that in their natural counterparts, and therefore can also be used as a way of distinguishing these two groups.

As can be seen from our final table, conflicting hypotheses on some color varieties and the absence of documentation on others attest to the continued existence of substantial gaps in our understanding of color. In-depth research is still needed on some of the most critical gemological issues, such as treated colored diamonds and color stability. As new treatments are developed and new color varieties are discovered, the need for ongoing research in this area will continue for many years to come.



**TABLE 4.** Causes of color in most gem materials.<sup>a</sup>

Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference
<b>Actinolite</b>	Yellowish green to green (nephrite)	Fe <sup>2+</sup> in octahedral coordination	Burns, 1970		Green (demantoid)	Cr <sup>3+</sup> in octahedral coordination	Anderson, 1954–55; Stockton and Manson, 1983, 1984
	Green	Traces of Cr <sup>3+</sup>	Anderson, 1954–55		Yellow (topazolite) to black (melanite)	Various charge-transfer processes and dispersed ion absorption involving Fe and Ti	Dowty, 1971; Moore and White, 1971
<b>Almandine</b>	Red	Fe <sup>2+</sup> in distorted cubic coordination	Manning, 1967a				
<b>Amber</b>	Blue to green	Fluorescence under visible light in Dominican amber; blue is due to light (Rayleigh) scattering in Baltic amber	Schlee, 1984				
	Yellow to orange to red to brown	Charge-transfer processes in large organic molecules	Nassau, 1975a	<b>Anthophyllite and gedrite (ortho-amphiboles)</b>	Multicolor ("nuummite")	"Iridescence," likely diffraction	Appel and Jensen, 1987
<b>Amphibole group</b> (see actinolite, anthophyllite and gedrite, glaucophane, hornblende and pargasite, or tremolite)				<b>Apatite series</b>	Pink	F vacancy with a trapped electron	Marfunin, 1979b
					Dark blue	O <sup>2-</sup> → Mn <sup>5+</sup> charge transfer	Marfunin, 1979b
<b>Andalusite</b>	Green and brown, pleochroism	Fe <sup>2+</sup> - O - Ti <sup>4+</sup> charge transfer	Smith, 1977	<b>Apophyllite</b>	Green	V <sup>4+</sup> in distorted octahedral coordination	Rossmann, 1974a
	Dark green (viridine)	Mn <sup>3+</sup> in octahedral coordination	Smith et al., 1982				
<b>Andradite</b>	Multicolors	Diffraction	Hirai and Nakazawa, 1982; Koivula, 1987	<b>Axinite group</b>	Blue	V <sup>3+</sup> in octahedral coordination	Schmelzer, 1982
	Yellow-green	Fe <sup>3+</sup> in octahedral coordination	Manning, 1967b, 1972		Brown	Fe <sup>2+</sup>	Faye, 1972
				<b>Azurite</b>	Blue	Cu <sup>2+</sup> in elongated octahedral coordination	Marfunin, 1979a
				<b>Benitoite</b>	Blue	Fe <sup>2+</sup> - O - Ti <sup>4+</sup> charge transfer	Not fully proven: Burns, 1970
				<b>Beryl</b>	Dark blue (Maxixe and Maxixe-type)	CO <sub>3</sub> <sup>2-</sup> (Maxixe-type) and NO <sub>3</sub> <sup>-</sup> (Maxixe) color centers due to irradiation	Andersson, 1979
					Light blue (aquamarine)	Fe <sup>2+</sup> in the channels of the structure	Goldman et al., 1978
					Darker blue (aquamarine)	Fe <sup>2+</sup> - O - Fe <sup>3+</sup> intervalence charge transfer	Goldman et al., 1978
					Green: yellow + blue	O <sup>2-</sup> → Fe <sup>3+</sup> charge transfer and Fe <sup>2+</sup> in the channels	G. Rossmann, unpub. data
					Green (emerald) and light green ("mint beryl")	Cr <sup>3+</sup> and/or V <sup>3+</sup> in octahedral coordination	Wood and Nassau, 1968
					Yellow to orange (heliodor)	O <sup>2-</sup> → Fe <sup>3+</sup> charge transfer	Loeffler and Burns, 1976; Goldman et al., 1978
					Red	Mn <sup>3+</sup> in octahedral coordination	Shigley and Foord, 1984
					Pink (morganite)	Mn <sup>2+</sup> in octahedral coordination	Wood and Nassau, 1968
				<b>Calcite</b>	Pink	Co <sup>2+</sup>	Webster, 1983; Rossmann, 1988
				<b>Chalcedony</b>	Purple	Microscopic sugilite inclusions	Shigley et al., 1987
					Purple ("damsonite")	Color center similar to that found in amethyst	Shigley and Koivula, 1985
					Blue to greenish blue (chrysocolla quartz)	Microscopic to submicroscopic inclusions of chrysocolla	J. Koivula, pers. comm., 1988
					Green (chrysoprase)	Microscopic inclusions of nickeliferous clay-like material	A. Manceau, pers. comm., 1985

*This 1759-ct emerald from the collection of the Banco de la República in Bogotá, Colombia, owes its magnificent color to a small amount of Cr<sup>3+</sup> in octahedral coordination. Photo © Harold & Erica Van Pelt.*



<sup>a</sup>This list of the origin of color in gem materials is based on spectra or explicit discussions as they appear in the literature or have been communicated to the authors. One color can be due to a combination of processes, while visually similar colors can have a variety of different causes. Within each gem group or subgroup, colors are listed in the order of the spectrum, from violet through purple, blue, green, yellow, and orange to red, and then pink, brown, black, and white when relevant. Dyes and colored coatings can be used on many of these materials, but they are mentioned here only if they are the most common cause of color in a particular material.

Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference
	Orange to red (carnelian, jasper)	Submicroscopic to microscopic inclusions of hydrous Fe oxides	J. Koivula, pers. comm., 1988				
<b>Chrysoberyl</b>	Yellow	Fe <sup>3+</sup> in octahedral coordination	Loeffler and Burns, 1976				
	Color-change (alexandrite)	Cr <sup>3+</sup> in octahedral coordination	Farrell and Newham, 1965				
<b>Chrysocolla</b>	Blue	Cu <sup>2+</sup> in octahedral coordination	Lehmann, 1978				
<b>Clinozoisite</b>	Green (tawmawite)	Cr <sup>3+</sup> in octahedral coordination	Schmetzer, 1982				
<b>Conch "pearl" and shell</b>	Pink	Organic pigment from the carotenoid family	Délé-Dubois and Merlin, 1981				
<b>Copal</b> (same as amber)							
<b>Coral</b>	Blue ( <i>Heliopora caerulea</i> )	An organic pigment of the bilins family, helioporobilin	Fox et al., 1983				
	Red to pink	Organic pigments from the carotenoid family, at least for <i>Corallium rubrum</i>	Délé-Dubois and Merlin, 1981				
	Black	Various organic materials of unknown nature	Rolandi, 1981				
<b>Cordierite</b>	Violet to blue (iolite)	Fe <sup>2+</sup> -O-Fe <sup>3+</sup> charge transfer	Faye et al., 1968; Smith, 1977; Goldman et al., 1977				
	Red ("bloodshot iolite")	Hematite and/or lepidocrocite inclusions	Gübelin and Koivula, 1987				
<b>Corundum</b>	Purple	Fe <sup>2+</sup> -O-Ti <sup>4+</sup> charge transfer coexisting with Cr <sup>3+</sup> in octahedral coordination	Schmetzer and Bank, 1981			minor contributions of V <sup>3+</sup> and Fe <sup>3+</sup> in octahedral coordination	
	Blue	Fe <sup>2+</sup> -O-Ti <sup>4+</sup> charge transfer with influence of Fe <sup>2+</sup> → Fe <sup>3+</sup> charge transfer	Smith and Strens, 1976; Schmetzer, 1987		Pink	Cr <sup>3+</sup> in octahedral coordination	G. Rossman, unpub. data
	Green	Fe <sup>3+</sup> in octahedral coordination coexisting with Fe <sup>2+</sup> → Ti <sup>4+</sup> charge transfer, Ti <sup>3+</sup> and Cr <sup>3+</sup> in octahedral coordination	Schmetzer and Bank, 1981		Color-change	Cr <sup>3+</sup> and/or V <sup>3+</sup> in octahedral coordination in a particular range of concentration	Schmetzer et al., 1980
	Yellow	O <sup>2-</sup> → Fe <sup>3+</sup> charge transfer	Schmetzer et al., 1982; Nassau and Valente, 1987				
		Fe <sup>3+</sup> and Ti <sup>3+</sup>	Schmetzer and Bank, 1981	<b>Covellite</b>	Blue and orange, pleochroism	Band theory	Berry and Vaughan, 1985
		A variety of unstable color centers of unknown structure	Schiffmann, 1981; Schmetzer et al., 1982, 1983; Nassau and Valente, 1987	<b>Crocoite</b>	Yellow to red	O <sup>2-</sup> → Cr <sup>6+</sup> charge transfer	Loeffler and Burns, 1976; Abou-Eid, 1976
		Fe <sup>3+</sup> pairs	Ferguson and Fielding, 1971	<b>Cuprite</b>	Red	Band theory	G. Calas, pers. comm., 1984
	Orange to orange-brown	Cr <sup>3+</sup> in octahedral coordination and color centers; with a contribution of Fe <sup>3+</sup>	Schmetzer and Bank, 1981	<b>Diamond</b>	Purple, pink to red	In natural-color diamonds, attributed to a structural defect of unknown nature	Collins, 1982
	Orangy pink ("padparadscha")	Cr <sup>3+</sup> in octahedral coordination and color centers	Schmetzer and Bank, 1981			In treated pink diamonds, attributed to the N-V defect (a carbon vacancy trapped at an isolated nitrogen impurity)	Collins, 1982
		Cr <sup>4+</sup> in octahedral coordination due to Cr <sup>4+</sup> and Mg <sup>2+</sup> substituting for two Al <sup>3+</sup> in the crystal structure	Nassau, 1983		Blue	Band transitions caused by the presence of dispersed boron atoms	Collins, 1982
	Red (ruby)	Cr <sup>3+</sup> in octahedral coordination, with	Harder, 1969; Gübelin, 1975		Green	Generally GR1 center (neutral carbon vacancy), plus defects that absorb in the blue (e.g., N3)	Collins, 1982



This 32.50-ct "padparadscha" sapphire owes its beautiful color to a combination of Fe<sup>3+</sup> and Cr<sup>3+</sup>-related absorptions. Jewelry courtesy of Harry Winston, Inc.; photo © Harold & Erica Van Pelt.



Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference
	Yellow	More rarely, due to very strong green fluorescence under visible light ("green transmitter" effect) of the H3 and/or H4 defect (a carbon vacancy trapped at an aggregate of two or four nitrogen atoms)	Collins, 1982		Greenish yellow	Mn <sup>2+</sup> in octahedral coordination (rare)	Rossmann and Mattson, 1986
		Most commonly due to the N3 defect, an aggregate of three nitrogen atoms (color center) at a carbon vacancy	Collins, 1982; Lowther, 1984		Orange	Yellow + pink	See Dietrich, 1985
		More rarely, due to band transitions caused by the presence of isolated nitrogen atoms	Collins, 1982		Pink to red (rubellite)	Related to manganese, generally believed to be due to Mn <sup>3+</sup> in octahedral coordination, sometimes created by irradiation	Manning, 1973; De Camargo and Isotani, 1988
	Orange	Most commonly H3 center (a carbon vacancy trapped at an aggregate of two nitrogen atoms), in natural and treated orange diamonds	Cottrant and Calas, 1981	<b>Enstatite</b>	Brown	Fe <sup>2+</sup> → Ti <sup>4+</sup> charge transfer	Rossmann and Mattson, 1986
		More rarely, originating from a color center of unknown nature	Collins, 1982		Greenish brown	Fe <sup>2+</sup>	Rossmann, 1980
	Brown	Color center of unknown nature, with various other color centers adding orange, yellow, pink, or green	Collins, 1982		Green	Fe <sup>2+</sup> with minor Cr <sup>3+</sup>	Anderson, 1954–55
<b>Diopside</b>	Green (chrome diopside)	Cr <sup>3+</sup> in octahedral coordination;	Rossmann, 1980	<b>Epidote group</b> (see clinozoisite, epidote, piemontite, or zoisite)			
		V <sup>3+</sup> in octahedral coordination	Schmetzer, 1982	<b>Epidote</b>	Green and brown, pleochroism	Fe <sup>3+</sup> in distorted octahedral coordination	Burns, 1970
	Yellowish green	Fe <sup>2+</sup> in octahedral coordination	Burns, 1970	<b>Euclase</b>	Blue	Fe <sup>2+</sup> –O–Fe <sup>3+</sup> charge transfer	Mattson and Rossmann, 1987
<b>Diopase</b>	Green	Cu <sup>2+</sup> in octahedral coordination	Lehmann, 1978		Green	Cr <sup>3+</sup> in octahedral coordination	Anderson, 1954–55
<b>Dravite</b>	Green ("chrome tourmaline")	V <sup>3+</sup> generally with minor amounts of Cr <sup>3+</sup> , both in octahedral coordination	Schmetzer and Bank, 1979	<b>Feldspar group</b> (see labradorite, microcline, oligoclase, orthoclase, or plagioclase series)			
	Yellow to brown	Related to titanium; due to Fe <sup>2+</sup> –O–Ti <sup>4+</sup> charge transfer, with those low in iron yellow and those rich in iron brown	Smith, 1977; Rossmann, as cited in Dietrich, 1985	<b>Fluorite</b>	Violet	Mie scattering on calcium microcrystallites	Braithwaite et al., 1973; Lehmann, 1978
	Red	Fe <sup>3+</sup> pairs	Mattson and Rossmann, 1984		Blue	Y <sup>3+</sup> + F vacancy + 2 electrons	Bill and Calas, 1978
<b>Elbaite and liddicoatite</b>	Blue (indicolite)	Fe <sup>2+</sup> in octahedral coordination with possible influence of some iron-related charge-transfer processes	See Dietrich, 1985		"Emerald" green ("chrome fluorite")	Sm <sup>2+</sup>	Bill and Calas, 1978; Rossmann, 1981
	Green	Fe <sup>2+</sup> and Ti <sup>4+</sup> in octahedral coordination. The influence of various charge transfer processes involving iron is a distinct possibility	Mattson, as cited in Dietrich, 1985		Yellowish green	Color center containing Y and Ce associated with an F vacancy	Bill and Calas, 1978
	Yellow-green	Mn <sup>2+</sup> –O–Ti <sup>4+</sup> charge transfer	Rossmann and Mattson, 1986		Yellow	O <sub>2</sub> <sup>-</sup> color center = O <sub>2</sub> substituting for fluorite	Bill and Calas, 1978
					Pink	YO <sub>2</sub> color center (Y <sup>3+</sup> + O <sub>2</sub> <sup>2-</sup> )	Bill and Calas, 1978
					Color change	Y <sup>3+</sup> –associated color center and Sm <sup>2+</sup> , with minor influence of a Ce <sup>3+</sup> –associated color center	Bill and Calas, 1978; Schmetzer et al., 1980
				<b>Gahnite and "gahnospinel"</b>	Blue	Fe <sup>2+</sup> in tetrahedral coordination	Dickson and Smith, 1976
				<b>Garnet group</b> (see almandine, andradite, grossular, hydrogrossular group, pyrope, spessartine, or uvarovite; also rhodolite)			
				<b>Glass (natural)</b>	Yellowish green (moldavite, tektite)	Fe <sup>2+</sup> in octahedral coordination	Pye et al., 1984
					Brown	Fe <sup>3+</sup> in octahedral coordination	Pye et al., 1984
				<b>Glaucophane</b>	Blue	Fe <sup>2+</sup> –O–Fe <sup>3+</sup> charge transfer	Smith and Strens, 1976
				<b>Grossular</b>	Green (tsavorite)	V <sup>3+</sup> in octahedral coordination	Gübelin and Weibel, 1975
					Orange (hessonite)	Mn <sup>2+</sup> in distorted cubic coordination; Fe <sup>3+</sup>	Manning, 1970
				<b>Gypsum</b>	All (alabaster)	Color usually due to dyes exclusively, except for some brown staining due to hydrous iron oxides	Manson and Stockton, 1986
							J. Koivula, pers. comm., 1988
				<b>Hematite</b>	Gray in reflection, red in transmission	Fe <sup>3+</sup>	Bell et al., 1975
				<b>Hornblende and pargasite</b>	Green to brown	Fe <sup>2+</sup> in various sites	Rossmann, 1988
				<b>Howlite</b>	Blue	Dyes exclusively	

Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference
<b>Hydrogrossular group</b>	Green ("Transvaal jade")	Cr <sup>3+</sup> in octahedral coordination	Manning and Owens, 1977				
	Pink	Mn <sup>3+</sup> in octahedral coordination	Manning and Owens, 1977				
<b>Jadeite</b>	"Emerald" green (chrome jadeite)	Cr <sup>3+</sup> in octahedral coordination	Rossman, 1981				
	Yellowish green	Fe <sup>3+</sup> in octahedral coordination	Rossman, 1981				
<b>Kornerupine</b>	Violet ("lavender jadeite")	Fe <sup>2+</sup> -O-Fe <sup>3+</sup> charge transfer; synthetic is colored by Mn <sup>3+</sup>	Rossman, 1974b; Nassau and Shigley, 1987				
	Blue	Cr <sup>3+</sup> in octahedral coordination	Schmetzer, 1982				
<b>Kyanite</b>	Green	V <sup>3+</sup> in octahedral coordination	Schmetzer, 1982				
	Blue	Fe <sup>2+</sup> -O-Ti <sup>4+</sup> charge transfer, Fe <sup>2+</sup> -O-Fe <sup>3+</sup> charge transfer, Fe <sup>2+</sup> and Fe <sup>3+</sup> in octahedral coordination can all be involved; with contribution from Cr <sup>3+</sup> in octahedral coordination	Parkin et al., 1977; Bosshart et al., 1982				
<b>Labradorite</b>	Green	V <sup>3+</sup> in octahedral coordination; Fe <sup>3+</sup> in octahedral coordination	Schmetzer, 1982; G. Rossman, unpub. data				
	Color change	Cr <sup>3+</sup> in octahedral coordination	Bosshart et al., 1982				
	Multicolors	Diffraction of light by the internal lamellar structure	Ribbe, 1972; Lehmann, 1978				
<b>Lazulite</b>	Red (in the material from Oregon)	Submicroscopic metallic copper particles	Hofmeister and Rossman, 1985b				
	Green and orange-pink, pleochroism	Could be Cu <sup>+</sup> IVCT or Cu <sup>0</sup> pairs	Hofmeister and Rossman, 1985b				
<b>Lazurite</b>	Blue	Fe <sup>2+</sup> -O-Fe <sup>3+</sup> charge transfer	Arnthauer and Rossman, 1984				
<b>Lazurite</b>	Blue (lapis lazuli)	S <sub>3</sub> <sup>-</sup> (charge transfer)	Loeffler and Burns, 1978				
<b>Lepidolite</b>	Pink	Mn <sup>2+</sup> in octahedral coordination; Mn <sup>3+</sup> in octahedral coordination	Faye, 1968; Marfunin, 1979a				
<b>Liddicoatite</b> (see elbaite)							
<b>Malachite</b>	Green	Cu <sup>2+</sup> in octahedral coordination	Marfunin, 1979a				
<b>Maw-sit-sit</b> (rock)	Green	Cr <sup>3+</sup> in octahedral coordination in the kosmochlor	Khomenko and Platonov, 1985				
<b>Microcline</b>	Blue (amazonite)	Color center involving Po <sup>3+</sup> and structural water	Hofmeister and Rossman, 1985a				
<b>Nephrite</b> (see actinolite)							
<b>Oligoclase</b>	Blue (moonstone)	Rayleigh scattering of light by lamellar structure	Lehmann, 1978				
	Red (sunstone)	Red lepidocrocite or hematite platelets give the aventurescence	J. Koivula, pers. comm., 1988; Lehmann, 1978				
<b>Olivine group:</b>							
<b>Forsterite-fayalite series</b>	Yellowish green (peridot)	Fe <sup>2+</sup> in octahedral coordination	Loeffler and Burns, 1976				
	Green (peridot, the material from Hawaii)	Fe <sup>2+</sup> with minor amounts of Cr <sup>3+</sup> in octahedral coordination	Anderson, 1954-55				
<b>Opal</b>	Multicolors (play-of-color opal)	Diffraction by the regular stacking of silica spheres	Darragh and Sanders, 1965				
				Orange to red (fire opal)	Microscopic to submicroscopic inclusions of iron hydroxides	J. Koivula, pers. comm., 1988	
				Green (prase opal)	Microscopic to submicroscopic nickeliferous clay-like inclusions	Koivula and Fryer, 1984	
<b>Orthoclase</b>	Yellow	Fe <sup>3+</sup> in tetrahedral coordination	Hofmeister and Rossman, 1983				
	Pink to red	Microscopic hematite and/or lepidocrocite inclusions	Andersen, 1915; J. Koivula, pers. comm., 1988				
<b>Pearls (oyster)</b>							
<b>Body color</b>	All colors	Charge-transfer processes in traces of porphyrins and metalloporphyrins	Fox et al., 1983				
	Green	High proportions of metalloporphyrins, apparently involving lead and zinc	Fox et al., 1983				
	Pink	Less total porphyrin than green	Fox et al., 1983				
<b>Orient and overtone</b>	Pink and green usually	Interference colors	E. Fritsch, unpub. data				
<b>Pectolite</b>	Blue	Cu <sup>2+</sup> in octahedral coordination	Koivula, 1986a				
<b>Phosphophyllite</b>	Bluish green	Fe <sup>2+</sup>	G. Rossman, unpub. data				
<b>Piemontite</b>	Purplish red	Mn <sup>3+</sup> in octahedral coordination	Burns, 1970				


These freshwater baroque and round saltwater cultured pearls exhibit the delicate iridescent color (here mostly pink) that gemologists call orient. Photo © Harold & Erica Van Pelt.



Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference
<b>Plagioclase series</b>	Blue	Color center involving Pb and water	Hofmeister and Rossman, 1986		Smoky (smoky quartz)	Color center related to the Al <sup>3+</sup> impurity	Partlow and Cohen, 1986
	Yellow	Fe <sup>3+</sup> in tetrahedral coordination and Fe <sup>2+</sup> in octahedral coordination	Hofmeister and Rossman, 1983		Pink (rose quartz)	Charge transfer between a substitutional Ti <sup>4+</sup> and an interstitial Ti <sup>3+</sup> ; unstable color center O <sup>-</sup> ion bridging between substitutional aluminum and substitutional phosphorus atom; dumortierite inclusions	Cohen and Makar, 1985
<b>Pumpellyite</b>	Green (chlorastrolite)	Fe <sup>2+</sup> -O-Fe <sup>3+</sup> charge transfer plus Fe <sup>2+</sup>	G. Rossman, unpub. data		White (milky quartz)	Scattering of light by inclusions larger than the visible wavelengths	Maschmeyer and Lehmann, 1983
<b>Pyrope</b>	Brownish red	Fe <sup>2+</sup> in distorted cubic coordination	Manning, 1967a				
	Red	Fe <sup>2+</sup> in distorted cubic site plus Cr <sup>3+</sup> in octahedral coordination	Anderson, 1954-55; Manning, 1967a				Applin and Hicks, 1987
	Color change (in pyrope and pyrope-spessartine)	V <sup>3+</sup> and/or Cr <sup>3+</sup> in octahedral coordination	Schmetzer et al., 1980				Fritsch, 1985
<b>Pyrope-Almandine</b>	Reddish purple (rhodolite)	Fe <sup>2+</sup> in distorted cubic coordination	Manning, 1967a	<b>Rhodochrosite</b>	Pink to red	Mn <sup>2+</sup> in octahedral coordination	Rossman, 1988
<b>Pyroxene group</b> (see enstatite, diopside, jadeite, kosmochlor in maw-sit-sit, or spodumene)				<b>Rhodolite</b> (see pyrope-almandine)			
<b>Quartz</b>	Violet to purple (amethyst)	O <sup>2-</sup> →Fe <sup>4+</sup> charge transfer, due to irradiation	Cox, 1977	<b>Rhodonite</b>	Pink	Mn <sup>2+</sup> in octahedral coordination, with minor Fe <sup>2+</sup> ; Mn <sup>3+</sup> in octahedral coordination	Marshall and Runcinam, 1975
	Blue	Inclusions of blue dumortierite	C. Fryer, pers. comm., 1988				Gibbons et al., 1974
		Inclusions of tourmaline	Gübelin and Koivula, 1987	<b>Rutile</b>	Blue (synthetic rutile)	Band transition due to the presence of Ti <sup>3+</sup>	G. Rossman, unpub. data
		Inclusions of ilmenite of a diameter smaller than visible wavelengths	Zolensky et al., 1988	<b>Scapolite series</b>	Various colors	Due to color centers related to irradiation of Cl, CO <sub>3</sub> <sup>2-</sup> or SO <sub>4</sub> <sup>2-</sup> groups present in the large voids of the crystal structure	Marfunin, 1979b
	Green ("greened amethyst" or prasiolite)	Fe <sup>2+</sup>	Nassau, 1980	<b>Scheelite</b>	Yellow	Fe	Not proven: Gunawardene, 1986
	Green (aventurine quartz)	Chromian mica (fuchsite) inclusions	Lehmann, 1978	<b>Serpentine</b>	Green (williamsite)	Cr <sup>3+</sup> around chromite inclusions	J. Koivula, pers. comm., 1988
Greenish yellow	Color center	Nassau and Prescott, 1977	<b>Shattuckite</b>	Blue	Cu <sup>2+</sup>	Fleischer, 1987	
Yellow to orange (citrine)	O <sup>2-</sup> →Fe <sup>3+</sup> charge transfer	Balitsky and Balitskaya, 1986	<b>Shell</b>	Pink (see conch shell)			
	Various Al <sup>3+</sup> -related color centers	Samoilovich et al., 1969		Black	A violet organic pigment, haliotiavin, has been recovered from the shell of the black abalone, <i>Haliotis cracherodii</i>	Fox et al., 1983	
				<b>Sillimanite</b>	Blue	Fe <sup>2+</sup> -O-Ti <sup>4+</sup> charge transfer, probably similar to blue kyanite	Rossman et al., 1982
					Yellow	Fe <sup>3+</sup> or Cr <sup>3+</sup> in tetrahedral coordination	Rossman et al., 1982
					Brown	Fe features of yellow sillimanite plus inclusions of iron-rich phase	Rossman et al., 1982
				<b>Sinhalite</b>	Brown	O <sup>2-</sup> →Fe <sup>3+</sup> charge transfer and Fe <sup>2+</sup> in octahedral coordination	Farrell and Newnham, 1965
				<b>Smithsonite</b>	Blue-green	Cu <sup>2+</sup>	G. Rossman, unpub. data
					Pink	Co <sup>2+</sup>	G. Rossman, unpub. data
				<b>Sodalite</b>	Blue	Interstitial oxygen ion O <sup>-</sup> near Al or Si	Pizani et al., 1985
					Pink (hackmanite)	Unstable electron substituting for Cl <sup>-</sup> in a tetrahedron of Na <sup>+</sup> ions	Pizani et al., 1985

*Pink rhodochrosite and yellow willemite contrast in hue, although they are both colored by Mn<sup>2+</sup>. Different coordination of the Mn<sup>2+</sup> ion is the clue here: octahedral in rhodochrosite, tetrahedral in willemite. Photo by Robert Weldon.*



Gem material	Color (variety or trade name, if any)	Cause	Reference	Gem material	Color (variety or trade name, if any)	Cause	Reference	
<b>Spessartine</b>	Orange	Mn <sup>2+</sup> in distorted cubic coordination	Manning, 1967a					
<b>Sphalerite</b>	Yellow to black	Iron → sulfur charge transfer	Marfunin, 1979a					
	Green	Co <sup>2+</sup> in tetrahedral coordination	Marfunin, 1979a					
<b>Spinel group</b> (see gahnite and gahnospinel, or spinel)								
<b>Spinel</b>	Violet to purple	Cr <sup>3+</sup> in octahedral coordination and Fe <sup>2+</sup> in tetrahedral coordination	G. Rossman, unpub. data					
	Cobalt blue	Co <sup>2+</sup> and Fe <sup>2+</sup> in tetrahedral coordination	Shigley and Stockton, 1984					
	Bluish green	Fe <sup>3+</sup> and Fe <sup>2+</sup> in tetrahedral coordination	G. Rossman, unpub. data					
	Green (synthetic spinel)	Cr <sup>3+</sup> in octahedral coordination	Vogel, 1934					
	Pink to red	Cr <sup>3+</sup> in octahedral coordination	Vogel, 1934; Anderson, 1954–55; Sumin, 1950					
<b>Spodumene</b>	Purple to pink (kunzite)	Mn <sup>3+</sup> in tetrahedral coordination; Mn <sup>3+</sup> in octahedral coordination	Hassan and Labib, 1978; Cohen and Janezic, 1983					
	Emerald green (hiddenite)	Cr <sup>3+</sup> in octahedral coordination with also unstable Mn <sup>4+</sup> color center; V <sup>3+</sup> in octahedral coordination	Cohen and Janezic, 1983; Schmetzer, 1982					
	Paler green	Unstable Mn <sup>4+</sup> in octahedral coordination plus Fe <sup>2+</sup> → Fe <sup>3+</sup> charge transfer; Fe <sup>3+</sup> in octahedral coordination	Cohen and Janezic, 1983; E. Fritsch, unpub. data					
	Greenish yellow to brownish orange	Color center of unknown structure	Rossman and Qiu, 1982					
<b>Staurolite</b>	Brown	Fe <sup>2+</sup> in tetrahedral coordination	Burns, 1970					
	Blue	Co <sup>2+</sup> in tetrahedral coordination	Cech et al., 1981					
<b>Sugilite</b>	Purple	Mn <sup>3+</sup> and Fe <sup>3+</sup> , presumably in octahedral coordination	Shigley et al., 1987					
<b>Taaffeite</b>	Red to violet	Cr <sup>3+</sup> in octahedral coordination	Schmetzer, 1983					
<b>Titanite (sphene)</b>	Green	High Fe content	Mottana and Griffin, 1979					
	Green (chrome sphene)	Cr <sup>3+</sup> in octahedral coordination	Schmetzer, 1982					
	Pink	Mn <sup>2+</sup> in octahedral coordination, for certain Mn/Fe ratios, as well as pink carbonate inclusions	Mottana and Griffin, 1979					
<b>Topaz</b>	Blue	Color centers of unknown structure	Schmetzer, 1986					
	Green	Yellow and blue color centers	Petrov, 1977					
	Yellow	Color center of unknown nature	Petrov, 1977					
	Orange ("imperial topaz")	Yellow color center and Cr <sup>3+</sup> in octahedral coordination	Petrov, 1977					
	Pink	Cr <sup>3+</sup> in octahedral coordination	Petrov, 1977					
	Reddish brown ("sherry topaz")	Yellow and red color centers	Petrov, 1977					
<b>Tortoise shell</b>	Yellow to brown	Charge transfer in organic products	Nassau, 1975a					
<b>Tourmaline group</b> (see dravite, elbaite and liddicoatite, or uvite)								
<b>Tremolite</b>	Pink (hexagonite)	Mn <sup>3+</sup>	Hawthorne, 1981					
<b>Tugtupite</b>	Pink	Color center(s) involving sulphur	Povarennykh et al., 1971					
<b>Turquoise</b>	Blue	Cu <sup>2+</sup> in octahedral coordination	Diaz et al., 1971					
<b>Uvarovite</b>	Green	Cr <sup>3+</sup> in octahedral coordination	Manning, 1969; Calas, 1978					
<b>Uvite</b>	Green ("chrome tourmaline")	V <sup>3+</sup> generally with minor amounts of Cr <sup>3+</sup> , both in octahedral coordination	Schmetzer and Bank, 1979; Schmetzer, 1982					
<b>Variscite (and Metavariscite)</b>	Green	Cr <sup>3+</sup> presumably in octahedral coordination	Anderson, 1954–55; Koivula, 1986b					
	Green	Fe <sup>3+</sup> in octahedral coordination; with possible influence of Fe <sup>2+</sup> → Fe <sup>3+</sup> charge transfer	Manning, 1976, 1977					
<b>Vesuvianite (idocrase)</b>	Yellow	O <sup>2-</sup> → Fe <sup>2+</sup> charge transfer	Manning, 1977					
	Brown	Fe <sup>2+</sup> → Ti <sup>4+</sup> charge transfer	Manning, 1977					
	Yellow	Mn <sup>2+</sup> in tetrahedral coordination	G. Rossman, unpub. data					
<b>Willemite</b>	Yellow	Mn <sup>2+</sup> in tetrahedral coordination	G. Rossman, unpub. data					
<b>Wulfenite</b>	Blue	Mo <sup>4+</sup>	Embrey et al., 1977					
	Yellow to red	O <sup>2-</sup> → Cr <sup>6+</sup> charge transfer	Edson, 1980					
<b>Zircon</b>	Blue	U <sup>4+</sup>	Mackey et al., 1975					
	Red	Nb <sup>4+</sup> color centers	Fielding, 1970					
<b>Zoisite</b>	Blue (tanzanite—heat treated)	V <sup>4+</sup> in octahedral coordination; with V <sup>3+</sup> in octahedral coordination	Hurlbut, 1969; G. Rossman, unpub. data					
	Brown-violet	V <sup>3+</sup> in octahedral coordination (treatment turns blue, tanzanite)	Hurlbut, 1965					
	Green	Cr <sup>3+</sup> in octahedral coordination	Schmetzer, 1982					
	Pink (thulite)	Mn <sup>3+</sup> in presumably octahedral coordination	Marfunin, 1979a					

*Wulfenite is an intrinsically colorless mineral (left), but it commonly acquires an orange coloration when impurity chromium atoms produce O<sup>2-</sup> → Cr<sup>6+</sup> charge transfer (center bottom), which is the intrinsic cause of color in crocoite (right). In contrast, blue wulfenite (top) is said to get its color from Mo<sup>4+</sup>. Photo by Robert Weldon.*



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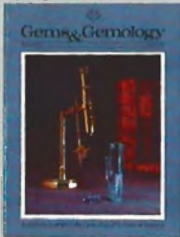
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## PASTEL PYROPEs

By Carol M. Stockton

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*Pyrope garnets occur in near-colorless to light orange and pink, as well as the familiar red. Because the pale-hued pyropes are unfamiliar to gemologists, their low refractive index usually results in their misidentification as grossular. This note clarifies the means by which these unusual garnets, predominantly from East Africa, can be properly and easily identified with a refractometer and a spectroscope.*

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The term *pyrope* comes from the Greek word *pyropos*, meaning "fiery-eyed," undoubtedly because of the intense red color for which these garnets are known. Therefore, most gemologists are surprised to learn that pure pyrope is completely colorless; its chemical formula,  $Mg_3Al_2Si_3O_{12}$ , contains no color-causing agents. The familiar red hue results from impurity ions of  $Fe^{2+}$  and/or  $Cr^{3+}$ . Pure pyrope is unknown in nature, but almost-pure, colorless material with up to 98 mol.% pyrope was recently found in the western Alps (Chopin, 1984). This material, however, is either too small or too fractured to be used as a gemstone. The same situation exists for high-

pyrope (70–77 mol.%) garnets from a number of localities worldwide (Deer et al., 1982), although none approaches the high content of the Alpine samples. Pale-colored, high-pyrope garnets from Arizona have been faceted as gems, but few cut stones exceed half a carat, so their gemological significance has been minor.

Once again, however, East Africa has introduced new gem-quality material: Low-iron, low-chromium pyrope (around 70 mol.%) occasionally turns up in parcels of grossular and malaia (pyrope-spessartine) garnet. Clean, faceted, pastel orange or pink stones can be obtained in 2- to 5-ct sizes.\* Because of their low refractive indices, such stones are often erroneously identified as grossular. However, pyrope (figure 1) and grossular garnets can be readily separated by a combination of R.I. and spectroscopy.

Pure grossular, which is also colorless, has a refractive index of 1.734, while the R.I. of pure pyrope is 1.714. Since the presence of coloring agents in either of these garnet types raises the refractive index, any pale-colored garnet with an R.I. below that of pure grossular is pyrope rather than grossular. Theoretically, of course, all sorts of chemical combinations could occur to contradict this conclusion, but no such material has yet been encountered among transparent gem-quality garnets.

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### ABOUT THE AUTHOR

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*Acknowledgments: The author wishes to thank Shabia Alimohammed of Tsavo Madini for bringing some of these unusual stones to her attention.*

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\*The largest pink pyrope that the author has seen to date was recently sent for identification to the GIA Gem Trade Laboratory in Los Angeles. The stone is a 63.06-ct pear shape (R.I. = 1.733); the large size resulted in a darker tone reminiscent of rhodolite garnet.



Figure 1. All four of the garnets pictured here are pyropes. The typical chrome pyrope at bottom left (GIA #13113, 1.08 ct) has a refractive index of 1.740. The orange pyrope (GIA #14400, 1.61 ct) has an R.I. of 1.732 and is colored by iron, and the pink pear shape (GIA #14002, 3.43 ct) is colored by a trace of chromium and has an R.I. of 1.740. The pale orange stone at the top (3.56 ct; courtesy of Tsavo Madini) has a 1.732 refractive index and contains manganese as its coloring agent. Photo © Tino Hammid.

In addition, the coloring agent in gem-quality orange grossular, or hessonite, garnet is  $\text{Fe}^{3+}$  (Manning, 1969, 1972; Moore and White, 1972; Manson and Stockton, 1982), whereas pale orange pyrope is colored by  $\text{Fe}^{2+}$  and/or  $\text{Mn}^{2+}$  (Stockton, 1987). This difference can be observed spectroscopically (Stockton and Manson, 1985).  $\text{Fe}^{3+}$  in grossular is associated with absorption bands at about 408 and 430 nm, but these are visible with a hand spectroscope only when the orange color is relatively intense or dark. Lighter orange or yellow grossulars show no visible spectrum under normal gemological testing conditions, although the 408 and 430 bands can often be detected with a laboratory spectrophotometer.  $\text{Fe}^{2+}$  in orange pyrope is related to absorption features at 504, 520, and 573 nm that can usually be observed with a hand spectroscope, unless the color is extremely pale.  $\text{Mn}^{2+}$  in orange (or any other color, for that matter) pyrope produces strong absorption in the

blue, with three bands at 410, 421, and 430 nm. In all cases, the lighter the stone is the weaker (and therefore more difficult to see) the absorption bands will be, and the closer the refractive index will be to that of the pure end member. Thus, on the basis of refractive index and spectrum, any low R.I., light-colored garnet can be identified as either pyrope or grossular. With an R.I. over 1.742, the presence of  $\text{Mn}^{2+}$  absorption lines denotes pyrope-spessartine (malaia) or pyrope-almandine, depending on the strength of these lines relative to that of other absorption bands present.

Pink pyrope owes its color essentially to the presence of trace amounts of chromium, associated with broad regions of absorption that generally cannot be resolved with a hand spectroscope. Small amounts of  $\text{Mn}^{2+}$  and/or  $\text{Fe}^{2+}$  are also present in these garnets, and the related spectral features are usually visible as weak bands. Pink grossular has been found in Mexico for about a





Figure 2. These two pink grossular crystals (12.07 and 18.35 ct) are from Xalostoc, Mexico. Their lack of spectral features distinguishes them from pink pyropes. Photo by Shane McClure.

century (DeLandro, 1891), but recent reports on the material are scarce (Prandl, 1966; Sinkankas, 1976). Although most of the rough is translucent to opaque, transparent material has occasionally been found and faceted. Refractive indices of 1.736 and 1.742 have been reported (Ford, 1915; Stockwell, 1927). Two crystals of this material (figure 2) were examined, and both had a 1.744 refractive index. Reported chemical analyses reveal only  $\text{Fe}^{3+}$ ,  $\text{Mn}^{2+}$ , and, in one case,  $\text{Ti}^{2+}$ , as potential coloring agents (DeLandro, 1891; Menzer, 1929; Prandl, 1966). Energy-dispersive X-ray fluorescence on the two stones in figure 2 confirmed these three impurities. However,  $\text{Fe}^{3+}$  imparts a yellow to orange hue to grossulars, while the effects of  $\text{Mn}^{2+}$  and  $\text{Ti}^{2+}$  have not been thoroughly investigated.  $\text{Cr}^{3+}$  and  $\text{V}^{3+}$  both produce green in grossu-

TABLE 1. Characteristic and distinguishing properties of colorless to light orange and pink garnets.

Species/ variety	Color <sup>a</sup>	R.I. range	Characteristic absorption bands (in nm)
Pyrope	Colorless to light orange and pink	1.714–1.742	None to one or more of 410, 421, 430, 504, 520, 573
Grossular	Colorless to light orange and pink	1.734–1.760	Usually none; orange may show weak 430 and even weaker 408
Pyrope- spessartine (incl. malaia)	Light orange and pink	1.742–1.780	Strong 410, 421, 430; weak 504, 520, 573
Pyrope- almandine (incl. rhodolite)	Pink	1.742–1.785	Strong 504, 520, 573; weak 410, 421, 430

<sup>a</sup>All these types of garnet occur in other hues, darker tones, and/or more saturated colors.

lars, so neither can be a significant trace constituent in the pink stones.

Further study is necessary to determine the cause of color in pink grossulars. In any event, the spectrum of pink grossular would not resemble the  $\text{Mn}^{2+}/\text{Fe}^{2+}$ -related spectrum of pink pyrope. Once a pink garnet has been identified as non-grossular on the basis of spectrum, a refractive index below 1.742 will identify it as pyrope rather than either pyrope-spessartine or pyrope-almandine. Table 1 summarizes the characteristic properties of the various types of light-colored garnets discussed above.

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## EXAMINATION OF THREE-PHASE INCLUSIONS IN COLORLESS, YELLOW, AND BLUE SAPPHIRES FROM SRI LANKA

By Karl Schmetzer and Olaf Medenbach

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*Three-phase inclusions in untreated natural colorless, yellow, and blue sapphires from Sri Lanka were found to consist of liquid and gaseous carbon dioxide as well as needle-like to tabular crystals of diaspore. The identification of diaspore was accomplished through the use of a microscope-mounted drill system and an improved version of the Gandolfi X-ray camera. Technical details for both methods are given. The conditions under which diaspore forms as a daughter mineral in corundum are briefly discussed.*

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Three-phase (solid, liquid, and gas) inclusions are commonly found in emeralds from certain localities, such as Muzo and Chivor in Colombia. Occasionally, similar three-phase inclusions are seen in other gem materials such as rubies and sapphires. For example, the *Photoatlas of Inclusions in Gemstones* (Gübelin and Koivula, 1986) provides two photographs of three-phase inclusions in blue sapphires from Sri Lanka. In both cases, the liquid and gaseous phases are described as CO<sub>2</sub>; but while the black solid phase in one example is identified as graphite (Gübelin and Koivula, 1986, p. 352), the transparent, needle-like mineral inclusions in the second (pp. 78–79) are not specified. Three-phase inclusions in natural pink and violet sapphires from Nepal were recently described by Kiefert and Schmetzer (1986, 1987). In samples from this new occurrence of gem-quality corundum, tabular flakes of doubly refracting mineral inclusions were determined to be the Ca-bearing mica, margarite, by X-ray powder diffraction and electron microprobe analysis. In one sample of yellow sapphire from Sri Lanka, small three-phase inclusions consisting of a transparent, doubly refractive tabular crystal, a liquid, and a gaseous substance were observed as well, but no exact determination of these phases could be performed at that time (Schmetzer, 1987).

To establish the identity of the transparent

solid phase in some of the three-phase inclusions in sapphire from Sri Lanka, the authors examined more than 300 samples of colorless, yellow, and blue sapphires from this area. In the past, a number of different techniques have been applied to the identification of individual daughter minerals in multiphase inclusions, for example, laser-excited Raman spectroscopy, scanning electron microscopy, and electron microprobe investigations, as well as Gandolfi X-ray techniques (e.g., Rosasco et al., 1975; Metzger et al., 1977; Rosasco and Roeder, 1979; Zolensky and Bodnar, 1982). If the inclusions are not exposed at the surface of the host crystal, laser-excited Raman spectroscopy is the only one of these techniques that is non-destructive, but the equipment required is not widely available.

The most comprehensive chemical and crystallographic information on daughter minerals in multiphase inclusions is obtained by a combination of SEM-EDS (Stockton and Manson, 1981), or an electron microprobe, with X-ray diffraction microtechniques. A key problem with any of these methods is the time-consuming procedure for selecting and preparing the small particles to be identified, and the possible loss of the minute daughter minerals when the sample is crushed. This problem can be avoided, however, by the use of a special microscope-mounted drill technique to open the cavities. In combination with X-ray diffraction using a modified Gandolfi camera, we successfully applied this technique to identify the transparent solid component of three-phase inclusions in colorless, blue, and yellow sapphires from Sri Lanka.

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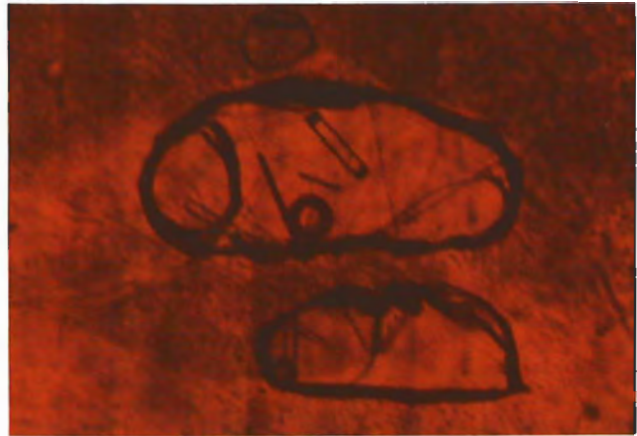


Figure 1. Three-phase—solid, liquid, and gas—inclusions are readily visible in this yellow sapphire from Sri Lanka. Note in the top two photos how the gaseous bubble is able to move about the crystal without restriction. With gentle heating in an immersion liquid, the gas bubbles gradually decreased in volume until they were totally homogenized (bottom right), at which point the temperature of the immersion liquid was measured in an attempt to verify the identity of the gas. The transparent, needle-like to tabular mineral inclusions are attached to the walls of the negative crystals. Magnified 65 $\times$ .

### DESCRIPTION OF THE THREE-PHASE INCLUSIONS

We observed two- and three-phase inclusions in approximately 20% of the more than 300 untreated colorless, light yellow, bluish, or blue sapphires from Sri Lanka that we examined. All of these inclusions were in the form of thin tabular negative crystals with the tabular face of the negative crystal parallel to the basal pinacoid (0001) of the corundum host. The tabular negative crystals were filled with liquid and generally contained one gaseous bubble, which was able to move around without any restriction within the negative crystals. In about 30% of the negative crystals, needle-like to tabular transparent mineral inclusions were observed (figure 1); examination with crossed polarizers showed that they were doubly refractive (figure 2). These mineral inclusions were attached to the walls of the negative crystals. In some cases, they lay diagonally across the entire cavity; in others, they projected into the

cavity and terminated inside the negative crystals (again, see figures 1 and 2).

**Identification of the Liquid and Gas Phases.** Two-phase inclusions in natural corundum from Sri Lanka have been described as consisting of liquid and gaseous CO<sub>2</sub> (Gübelin and Koivula, 1986; Koivula, 1986). We confirmed that the liquid and gaseous phases of the inclusions we examined were also CO<sub>2</sub> by measuring the homogenization and freezing temperatures of several inclusions.

First, the temperature of several crystals was slowly increased by gentle heating of the immersion liquid. During this process, a continuous decrease in the volume of the gas bubble was observed (again, see figure 1) and the temperature of the immersion liquid was measured exactly at the point of homogenization (figure 1, bottom). Within the limits of experimental error, the homogenization temperatures measured for the liquid and gaseous components of three-phase inclu-

sions in several crystals were found to be in the range of 28°–31°C, that is, below the critical temperature of CO<sub>2</sub> (31.2°C).

However, contrary to the assertion by Koivula (1986), we feel that homogenization temperatures of the liquid and gaseous components of two-phase inclusions are not sufficient to make a precise determination of the chemical nature of the material trapped in the corundum host crystals, since homogenization temperatures generally vary with the density and/or composition of the inclusions (cf. Roedder, 1972). Thus, determination of the temperatures at which the inclusions freeze is also necessary to characterize them accurately.\* For the material trapped in corundum from Sri Lanka, we recorded a freezing temperature of –56°C, which is close to the freezing temperature of carbon dioxide (–56.7°C). This confirms that the liquid and gaseous components of three-phase inclusions in corundum from Sri Lanka are almost pure carbon dioxide.

**Identification of the Solid Phase.** We identified the transparent needle-like to tabular solid components of the three-phase inclusions by X-ray diffraction using an improved Gandolfi camera. For this part of the study, we selected three samples that contained numerous typical needle-like daughter crystal inclusions. Each sapphire was then sawed to position a cavity with three-phase inclusions just below the surface. After polishing the face, we carefully opened one cavity in each sapphire using a special microscope-mounted drill system.

The drill system used here is based on a suggestion by Verschure (1978) and was originally developed to isolate small single crystals from thin sections. A similar procedure using a dental microdrill to open cavities with daughter minerals has also been described by Graziani (1983). The instrument we used adapts a diamond microdrill to the objective of a polarizing microscope (figure 3). Progressive manual adjustment of the stage height produces a cylindrical sample no more than 50 μm in diameter, with a height corresponding to the thickness of the section drilled through, that can be picked out with a needle. The drilling process can be supervised optically through a planar glass

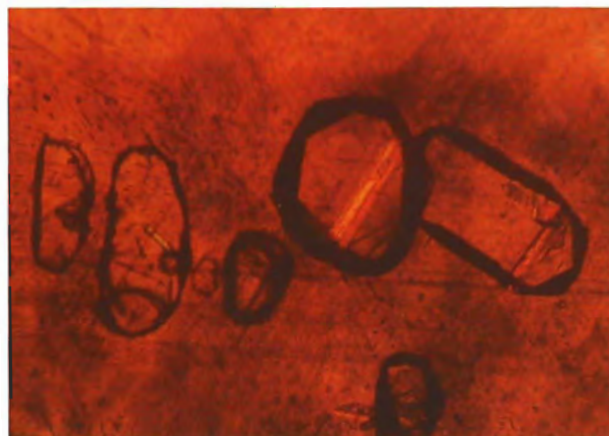


Figure 2. When these three-phase inclusions in yellow sapphire from Sri Lanka were viewed with crossed polarizers, the needle-like mineral phase was found to be doubly refractive. Magnified 30×.

cover, and the H<sub>2</sub>O coolant for the drill also provides a satisfactory immersion medium. Samples obtained in this manner (either attached to the core or picked out of the cavity) are ideally suited for optical study (e.g., on a spindle stage) or single-crystal X-ray investigations. This system may also be used to isolate homogeneous parts of larger, chemically zoned crystals for further study after electron microprobe analysis of the same section (see Medenbach, 1986; Graziani, 1983).

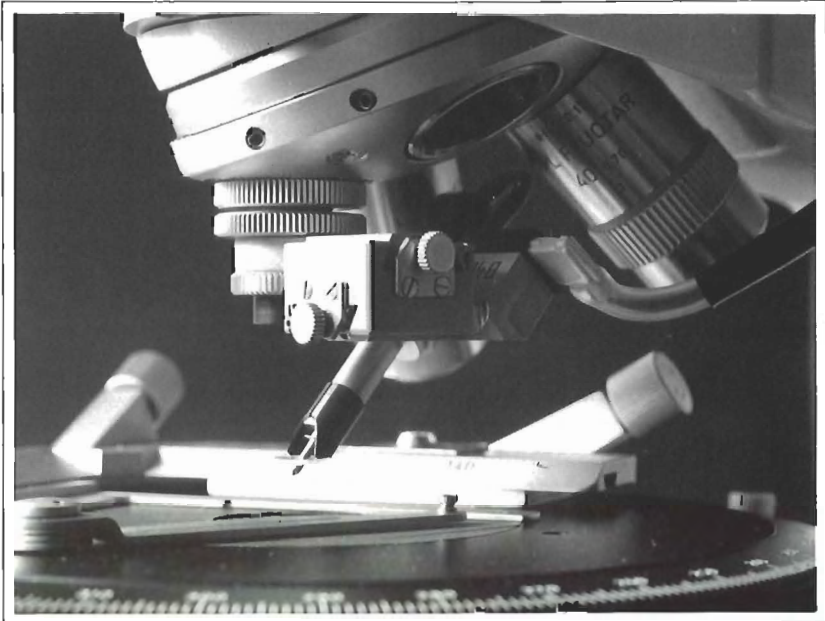
In the present study, after the microdrill was used to open inclusion cavities near the surface of each sapphire, several of the small daughter crystals were carefully selected and mounted onto a glass fiber for X-ray powder diffraction analysis by means of a Gandolfi camera. The Gandolfi camera is generally applied to X-ray microparticle phase analysis if the materials to be identified are not to be powdered (Gandolfi, 1964, 1967). In the present case, as in most of these cases, only very small amounts of the single crystals or polycrystalline aggregates were available.

To obtain good powder-type diffraction patterns, the operator must place the sample to be X-rayed at the precise intersection of two independent rotation axes, that is, the conventional Debye-Scherrer axis and the Gandolfi axis, which is inclined 45° to the former. While sample adjustment was difficult and time-consuming with the original Gandolfi camera, modified Gandolfi cameras as well as additional centering devices have been developed (Nuffield, 1975; Grüttner et al.,

\*Editor's note: This procedure is potentially destructive and should not be attempted as a routine gemological test.



*Figure 3. The solid phase of the three-phase inclusions was isolated by means of this microdrill adapted to a polarizing microscope.*



1978; De Bruijn et al., 1984). Another solution to the adjustment problem is presented by Sussieck-Fornefeld and Schmetzer (1987). The basic principle is the introduction into a modified camera of a complete goniometer head as sample holder instead of a simple glass fiber. The adjustment is accomplished by use of an inner thread for crystal translation parallel to the Gandolfi axis in addition to the two perpendicular sets of arcs and slides of the conventional goniometer head. The camera adjustment system enables three perpendicular translations and two perpendicular rotations, and thus the precise adjustment of the crystal at the intersection point of the two rotation axes.

As a result, good-quality powder diffraction patterns of the daughter crystals in the three-phase inclusions were obtained and subsequently matched to JCPDS file number 5-355—diaspore,  $\alpha$ -AlOOH. Because the pattern was definitive, a planned follow-up chemical analysis by electron microprobe was deemed unnecessary.

#### **DISCUSSION: THE FORMATION OF DIASPORE IN CORUNDUM FROM SRI LANKA**

Although most gem-quality corundum and other gem minerals from Sri Lanka originate from secondary deposits, research has been undertaken to characterize the primary sources of these gem

minerals (e.g., Katz, 1971, 1972; Dahanayake, 1980; Dahanayake et al., 1980; Munasinghe and Dissanayake, 1981; Dahanayake and Ranasinghe, 1981, 1985; Katz, 1986). Corundum is found in sillimanite-bearing high-grade metamorphic rocks, which were formed under pressure/temperature (PT) conditions characteristic of pyroxene granulite facies. During the formation of corundum under these PT conditions—that is, at high pressure with decreasing temperatures in the system  $\text{Al}_2\text{O}_3\text{-H}_2\text{O}$  (see Deer et al., 1962)—diaspore becomes the stable mineral phase instead of corundum. At lower pressures, böhmite,  $\alpha$ -AlOOH, becomes stable instead of corundum. The formation of böhmite within cavities or negative crystals in one sample of corundum from Sri Lanka is described by Sahama et al. (1973). In the experience of the present authors, however, the AlOOH polymorph diaspore is more abundant in three-phase inclusions in corundum from this locality. Similar-appearing daughter minerals have been described in three-phase inclusions in corundum from Malawi (Grubessi and Marcon, 1986), but were reported as probably being rutile. Further examination should be done to confirm their identity before diaspore can be considered an identifying characteristic of the Sri Lankan origin of sapphire.

The presence of this particular type of three-

phase inclusion in corundum from Sri Lanka also proves that the stone has not been heat treated; as described by Koivula (1986), the CO<sub>2</sub> would respond dramatically to such high temperatures.

Moreover, since diaspore becomes unstable at temperatures over 600°C, it is possible (although not yet proved) that this daughter mineral would also be affected.

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# Gem Trade LAB NOTES

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### Star (or Cat's-Eye?) ALMANDITE GARNET

Although star garnet is not especially rare, the East Coast laboratory recently encountered one that was different from most others we have seen. Figure 1 shows the 2.52-ct stone that was identified as almandite from the typical properties obtained by standard gemological testing procedures. The difference is that one arm of the star is so weak that the stone almost has the appearance of a cat's-eye. A garnet such as this would be a welcome addition to any collection of phenomenal stones.

Clayton Welch

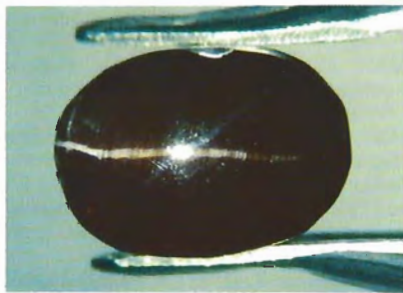


Figure 1. One leg of this 2.52-ct star almandite garnet is so weak that the stone appears to be a cat's-eye. Magnified 10 $\times$ .

### DIAMOND

#### Grayish Purple

In our experience, truly purple diamonds are very rare. A short time ago the East Coast laboratory tested the 0.21-ct grayish purple stone shown in figure 2. The natural color appears to be the result of grayish purple grain-

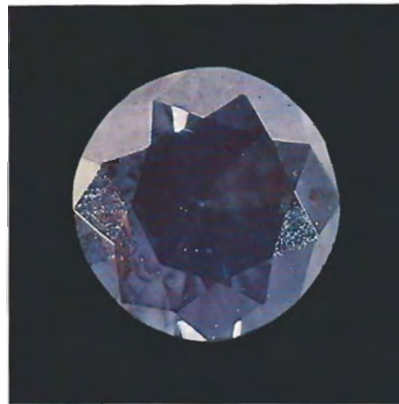


Figure 2. The natural grayish purple color of this 0.21-ct diamond appears to be caused by graining.

ing in the stone. Also present was the 550-nm absorption band typical of natural-color pink and purple diamonds. The diamond displayed a strong yellow fluorescence to long-wave ultraviolet radiation.

David Hargett

#### Saint Valentine's Inclusion

One of our New York clients was handling a 13.08-ct marquise-shaped diamond just in time for a sale as a St. Valentine's day present. On closer examination, he was delighted to find that the diamond contained a heart-shaped inclusion (figure 3).

One of the advantages of inclusions is that they can provide proof of a stone's identity and ownership. How much better it is when the inclusion is as unusual, attractive, and appropriate as this one.

Clayton Welch

#### Treated Pink

According to some of the people who color enhance diamonds commercially, pink in a treated stone is usually an accident of the treatment process. In most of these rare cases, the treater is trying for a fancy yellow color when, for some unknown reason, the stone turns pink instead.

Fourteen pink diamonds, ranging from 1.5 mm to 4.0 mm in diameter, were recently seen in our East Coast laboratory. They had been represented to our client as natural-color pink diamonds from Australia. However, the 575-nm fluorescent line and 594-nm and 637-nm absorption lines proved that the color was the result of treatment. Further proof was provided by additional lines in the red area of the spectrum, at approximately 620 and 630 nm, that are typical of treatment.

These treated stones are color zoned yellow and pink. The zoning appears to be related to a zoned fluorescence that is also evident when the stones are exposed to long-

Figure 3. At 45 $\times$  magnification, this heart-shaped inclusion is readily visible in the 13.08-ct host diamond.

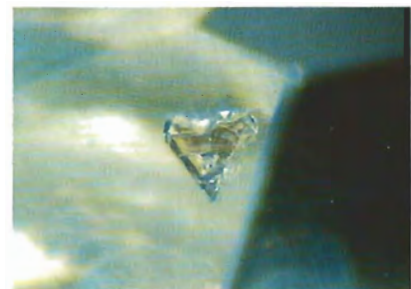




Figure 4. Pink and yellow zoning is evident in this 0.12-ct treated pink diamond. Magnified 20 $\times$ .

wave ultraviolet radiation. The zoning in the 0.12-ct stone shown in figure 4 displays a dramatic yellow and pink cruciform pattern. It has been our experience that treated pink diamonds invariably fluoresce orange to long-wave U.V. radiation.

David Hargett

#### Biron Synthetic EMERALD

The West Coast laboratory received a Biron synthetic emerald for identification that displayed higher refractive indices (1.570–1.578) and birefringence (0.008) than we had previously observed. The Fall 1985 issue of *Gems & Gemology* (pp. 156–170) reported on the extensive examination of 202 samples of Biron synthetic emerald. Those stones all showed R.I.'s of 1.569 to 1.573 or 1.574, with a corresponding birefringence of 0.004 or 0.005. Although higher refractive indices ranging up to 1.570–1.577, with a birefringence of 0.007, had been reported in the literature by others, this is the first such stone we have examined. The inclusions and other gemological

*Editor's Note: The initials at the end of each item identify the contributing editor who provided that item.*

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properties of this stone are the same as those described for Biron synthetic emeralds in the 1985 article.

These refractive indices and birefringence may be the result of minor differences in chemical composition caused by slight changes that are occasionally made in the manufacturing process. Studies of natural beryls have shown that both the filling of structural voids and the substitution of Cr, Fe<sup>3+</sup>, Fe<sup>2+</sup>, Mg, Li, other ions, and water molecules appear to be the major cause of variations in the refractive indices and specific gravity. These same properties in hydrothermal synthetic emeralds are also dependent on the nature, and amount, of impurity ions and molecules the synthetic products contain.

RK

#### Unusual GLASS

The 12.38-ct opaque black modified round brilliant shown in figure 5 recently provided the staff of the East Coast laboratory with an interesting identification problem. This stone had an almost metallic luster and an indistinct red/green blink to the refractive indices of 1.59 and a very low 1.35. Further testing revealed a specific gravity of 3.21, a Mohs hardness of approximately 4 to 5, vitreous conchoidal fractures, and no reaction to either the hot point or dilute HCl acid. The stone was warm to the touch when compared to a known crystalline sample of similar size at the same temperature.

The test results suggested glass, except for the red/green blink, even though the latter looked unusual when compared to the typical carbonate blink. We discovered that we could not go from the high R.I. reading to the low one by simply rotating the stone as is usually done.

Conclusive proof was provided by high magnification (approximately 100 $\times$ ), which revealed a shallow ring of bubbles at the girdle. This stone seems to have been cut from a glass preform or cylinder. We suspect that the unusual appearance

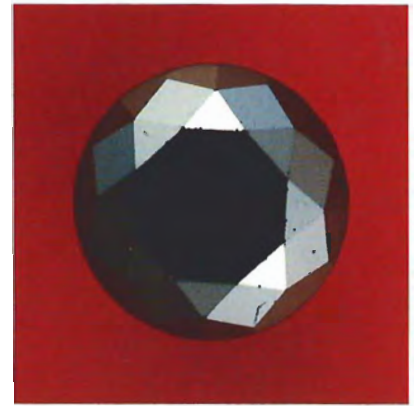


Figure 5. This 12.38-ct opaque black round brilliant cut proved to be glass, although there appeared to be a red/green blink when the R.I. was measured.

and strange optical characteristics are probably due to a high opacifier content and the tarnishing of this substance. The cause of the apparent blink remains a mystery.

Clayton Welch

#### JADEITE JADE

##### Pendant

A fine jadeite piece was recently examined at the West Coast laboratory (figure 6). This pendant, of yellow and white metal, is set with 18 small brilliant-cut diamonds around a green hololith (27.1 mm in outside diameter). The hololith has been cemented into the brightly polished yellow metal closed-back bezel mounting.

The hololith, which was estimated to be approximately 1 mm thick, was proved to be jadeite by the refractive index of 1.66 and the characteristic 437-nm absorption line. Although the jadeite was inert when exposed to ultraviolet radiation, the glue around the edges of the hololith fluoresced a strong chalky yellow to long-wave, and a weaker chalky yellow to short-wave, U.V.

The most interesting feature of this jadeite is the strong contrast between the green and white por-





Figure 6. This natural-color jadeite jade hololith (27.1 mm in outside diameter) displays an unusually strong contrast between the green and white areas.

tions of this variegated piece. Microscopic examination revealed a fine crystalline structure, with an almost fibrous appearance to the green portion. To a gemologist not familiar with this type of jadeite, this appearance could be mistaken for dye concentrations; however, the prominent chromium lines in the red area of the absorption spectrum easily prove that the color is of natural origin.

RK

#### Teapot

The West Coast laboratory also recently examined the magnificent "white" jadeite jade teapot shown in figure 7. The entire piece measures

19 cm long × 10 cm wide × 12 cm high (with the lid). The thickness of the domed portion of the delicate and beautifully carved lid ranges from 0.3 mm to 2.7 mm. We could not measure the thickness of the center portion of the teapot, but we estimated that it ranges from approximately 2 mm to 4 mm. Some areas, such as the carved ridges and portions of the spout, are, of course, much thicker.

The identity of the carving as jadeite was based on the standard gemological properties for this gem material: R.I. of 1.66, an aggregate reaction in the polariscope, specific gravity estimated with heavy liquids

at 3.34, and a fairly strong 437-nm line in the absorption spectrum. A patchy, very dull yellowish green fluorescence of weak intensity was observed in the white areas when the piece was exposed to long-wave ultraviolet radiation. The colorless areas were inert.

This exquisitely carved teapot is strongly mottled with translucent to opaque white areas and transparent to semitransparent colorless portions; there are also a few small areas of pale green. The presence of relatively large areas that are both transparent and colorless is another highly unusual feature of this piece (figure 8).

RK

## PEARLS

### Imitation

The East Coast laboratory recently had the opportunity to examine the earrings shown in figure 9. The drop-shape "pearls" (approximately 10 × 14 mm) proved to be a glass imitation with *essence d'orient* coating. However, the smaller pearls were of natural origin. The style and quality of manufacture of the earrings strongly suggest that the imitations were probably replacements.

Just when this type of imitation pearl (solid glass with *essence d'orient*) supplanted the older wax-filled type is not known. If the earrings were made in Edwardian times (late 1800s to early 1900s) as the style suggests, would these imitations have been the wax-filled type? Max Bauer, writing in 1896, did not mention essence-coated solid glass beads in the imitation-pearl section of his great book *Precious Stones*. He does mention, however, that the hollow glass types were made in many shapes, including spherical, oval, pear shape, and even baroque. RC

### A Rare Cultured Pearl

Another mystery encountered in the East Coast laboratory is shown in figure 10, a routine X-radiograph of an unusually fine necklace of uni-



Figure 7. This teapot is beautifully carved out of highly translucent white jadeite jade. The piece measures 19 × 10 × 12 cm high, including the lid.

Figure 8. The lid of the jadeite jade teapot is almost transparent.



form-size 9-mm cultured pearls. The mystery is the single light-toned sphere that appears in the upper left of the X-radiograph. Unlike the other cultured pearls, this one did not fluoresce to X-rays in a dark room. A pin inserted through the drill hole established that the core was soft; in addition, a small bit of the core melted under low heat. The surface of this bead was clearly nacreous, with the same structure as the other cultured pearls in the necklace.

Although we have encountered spherical cultured pearls with plastic nuclei in the lab, we had not previously seen any with wax cores. One possible deterrent to using either plastic or wax as a nucleus is the low specific gravity of these materials, which contributes to necklaces with the "wrong heft." They just feel too light for their size.

RC





Figure 9. The two small pearls at the top of these earrings are natural, but the larger drops (approximately 10 × 14 mm) proved to be imitations made of solid glass coated with essence d'orient.

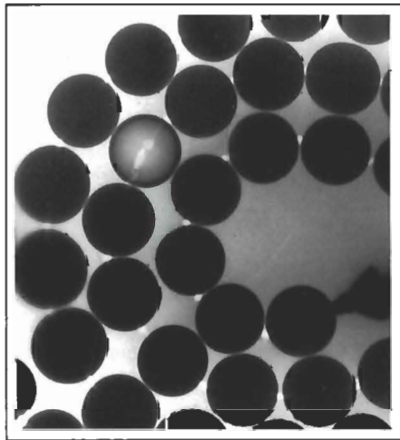


Figure 10. The unusual wax nucleus of the 9-mm cultured pearl in the upper left of this X-radiograph is responsible for the light center.

### PLASTIC Costume Jewelry

The West Coast laboratory received a round yellow metal earring with a center segment of highly reflective

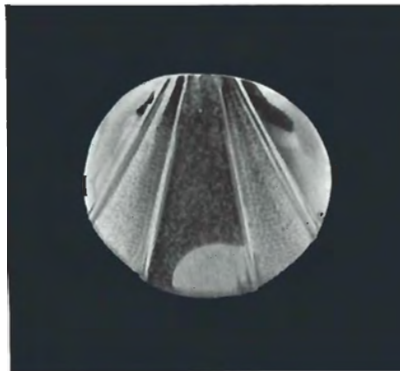
tinsel-like flakes embedded in a transparent colorless material, which was purported to contain diamond. As shown in figure 11, part of the center section had broken off, which exposed the metal backing. We were asked to determine if there was indeed any evidence of diamond in the colorless material. Permission was granted to perform any destructive tests that might be necessary.

Examination under the microscope revealed that the tinsel-like particles are rectangular in shape, very thin, and quite transparent in transmitted light. X-ray diffraction of one of these platelets resulted in an amorphous pattern, which proved that they are not diamond.

Numerous gas bubbles were visible in the surrounding material (figure 12), which was very soft and could be indented easily by the pin-point end of a brushprobe. Application of the thermal reaction tester probe (a hot point) produced the acrid odor that is characteristic of some plastic.

To determine if any diamond powder was present in this plastic material, we dissolved a portion in sulfuric acid. No residue resulted from this solution process. As an additional test, another portion of the material was melted and vaporized. Again, there was no evidence of any residue. The conclusion reached

Figure 11. A search for evidence of diamond in the decorative material on this earring revealed only plastic on the metal backing.



was that this plastic material shows no evidence of containing any diamond. KH

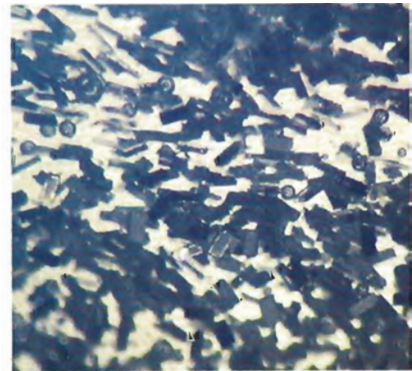
### Black PYROPE GARNET

One of our friends of the West Coast laboratory submitted several small faceted and cabochon stones that he had cut from rough material represented to him as black pyrope. Figure 13 shows a small cabochon as it appears in reflected light. The stones were submitted to us for testing to see if they really were black pyrope.

The single refractive index was 1.740 and the specific gravity was determined to be 3.72 by the heavy liquid method; both of these properties are consistent with pyrope. The absorption spectrum showed a general absorption up to about 480 nm and again above 620 nm.

Examination by transmitted light revealed that the color is actually a dark brown. With magnification (figure 14), we observed numerous black ilmenite inclusions, which contributed to the black color apparent when the stones were viewed by reflected light. X-ray diffraction confirmed that the material is indeed pyrope, with perhaps just a little admixture of andradite indicated by the line spacing in the diffraction pattern. CF

Figure 12. Gas bubbles in the decorative material on the earring shown in figure 11 proved that it was man-made. Magnified 30×.



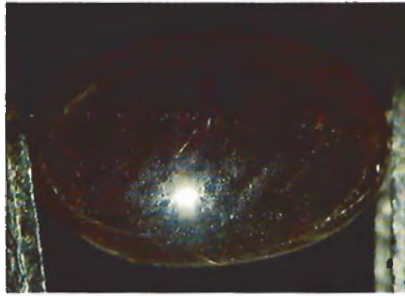


Figure 13. In reflected light, this pyrope cabochon appears to be almost black.



Figure 14. When the stone shown in figure 13 is viewed with transmitted light and at 10x magnification, both the actual brown color and the ilmenite inclusions that make the stone look black in reflected light are evident.



Figure 15. Plato lines characteristic of synthetic yellow sapphire were visible in this 6.93-ct stone even without magnification (shown here at 10x for clarity).

### Synthetic SAPPHIRES

In the Lab Notes section of the Summer 1987 issue of *Gems & Gemology*, we reported on unusually strong curved color banding in a synthetic yellow sapphire. More recently, the East Coast laboratory had the opportunity to examine two synthetic yellow sapphires that were unusual in other ways.

When no color zoning or inclusions are present in a yellow sapphire, it is standard procedure to use immersion, magnification, and crossed polarizers to look for Plato lines as proof of synthesis. One of the two stones we examined displayed such strong Plato lines that they were actually visible without magnification or immersion (figure 15). In contrast, the second stone showed no discernable Plato lines at all, which is unusual for a flame-fusion synthetic yellow sapphire. This stone was proved to be synthetic when high magnification revealed the presence of several small gas bubbles.

An interesting blue synthetic sapphire, also examined in New York, showed two sets of curved color banding that intersected each other at a very shallow angle. This is clearly indicated in figure 16 by the wedge of blue with its point almost dead center in the photo. The wedge marks the boundary between the two sets of banding, which are probably a result of changes in the growth conditions while the boule was being formed.

Clayton Welch

### Brecciated TIGER'S-EYE QUARTZ

The West Coast laboratory recently received for identification two interesting pieces of brecciated (i.e., containing angular fragments naturally cemented together into one mass) tiger's-eye quartz. Our client had obtained the samples from a deposit in South Africa. The polished slab shown in figure 17 (8.2 cm long x 3.4 mm thick) illustrates quite well the



Figure 16. Two sets of curved color bands intersect in the wedge-shaped area at the center of this synthetic blue sapphire (7.5 x 5.0 x 3.1 mm). Magnified 10x.

Figure 17. This 8.2 cm x 3.4 mm polished slab is a good example of brecciated tiger's-eye quartz.







Figure 18. In this rough piece (5.4 cm at its largest dimension), the components of this material are evident in a 1-cm-deep cavity lined with drusy quartz on the left, brecciated tiger's-eye quartz in the center, and unaltered blue crocidolite on the right.

brecciated nature of this material. Most areas are the typical brownish yellow to brown color of tiger's-eye, while some are reddish brown and a few portions are distinctly gray-blue. In several places on the top and bottom of the slab, a few small cavi-

ties lined with tiny, well-formed, colorless quartz crystals are evident.

Tiger's-eye is the variety of quartz in which quartz has replaced crocidolite (an asbestos variety of the amphibole mineral riebeckite) without disturbing the fibrous structure

of the original mineral. Figure 18 shows an excellent example of this interesting mineralogic relationship. The left side of this specimen (5.4 cm at its largest dimension) has a 1-cm-deep cavity lined with drusy quartz, the center is the brecciated tiger's-eye, and on the right is some of the unaltered blue crocidolite.

The material displayed the geological properties expected of tiger's-eye. X-ray diffraction showed a quartz pattern, with one extraneous line. This material appears to be very similar to a sample illustrated on page 90 of an article by Robert Webster titled "Pseudocrocidolite," published in the *Journal of Gemmology*, Vol. 11, No. 3, July 1968. Webster reported at that time that the material had been marketed under the name "Pietersite." RK

#### FIGURE CREDITS

Figures 1, 3, 5, 9, 15, and 16 were supplied by Clayton Welch. Dave Hargett took photos 2 and 4. Shane McClure is responsible for figures 7, 8, 17, and 18. Figure 6 is © Harold and Erica Van Pelt. The X-radiograph in figure 10 was taken by Tom Moses. Karin Hurwit took the photos in figures 11 and 12. Figures 13 and 14 came from John Koivula. Sotheby-Parke-Bernet supplied the photo of the original pink diamond used in the "Historical Note"; Andrew Quinlan took the photo of the "painted" stone.

## A HISTORICAL NOTE

### Highlights from the Gem Trade Lab 25, 15, and five years ago

#### SUMMER 1963

One of the most unusual items encountered 25 years ago in the New York lab was petrified dinosaur bone. The material is believed to occur in several localities in the western United States. The stones examined had a mosaic structure of reddish to yellowish chalcedony replacing part of the bone, with the balance of the material intact as calcium carbo-

nate. Other examples previously seen had the bone completely replaced with chalcedony.

The Los Angeles lab encountered a number of unusual collector stones in this same time period. Notable among those mentioned were a 4.5-ct emerald-cut benitoite and an unusual colorless benitoite. Others of interest were faceted lazulite, blue apatite, chrome green sphene, and

transparent faceted rhodochrosite, tremolite, and yellow zoisite.

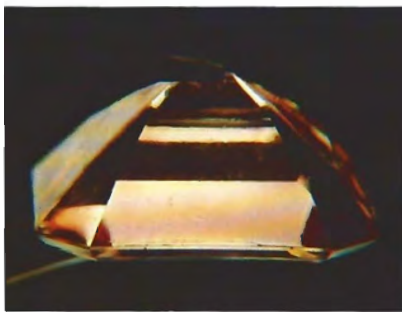
#### SUMMER 1973

The highlight of the Summer 1973 GTLN column from Los Angeles was the identification of the very rare material jeremejevite. A 1.52-ct long slender emerald cut was submitted



*This 9.58-ct fancy pink diamond was stolen from Sotheby's in New York.*

for identification. Prior to this, jermeyevite was known only as particles the size of sugar granules from the USSR. This material has the



*This 10.88-ct light yellow diamond was coated with pink nail polish and substituted for the stone shown at left.*

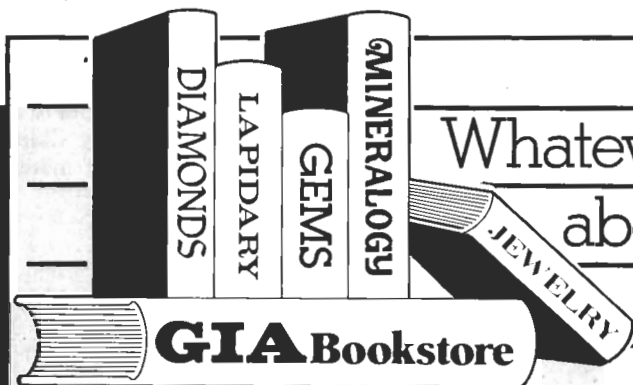
unusual property that some parts of a single crystal are uniaxial while others are biaxial. Other properties include refractive indices of 1.639–1.648 and a specific gravity of 3.30.

The New York lab provided a rather lengthy discussion on the irra-

diation of gem materials with gamma rays. The known effects of such irradiation on topaz, quartz, spodumene, cultured pearls, and beryl were given. The lack of any test to detect this type of treatment, except for the fading of some materials, is mentioned.

#### SUMMER 1983

The big story of the Summer 1983 GTLN section was the switching of a painted stone for a fancy pink diamond during a presale viewing at one of the large auction galleries. A 10.88-ct light yellow emerald cut was painted with pink fingernail polish and switched for an attractive 9.58-ct fancy pink stone. The pre-auction estimated value of the fancy pink was in excess of \$500,000, compared to an estimated \$12,000 to \$15,000 for the substituted stone.



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# GEM NEWS

John I. Koivula and Robert C. Kammerling, *Editors*

## DIAMONDS

**Diamond dredging in a big way.** During Gem News editor John Koivula's visit to Brazil in the fall of 1987, he observed the operation of the "Tejucana diamond dredge," an unusually large and efficient floating earth mover-processor that is currently operating near the city of Diamantina, in Minas Gerais (figure 1). Modeled after the gold dredges used in the western United States in the early 1900s, this dredge has been considerably enlarged and modernized to handle diamonds as well as gold. It is reported to be approximately 90% effective in its recovery of both diamonds (the primary target) and gold.

The Tejucana dredge floats on a lake that it manufactures by diverting nearby streams, in an area where diamondiferous gravels have been identified in ancient riverbeds. As it moves slowly along, the dredge excavates (down to the bedrock) all of the soils and gravels in its path. A conveyor system of buckets 3-4 ft. in diameter (figure 2) carries these materials into the processing plant atop the dredge. Here the gravels are mechanically sorted by size and density, and the gold and diamonds are eventually separated out. Once processing has been completed, the residual gravels and other materials are ejected from the dredge into piles on either side of, and

behind, it. Although very efficient, this process leaves massive scars on the land, which is the main reason such dredges are illegal in the U.S.

This dredge is one of two that the owners (Mineração Tejucana S.A.) operate on two different water systems approximately 40 km apart. In September 1987, it was producing an average of about 2,500 ct of gem diamonds, and as much as 25 kg of gold, per month.

**Diamond brings largest per-carat price at auction.** A 52.59-ct emerald-cut diamond (see figure 3) sold at the April 1988 Christie's auction for US\$7.48 million. The US\$142,232 per carat commanded by this D-internally flawless diamond is the highest per-carat price ever paid at auction for a colorless diamond.

## COLORED STONES

**More on Mexican andradites.** More iridescent andradite garnet from Sonora (see Gem News, Fall 1987) has been brought to our attention by Mr. Ralph Coello of Oasis Investments USA, Sherman Oaks, California. Mr. Coello's samples (which he had obtained from Bernhard and Muriel De Koning of R&B Gems, Temple City, California) included rough similar to the iridescent material



*Figure 1. The Tejucana diamond dredge (here, operating near Diamantina, in Minas Gerais, Brazil) removes river gravels and mechanically sorts them for diamonds and gold. Photo by Kristi A. Koivula.*

that we previously noted and a few small, transparent, slightly brownish yellow faceted stones. Each of the latter stones showed a very distinct, colorful, internal diffractive quality when viewed through the table using darkfield illumination (figure 4); we were told that these stones had been cut from small euhedral crystals.

The larger, iridescent pieces of rough showed two distinct layers of color (figure 5). The underlying layer consisted of a translucent dark red-brown material; the outer layer, which provided the iridescence, was bright yellow with a very slight brownish cast. X-ray diffraction analyses of both layers by Chuck Fryer showed the material to be andradite garnet.

**Ruby from North Carolina.** While digging through "gray muck" at a corundum-producing area near Franklin, Macon County, North Carolina, gemologist John Fuhrbach recovered a fine 2.53-ct tabular ruby crystal (figure 6). For size, color, and overall quality, it is an unusual crystal from this North American locality.

*Figure 2. Dredge buckets on the Tejucana diamond dredge systematically scrape the river bottom and bring all of the material into the dredge for sorting. Photo by Kristi A. Koivula.*



*Figure 3. This 52.59-ct D-internally flawless diamond brought the largest per-carat price at auction ever received for a colorless diamond. Courtesy of Christie's; photo © Tino Hammid.*

**Sri Lanka update.** Mr. Gordon Bleck, a geologist who currently resides in Viyalagoda Eheliyagoda, Sri Lanka, recently wrote to Dr. Emmanuel Fritsch, of the GIA Research Department, with news of his latest discoveries from this prolific gem-producing island. Bleck reports that because most of the gem workings involve various small, quickly executed, dispersed mines, each visit to the gem-mining areas of Sri Lanka inevitably reveals many surprises. Following are some of the more interesting discoveries reported by Bleck:

- He observed a beautiful 10-ct color-change sapphire with a large, well-defined, doubly terminated zircon crystal as an inclusion near the surface of the pavilion.
- A dark green 190-ct piece of rough ekanite, with a natural shape that mimics the outline of the island of Sri Lanka, was found near the village of Maligavila, in the Monarayala district of the well-known gem-producing area of Okkampitiya. This piece was mined on jungle flat land from a depth of approximately 3–4 ft., under a layer of small alluvial boulders. This area started producing significant quantities of ekanite about two years ago. At least 50 to 60 kg of ekanite have been recovered since then, with some pieces as large as 1.5 kg. Because of the limited demand for this material, mining for ekanite has now come to a halt.
- A well-formed, relatively fresh, twinned crystal of opaque metallic-black, highly radioactive uraninite



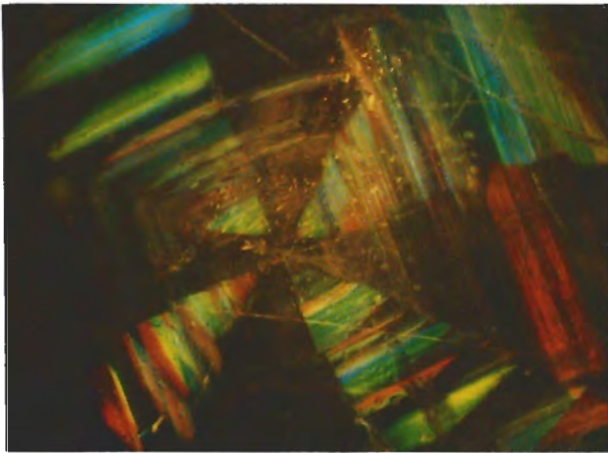


Figure 4. Bright, diffraction-caused colors are visible in this faceted andradite from Hermosillo, Mexico. Darkfield illumination; magnified 25 $\times$ . Photomicrograph by John I. Koivula.

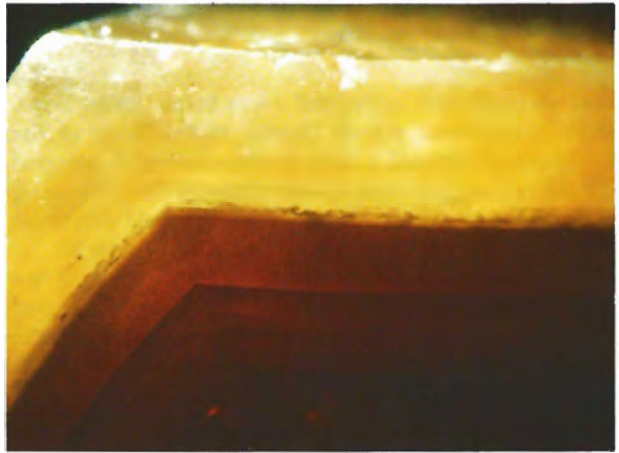


Figure 5. This layered structure is typical of the iridescent andradite garnets from Mexico; both layers are andradite. Magnified 10 $\times$ ; photomicrograph by John I. Koivula.

(uranium oxide) was discovered in Rajaweka, a small village approximately 10 km (6 mi.) from the town of Balangoda. Bleck made the identification based on the fact that a similar crystal that he had sent to GIA Research earlier was determined to be uraninite. This earlier crystal was so radioactive that a special "stone paper" was constructed for it out of 2-mm thick lead sheet. Even when the stone was encased in the lead sheet, radiation was easily detected.

- An apparently flawless rough orange scapolite (118 ct) was found at the village of Ellawel near the town of Eheliyagoda, approximately 5 mi. (8 km) from where most of the colorless Sri Lankan scapolite is found. Thus far, this is the only known orange scapolite from this area. It was recovered from a long-standing mine (approximately 10 m deep) in a rice paddy. A 100-ct piece of green beryl was also recovered from the same mine in recent months.

Figure 6. This 2.53-ct ruby crystal (10.51  $\times$  7.47  $\times$  2.63 mm) was found recently in Macon County, North Carolina. Courtesy of John Fuhrbach; photomicrograph by John I. Koivula.



**Clarification.** With regard to the report on inclusions in the new Hematita alexandrites that appeared in the Spring 1988 Gem News section, it was Dr. Edward Gübelin who actually identified the apatite inclusions in this new material and initially suspected that fluorite

Figure 7. These watches are decorated with plastic imitation malachite. Photo by Robert Weldon.



inclusions might also be present (on the basis of the isometric morphology of the inclusions in question and their similarity in appearance to inclusions of fluorite identified in topaz from Nigeria). Following preliminary testing of these inclusions by Dr. Karl Schmetzer and Mr. Charles Schiffman, at Dr. Gübelin's request, Dr. Henry Hänni performed the chemical analysis that proved that they were indeed fluorite.

#### SYNTHETICS AND IMITATIONS

**Plastic imitations of lapis lazuli and malachite.** Watches decorated with inlaid gem materials are currently a popular item in the jewelry trade. Ellie Page, a resident instructor at GIA-Santa Monica, informed us that some of these watches may actually be decorated by plastic substitutes for malachite (figure 7) and lapis lazuli.

To the unaided eye, the authentic gem-decorated watches and the plastic imitations appear virtually identical. In addition to standard gemological testing techniques, however, there are three simple methods that can be used to spot a fake. First, heft the watch. A watch decorated with one of these gem materials will feel much heavier than its plastic imitator, because the specific gravities of lapis and malachite are much greater than that of plastic. Second, examine the unpolished edges between each link of the band. Since lapis and malachite are aggregates, the unpolished surfaces will be grainy to uneven, in contrast to the smooth-textured surface of plastic. Last, the asking price for the watches made of the actual gem material (which ranges from about \$35.00 to \$100.00 or more) is significantly greater than that of the plastic imitation (approximately \$15.00-\$25.00).



Figure 8. These blister packs contain synthetic spinels, designed for mass marketing just like pills. Photo by Robert Weldon.

**Clever marketing.** A new, somewhat humorous method of "packaging" synthetic gems was recently brought to our attention. Dark blue "cobalt"-colored synthetic spinels, faceted into uniform 6-mm round brilliants, were placed in blister packs in much the same way as cold pills or similar medicines. They were positioned individually in plastic depressions, uniformly spaced on a large sheet that was backed and sealed by metal foil. And, just like pills, if you need one, a little finger pressure on the plastic bubble will pop a spinel out through the foil backing (figure 8).

## ANNOUNCEMENTS

**The American Museum of Natural History** has opened an exhibit of 153 colored diamonds compiled from the Aurora Gem Collection and the Goldberg Collection. This display, in the Morgan Memorial Hall of Gems, is the largest and most comprehensive suite of colored diamonds ever shown at a public institution. A superb range of colors, as well as numerous localities, are represented. For more information on the museum and this unique exhibit (which is scheduled to remain on display until at least March of 1989), telephone (212) 769-5800.

**Matrix: A Journal of the History of Minerals** was introduced at the February 1988 Tucson Gem & Mineral Show. This informative and well-illustrated 16-page newsletter (scheduled to be published six times a year) is dedicated to the history of minerals and significant people in mineralogy. For subscription information, contact Matrix Publishing, P.O. Box 129, Dillsburg, PA 17019.

**The Sixth Jewel and Diamond Fair** will be held in Antwerp September 4-6, 1988. Over 100 exhibitors will participate in the Bouwcentrum.

For more information and reservations, contact: Promaz BVBA, Lamounierestraat 69-71, B2018 Antwerp, Belgium; telephone (03) 239-51-22.

**The Hong Kong Jewelry & Watch Fair** is scheduled for September 18-21, 1988, at five area hotels in Hong Kong. Over 500 exhibitors from 25 countries will be represented. For information, contact: Headway Trade Fairs, Ltd., 9/F Sing-Ho Finance Building, 168 Gloucester Road, Hong Kong; telephone 5-8335121.



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# GEMOLOGICAL ABSTRACTS

*Dona M. Dirlam, Editor*

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## COLORED STONES AND ORGANIC MATERIALS

**Beryl: A summary.** J. Sinkankas, *Rocks and Minerals*, Vol. 63, No. 1, 1988, pp. 10–22.

Sinkankas presents a wonderful article based on his now out-of-print *Emerald and Other Beryls*. The most common variety of beryl is the so-called common beryl—poorly formed, non-gem quality beryl with value only as the primary ore of beryllium. In order of abundance (from most to least), the varieties of gem beryl include blue to bluish green aquamarine, golden beryl (sometimes called heliodor), and morganite (pale peach or pink

to a fairly intense apricot or purplish pink). The next most abundant would be emerald, followed by the completely colorless variety known as goshenite. Now considered to be the rarest of all beryls is the stunning red variety that was originally discovered in the Thomas Range, Utah, in the early 1900s; more recently, red beryl has been found in the Wah Wah Mountains of that same state.

Using charts and illustrations, Sinkankas describes the crystal structure and composition, physical properties, and causes of color. The basic geology of beryl deposits and some classic worldwide occurrences (together with maps) are also included. *BCC*

**Blue spinel from the Hunza Valley, Pakistan.** R. R. Harding and F. Wall, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 403–405.

Small, gem-quality spinel crystals have been found in the Hunza valley of Pakistan. They are described as black or dark blue in reflected light and as “a range of blue, lilac and pink” in transmitted light. All of the material studied exhibited absorption bands at 650–630, 600–590, 580–565, 555–540, and 470–455 nm in a hand spectroscope; in addition, pink crystals showed a band at 680 nm which was attributed to chromium. A Pye-Unicam spectrophotometer was used to confirm these locations, with the spectrum of a synthetic blue spinel provided for comparison. Comparison was likewise

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*This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that we feel will be of greatest interest to our readership.*

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made to the spectrum of a cobalt-containing blue spinel as published in a 1984 article by Shigley and Stockton (*Gems & Gemology*, Vol. 20, No. 1, pp. 34–41). Unfortunately, this spectrum does not have a linear wavelength scale, which the authors (including this abstracter) did not explicitly state in their article. As a result, Harding and Wall's observation that "the centres of the absorptions between 500 and 700 nm are not identical" is based on spectra that cannot be compared visually. A correction, including linearly scaled versions of the 1984 spectra, has been sent to *Journal of Gemmology* for publication in a future issue.

Harding and Wall also provide, however, microprobe chemical data for a Hunza valley blue spinel, showing similarity to the Sri Lanka material except that the Pakistan material contains more chromium and titanium. They note that cobalt, if present, is below microprobe detection limits. CMS

**Colour-changing chromiferous tourmalines from East Africa.** H. Bank and U. Henn, *Journal of Gemmology*, Vol. 21, No. 2, 1988, pp. 102–103.

Drs. Bank and Henn provide the first gemological description of green-to-red color-change tourmalines from East Africa. These gems have refractive indices of 1.644–1.645 and 1.622–1.623, a birefringence of 0.022, and a specific gravity of 3.04–3.06. Electron microprobe analyses are provided, as are spectroscopic results that support the significance of  $\text{Cr}^{3+}$  as the principal color-causing element. CMS

**Zur Deutung der Farbursache blauer Saphire – eine Diskussion (The cause of colour in blue sapphire – a discussion).** K. Schmetzer, *Neues Jahrbuch für Mineralogie Monatshefte*, Vol. 8, 1987, pp. 337–343.

This article provides an overview of the causes of color in blue sapphires from various localities. The origin of color in blue sapphire historically has been related to the presence of  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  intervalence absorption, sometimes induced by heat treatment. Other components may also be present in the spectrum, such as  $\text{Fe}^{3+}$  absorptions, and sometimes  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$  charge transfer. Blue sapphires of desirable color from Kashmir, Mogok, Umba Valley, and Montana, as well as Verneuil synthetic sapphires, show  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  charge transfer with weak  $\text{Fe}^{3+}$  bands but no  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$  charge transfer. The less desirable greenish blue stones from Australia, Nigeria, Thailand, and Kenya display intense  $\text{Fe}^{3+}$  bands and variable amounts of  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  and  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$  charge transfer. Chatham flux-grown synthetic blue sapphire shows small  $\text{Fe}^{3+}$  bands,  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  charge transfer, and variable intensities of  $\text{Fe}^{2+} \rightarrow \text{Fe}^{3+}$  charge transfer, a spectrum that is also found in some blue sapphires from Pailin, Kampuchea. Sapphires of similar chemical composition with no  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  charge transfer have been found in Thailand and have a green color.

Heat treatment not only can dissolve rutile needles, thus enhancing the  $\text{Fe}^{2+} \rightarrow \text{Ti}^{4+}$  charge transfer, but it also can produce a variety of dissolution reactions involving many types of inclusions. The results depend on the heating parameters, the relative concentrations of the various impurities, and the atmosphere in the furnace. EF

**Emerald: The stunning adornment.** D. A. Hiss and H. Walowitz, *Jewelers' Circular-Keystone*, Vol. 154, No. 4, April 1988, pp. 203–210.

This lengthy article gives an excellent overview of various aspects of emeralds. It includes 18 color photographs illustrating the color range of emeralds, distinctive features and characteristic inclusions, as well as a number of exceptional estate pieces and various aspects of the mining operations at Muzo.

The authors describe the color of emeralds in detail, using GIA ColorMaster nomenclature as written by Drucker of "The Guide." They also discuss oiling and practical care tips, as well as interesting lore (including a brief history of the fascinating Colombian emerald deposits). Emerald's use as a birthstone, its identifying characteristics, short source descriptions, the synthetic counterparts available, and a column of technical data round out this comprehensive article on emerald.

Jay G. Lell

**Fibers of dumortierite in quartz.** K. R. Applin and B. D. Hicks, *American Mineralogist*, Vol. 72, No. 1/2, 1987, pp. 170–172.

Etching experiments on quartz from various localities reveal the presence of dumortierite fibers 100–400 nm wide, 100–200 nm thick, and at least hundreds of microns long. These fibers are most abundant in rose quartz from the Ruby Range, Montana; fine optical quartz from Arkansas does not contain any fibers. Although the article does not establish a clear connection between the presence of pink dumortierite inclusions and the color of the host mineral, one can deduce that pink dumortierite is a possible cause of color in rose quartz. EF

**The not-so-rare earths.** G. K. Muecke and P. Moller, *Scientific American*, Vol. 258, No. 1, January 1988, pp. 72–77.

A recent survey finds that the rare-earth elements are not that rare. Indeed, most of them are more abundant than gold in the earth's crust. They are usually present in the trivalent state, and they commonly substitute for calcium, regardless of the size of their ions. This means that calcium minerals (such as calcite, fluorite, scheelite, some plagioclase feldspars, and many other gem materials) are likely to contain large concentrations of rare earths. The chemical characteristics and geochemical cycle of these elements are explained, and two opposite tendencies are shown: Light rare earths are



incorporated more easily into crystals that grow in hydrothermal solutions, whereas heavy rare earths are incorporated first in minerals formed in magmatic systems. This suggests a guideline as to what kind of rare earths one should expect to find in gem minerals deposited in hydrothermal veins or magmatic—especially pegmatitic—occurrences. JLC/EF

**Pyrite in Canadian ammonite.** J. I. Koivula, *Australian Gemmologist*, Vol. 16, No. 8, 1987, pp. 304–307.

Beginning with a brief review of the history, geologic setting, and recovery of Canadian ammonites, the author proceeds to describe his examination of a section of *Placentoceras meeki* shell. The specimen consisted of an iridescent layer on a natural brownish gray shale base. Whitish, rounded blebs were visible on the specimen with the unaided eye; under magnification they appeared pale whitish yellow with a metallic luster, resembling pyrite.

Rather than apply sophisticated testing techniques (e.g., X-ray powder diffraction and electron probe microanalysis) to identify these inclusions, the author chose to use what he describes as “a more traditional” approach, that is, microchemical analysis, a form of testing that is still used by exploration geologists. What follows is a fascinating description of the testing techniques, which led to the identification of the inclusions in question as pyrite. The author suggests that a small kit for microchemical testing might be assembled and used effectively by gemologists, mineralogists, and geologists who do not have access to sophisticated instrumentation. RCK

## DIAMONDS

**Colored diamonds.** S. C. Hofer, *New York Diamonds*, Vol. 1, No. 1, 1988, pp. 28, 30.

Mr. Hofer introduces his column “Colored Diamonds” in the premier issue of this new trade journal. He begins by providing several historical references to colored diamonds, touching briefly on the formation, history, and marketing of these rare gems. He states that his intention in this column is “to educate and inform members of the industry . . . on the mysterious and often misquoted colored diamonds.”

Included in this first column is an announcement and description of the fancy-color diamonds in the Aurora Gem Collection and the Goldberg Collection, which are currently on display at the American Museum of Natural History in New York City. Two color photographs of diamonds from the two collections illustrate the column. Bill Videto

**A diamond as big as the Ritz—well, just about that big.** P. F. Kluger, *Smithsonian*, Vol. 19, No. 2, May 1988, pp. 72–83.

In August 1984, diamond cutter Marvin Samuels, in

partnership with the Zale Corporation, purchased an 890-ct fancy yellow rough diamond—the fourth largest diamond ever found. The partners believed that they could cut a stone to surpass the weight of the famed Cullinan I, at 530.2 ct the world’s largest faceted gem diamond.

This article allows the reader to live the drama of the cutting of this unique diamond and the decision to go for quality rather than size. The finished stone, cut in an unusual “triolette” shape, is, at 407.43 ct, the world’s largest fancy-color diamond and the second largest diamond overall. Patrick B. Ball

## Famous diamonds of the world XXVI: La Belle Hélène.

1. Balfour, *Indiaqua*, Vol. 44, No. 2, 1986, pp. 124–127.

La Belle Hélène was discovered in the region along the southwest corner of Africa known as the “Skeleton Coast.” Although forbidding, it is one of the world’s richest sources of gem-quality diamonds under one carat. Large diamonds of fine quality are a rarity here; therefore, the 160-ct rough found in 1951 was very unusual.

The diamond rough was sold to Mr. Romi Goldmuntz, a recognized personality in the Belgium diamond industry since World War II. The diamond was named after his wife Hélène. Later, the stone was sent to New York where it was cut into two matching pear shapes, weighing 30.38 and 29.71 ct, and a 10.50-ct marquise. All three stones were eventually sold to private buyers through Cartier. JLC

## Famous diamonds of the world XXVII: The Vainer Briolette. I. Balfour, *Indiaqua*, Vol. 44, No. 2, 1986, pp. 129–130.

In his continuing series on famous diamonds, Balfour here discusses how the London firm of M. Vainer Ltd. cut a 202.85-ct yellowish rough diamond into the largest briolette-cut diamond in the world.

The firm was first told of this diamond, believed to be from South Africa, in the autumn of 1984. The stone, an almost perfect octahedron, would have been fashioned into two matching round brilliants by most cutters. Mr. Vainer, however, opted for the briolette cut, which ultimately produced a 116.60-ct fancy light yellow diamond with 192 facets in this unusual shape. The Sultan of Brunei subsequently purchased the stone. JLC

## First joint venture to mine in China. P. Brindisi, *Jewelry News Asia*, Vol. 41, No. 1, January 1988, pp. 51–54.

In October 1987, a joint venture between partly Australian-owned City Resources (Asia) Ltd. of Hong Kong and the People’s Republic of China was issued a license to explore for and mine diamonds and precious metals in China. They will begin exploration in the Hunan Provi-

nance in May of 1988. Diamonds have been mined on a limited basis in this area for over 30 years. A 60-km mining area has been allocated in the lower Yuan Jiang River, thus giving the name Yuan Jiang River Project to the venture. The group also plans to mine the terraces along the river. Several large diamonds have already been found, but the dredging method used does not recover small stones. Systematic sampling of alluvial deposits and deep drilling will allow a detailed assessment of the potential of the deposit. To date, the extent of diamond reserves in China is not known.

Gold is also found in the river. The flaky structure suggests a nearby origin. All gold recovered is to be sold to the Bank of China. While City Resources is the first outside group to be licensed for such a joint venture with the PRC, other companies are currently negotiating for similar licensing to explore for diamonds. JLC

**Industry listens carefully to anti-apartheid debate.** *New York Diamonds*, Vol. 1, No. 1, 1988, pp. 54, 56.

In the premier issue of this quarterly trade magazine (which is sponsored by the Diamond Dealers Club, Inc., of New York) a staff writer reviews the present status of the anti-apartheid debate in the U.S. An amendment to the 1986 Comprehensive Anti-Apartheid Act has been proposed that would prohibit the importation of diamonds "(1) produced in South Africa, (2) exported, directly or indirectly, from South Africa, or (3) offered for sale by, or on behalf of, the Government of South Africa or a South African entity" (as quoted directly from the proposed amendment).

The article mentions the impact such legislation would have on the international diamond market as well as specifically here in the U.S. In particular, emphasis is placed on the role that the Jewelers of America organization has taken to inform jewelers and legislators of the ramifications of such an amendment. The article ends with a quote from Sheldon London, legislative counsel to Jewelers of America: "It's not something that needs to alarm the industry, but it is something we have to watch constantly." DMD

**Producción record de diamantes (Record production of diamonds).** *Joyas e Joyeros*, Vol. 25, September 1987, pp. 43-45.

The 1980s have provided a major challenge for the Central Selling Organization (CSO) in terms of the production and marketing of diamonds; this article (written in Spanish) analyzes and chronicles diamond production in this decade. Because of the world recession that dominated the beginning of the decade, diamond production was low, reaching its lowest level in 1982. Recovery came after 1985, as demand surged and the costs of production were reduced.

For the Spanish-speaking gemologist, this article also provides an unbiased glimpse into the world of De

Beers, with a particular emphasis on the CSO. However, it does highlight such emotive topics as political sanctions against South Africa and, conversely, portrays De Beers as a beneficial "cooperative," whose presence and industry benefits producers, hosting countries involved, and consumers alike.

Considerable attention is also given to other producers such as the Argyle mines in Australia and the now recuperating mines of Zaire. RW

## GEM LOCALITIES

**Lightning Ridge—die Wiege der Australischen Schwarzopale** (Lightning Ridge, the cradle of Australian black opals). E. Gübelin, *Lapis*, Vol. 13, No. 2, February 1987, pp. 15-30.

The first part of this article about Lightning Ridge covers the history and geology of the area, the origin of the opals, and the methods of mining and processing the rough material. Although opal was first discovered here in 1887, production on a (comparatively) large scale began only about 30 years ago. More sophisticated mining techniques—such as the use of explosives and pneumatic drills, bulldozers, surface mining, and processing with "agitators," in addition to "dry" and "wet puddling"—are quite new and have become profitable because of an increasing demand for black opal. Dr. Gübelin discusses the geologic and chemical conditions of opal formation in the Lightning Ridge area and concludes that the opals were formed during the kaolinization of feldspars in the early Tertiary period. The mining activities are illustrated by 17 informative color photographs and two geologic sketches.

The second part of the article gives general information on opal, including sources, varieties, and some mineralogic and gemological data. Two electron photomicrographs show the different structures of common and gem-quality opal. Examples of fine black opals as well as other varieties (rough and cut) are shown in 16 color photographs.

While the second part of the article may be too general for the reader already familiar with the material, it is of value for newcomers. The description of opal mining at Lightning Ridge, however, is of interest to all for its fresh view of the activities in this mining area. The article is written in German, but the beauty of the photographs is international.

Rolf Tatje  
Duisburg, West Germany

**A review of jade in South Australia.** J. G. Olliver, *Australian Gemmologist*, Vol. 16, No. 8, 1987, pp. 283-286.

This article reviews the geology and mining of the Cowell nephrite deposit on the Eyre Peninsula, South Australia. This deposit was discovered relatively recently, in 1966. Since that time, 115 outcrops have been



identified in a 6 × 3 km area designated the Cowell Jade Province. An evaluation of the deposit conducted in 1986 conservatively placed the recoverable reserves at 60,000 tons, with an average price of \$A4,000 per ton.

Nephrite at this site is associated with quartzofeldspathic gneiss and dolomitic marble. It is formed in three ways: (1) intrusion of granite, causing extensive replacement of marble and contamination of the intrusive; (2) mylonitization during and after granite intrusion, producing further alteration; and (3) cross-fracturing and warping in the orogeny, imparting a schistosity on early phases, including nephrite. Nephrite formed by the third method is reportedly of the highest quality because of its minute grain size, the random orientation and interlocking nature of its fibers, and the relative absence of inclusions.

Cowell nephrite is mostly dark green to black, with the color related to iron content (the blackest material contains up to 7.9% iron); chromium content is only 30–40 ppm. Many boulders and outcrops exhibit a white rind and a red weathering skin; some have multiple weathering patterns in the rind. Mining is accomplished through removal of overburden, followed by drilling and blasting. RCK

**Some notable Maine gemstones.** J. C. Perham, *Rocks and Minerals*, Vol. 62, No. 6, 1987, pp. 420–427.

Maine has long been known for its production of spectacular multicolored tourmaline. In particular, during 1972–1973, the Dunton quarry in Oxford County produced beautiful pink tourmalines, many of which are an intense raspberry color. Cut stones over 50 ct were not uncommon from this locality; the largest is a 60.05-ct intensely colored stone that is all but flawless. Mt. Apatite and Mt. Mica are also well known for beautiful tourmaline. The rich green color of the Mt. Apatite tourmalines has been compared to that of fine emeralds. The largest cut stone from Mt. Mica is a flawless 246-ct green tourmaline mined in 1978.

Maine has also produced beautiful examples of other gemstones. Fine aquamarine has come from the Sugar Hill area in Stoneham. Richly colored amethyst, said to rival the finest of the Siberian material, has been found at Pleasant Mountain in Denmark (Maine) and at Deer Hill in Stow. Rose quartz and purple apatite from Maine are described as well. BCC

## INSTRUMENTS AND TECHNIQUES

**Identifying yellow sapphires—two important techniques.** R. W. Hughes, *Journal of Gemmology*, Vol. 21, No. 1, pp. 23–25.

Yellow corundum can often be difficult to distinguish from its synthetic analog, because the colored banding is not easily resolved. Mr. Hughes discusses (and illustrates) the usefulness of a blue color filter as an aid in this

problem. The value of various filters for other colors of corundum is reviewed as well.

Also discussed is the use of low-temperature heating of yellow corundum to determine color treatment. The test described is certainly useful, but reference to the article by Nassau and Valente in the Winter 1987 issue of *Gems & Gemology* reveals just how complex this problem is. Together, however, the two articles provide valuable insight into the problem of stability in yellow sapphires, heat treated and otherwise. Mr. Hughes wisely cautions about the necessity both of obtaining permission to perform such color-altering tests and of avoiding damage that could be caused by overheating important CO<sub>2</sub> inclusions. CMS

**LWUV fluorescence of gemstones: A photographic review.** J. Snow and G. Brown, *Australian Gemmologist*, Vol. 16, No. 8, 1987, pp. 296–300.

This article, as the title implies, was prepared to provide a visual record of the reactions of a number of gem materials to long-wave ultraviolet radiation. The author photographed the subject materials in groups, using 400 ASA color slide film in a 35-mm camera fitted with a 50-mm macro lens and an extension tube. The gems are illustrated as they appear both under white fluorescent light and when exposed to long-wave U.V. radiation, to provide a quick comparison between daylight-equivalent and fluorescent colors.

The gemstone groups illustrated include: diamond and its imitations; corundum (both natural and synthetic, as well as yellow sapphire and its imitations); emerald and its imitations; spinel (natural and synthetic); opal (natural and synthetic); zircon; scapolite; chrysoberyl; fluorite; turquoise; various organics; and a number of miscellaneous gem materials.

The article is all the more useful because it includes source information on most of the natural materials as well as the manufacturers of the synthetics. RCK

**Some DIY gemmological instruments.** J. Eadie, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 482–485.

For the more enterprising—as well as thrifty—gemologist, this brief article provides instructions on how to make your own polariscope, dichroscope, and light intensity unit. These projects are particularly informative, too, for the student learning about gemmological instruments. Diagrams and photos illustrate the procedures. CMS

## JEWELRY ARTS

**The gemstones in a Maharajah's sword.** R. R. Harding and S. H. Stronge, *Journal of Gemmology*, Vol. 21, No. 1, 1988, pp. 3–7.

The known history of the Indian jeweled sword described in this article dates only to 1817, when it was taken from the defeated cavalry of the Maharajah Holkar

and subsequently presented as a gift to a British officer. It was purchased in 1888 by the Victoria and Albert Museum, where it still resides.

The sword's hilt (described simply as "gold") contains 694 gemstones, including 378 rubies, 276 diamonds, 38 emeralds, and two pieces of onyx. The rubies and emeralds were all identified as such on the basis of inclusions and absorption spectra. Some of the rubies and all of the emeralds are backed by colored foil or enamel to compensate for paler colors. The emeralds range up to 15 mm across and include four carved stones. While the majority of the emeralds are of poor color, a few are typical of fine Colombian material. Most of the rubies are comparable to good Burmese stones. The diamonds range up to 9 mm in diameter, with most being just polished cleavage pieces. Two larger stones, however, are cut in a fashion typical of old Indian stones such as the Koh-i-noor in Tavernier's day; line drawings are provided for comparison. The two seemingly ill-sorted black-and-white onyx cabochons are inlaid as the eyes of a tiger.

A gold-inlaid symbol on the sword blade indicates royal ownership, but the poor quality of even some of the prominent stones attests to the limited resources of the house of Holkar. Nevertheless, the total effect is impressive, as can be seen from the color photographs that accompany the article. CMS

**The Picasso of gems.** J. Everhart, *National Jeweler*, Vol. 31, No. 21, November 16, 1987, pp. 45-46.

Bernd Munsteiner: The name alone conjures up images of intricately carved gems. Modern, angular, and graceful, they bring life to any jewelry setting. This article focuses on the creator of these carvings, from his early struggles as a pioneer in fantasy cuts, to the present-day recognition of his uniqueness as an artist in gem cutting.

The article stresses Munsteiner's frustrations on having his ideas copied by stone cutters around the world, and the steps he has taken to ensure that his work remains "original." He now incorporates his trademark into each piece and includes a Munsteiner certificate to verify its authenticity.

Although Everhart's comparison of Munsteiner to Picasso is oblique at best, the reader nevertheless understands the message: Munsteiner has popularized a whole new concept in gem cutting, a concept that is here to stay. Just as Picasso's work inspired other artists to new expression in abstract art, so Munsteiner's work has given rise to a whole new generation of gemstone artists. Eight color photographs accompany the article. RW

## SYNTHETICS AND SIMULANTS

**Diamond film about to turn itself into manufacturing's best friend.** J. E. Ferrell, *San Francisco Examiner*, January 7, 1988, pp. E1-2.

Synthetic diamond thin films are of increasing interest

not only to scientists, but also to manufacturers. Diamond is the hardest substance known, chemically inert, and transparent up to the infrared range. It conducts heat very well and resists radiation. These properties make for numerous applications for synthetic diamond thin films. Cutting tools, ball bearings, and sound reproduction (acoustics) equipment have already been manufactured with this technology. Crystallume, a Palo Alto firm, is producing windows for soft X-rays, and is hoping to develop other ideas such as scratch-proof lenses. It has been suggested that coatings of synthetic diamond thin film could considerably improve the properties of plastic; reportedly, Russian scientists have already achieved success in this area.

Because of its resistance to radiation, synthetic diamond thin film has attracted \$2.7 million in research grants from the U.S. Defense Department. Such films could also help cool the electronics in missiles and aircraft more quickly. Primary research, however, is on their use in semiconductors, that is, the development of synthetic diamond computer chips that can run four times faster than current chips.

The key to obtaining true synthetic diamond films was revealed by Russian scientists in 1977. Hydrogen needs to be mixed with the methane gas which, excited by microwave frequencies, breaks down and deposits synthetic diamond on a substrate under a very low pressure. Crystallume's Schultz points out that this technology "could have the same impact as the invention and cheap manufacture of aluminum did 100 years ago." EF

### **Growth of crystalline diamond from low-pressure gases.**

K. E. Spear, *Earth and Mineral Sciences*, Vol. 56, No. 4, 1987, pp. 53-59.

This article outlines, in fairly simple terms, the most important facts about the synthesis of diamond films and coatings from low-pressure gases. The basic principles are explained, and a history of diamond film research is provided. Emphasis is given to Pennsylvania State University's role in developing this technique. After presenting a short description of the many potential applications of this technology, the author explains that little is known about the actual mechanisms for the growth of crystalline diamond at low pressure, and emphasizes the difficulties of characterizing such a product. The author then develops his hypotheses on the growth mechanisms involved. He concludes with a discussion of the need for more research on the fundamental aspects of this technology to make better diamond films, which have considerable economic potential. EF

**Synthetic gem diamonds top congress subject.** *New York Diamonds*, Vol. 1, No. 1, 1988, p. 76.

In the "World Wide Diamonds" section of this new trade journal, a staff writer details the agenda for the 24th



World Diamond Congress to be held the end of July 1988 in Singapore. Emphasis will be placed on synthetic diamonds, including the reports of three bourse members who conducted independent investigations with Sumitomo synthetic diamonds. In London, a bourse member submitted a piece of Sumitomo rough to a diamond cutter who reported that its properties were indistinguishable from those of natural diamond. In Vienna, two other bourse members had a Sumitomo synthetic diamond cut into a baguette shape that was "submitted to several laboratories and each time received reports that the stone was a natural diamond." The article concludes with a list of other issues, mostly procedural, that are on the congress agenda.

Bill Videto

## TREATMENTS

**Gemmology study club lab reports.** G. Brown and J. Snow, *Australian Gemmologist*, Vol. 16, No. 8, 1987, pp. 287-292.

This well-illustrated series of reports covers a number of interesting items examined by the authors. One of these is a rather unusual opal triplet: The high dome (cap) consists of whitish translucent patch with a distinct orbicular patterning, while the bottom dome (base) is manufactured from colorless glass; the opal slice at the center had not been blackened. The triplet reportedly is a convincing imitation of white opal.

Also described is a cameo carved out of "bog oak," an organic gem material that consists of semifossilized wood recovered from peat bogs in Ireland. Key identifying features include a distinctive dark brown color, an obvious woody texture, a generally poor surface polish, and a splintery fracture. This cameo also exhibited yellowish brown plant resin in association with the woody fibers and a junction where the two independently carved sections of the piece had been glued together with a resinous cement.

Other items in this report include: a highly translucent turquoise of alleged Egyptian origin—the authors question whether the high diaphaneity might be due to silica impregnation of porous turquoise; a plastic imitation of ivory that had been deliberately patterned with "engine turning" (the intersecting brownish arcs characteristic of ivory); a strand of plastic imitation "flesh-nucleated" (i.e., mantle-tissue nucleated) cultured pearls; and a strand of "flesh-nucleated" cultured pearls purported to have been natural.

RCK

**Internal diffusion.** J. I. Koivula, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 474-477.

This article by inclusion expert John Koivula discusses the means by which coloring agents are cannibalized by corundum from certain types of inclusions. Koivula

supports his thesis with five photomicrographs of synthetic and heat-treated natural sapphire that show concentrations of intense color around inclusions, the result of incomplete diffusion of the chromophoric elements being cannibalized.

CMS

**A new treatment for turquoise.** G. Brown, J. Snow, and J. Lamb, *Australian Gemmologist*, Vol. 16, No. 8, 1987, pp. 307-309.

This brief report covers the examination of two turquoise cabochons purchased at a gem fair in Australia. The cabochons were opaque, of a medium blue color with slight greenish overtones and a waxy luster. Both exhibited black matrix on their convex surfaces, but, surprisingly, the base of one had a network of fine whitish to brownish veins.

A scratch test followed by hot point testing proved that the two specimens were paraffin impregnated. Magnification revealed two interesting features: (1) the black matrix appeared to be painted over whitish veins on the convex surfaces; and (2) the turquoise had a cellular texture consisting of lighter colored rounded "cells" surrounded by darker bluish borders. A detailed examination of a segment of the black matrix removed from one cabochon showed that it was formed from very fine black particulate matter suspended in a paraffin wax. The article includes six good color photomicrographs and a listing of the specimens' gemological properties.

RCK

## MISCELLANEOUS

**Lifetime Achievement Award: James B. White.** D. Federman, *Modern Jeweler*, Vol. 86, No. 12, December 1987, pp. 43-54.

Each December, *Modern Jeweler* presents their Lifetime Achievement Award to an individual who has been instrumental in the jewelry industry. The 1987 award has been given to James B. White of the Jewelers' Security Alliance.

This article follows the career of Mr. White first with the FBI, then with the New York City district attorney's office and various other law enforcement concerns, to his present position with the Security Alliance. His success is in part due to his emphasis on preventing crimes and to the mail alert and telephone networks he has set up as a warning system. Moreover, when he assumed full leadership of the Alliance in 1965, little more than a year after joining it, he began changing the attitudes of jewelers by espousing "rational behavior in the face of the crimes that jewelry . . . so frequently invites." Mr. White's efforts over the past 22 years have earned him a reputation as the best crime fighter for the jewelry industry.

JLC

## AMERICAN JEWELRY

By Penny Proddow and Debra Healy, 208 pp., illus., publ. by Rizzoli, New York, 1987. US\$75.00\*

Authors Penny Proddow and Debra Healy have created an elegant book on American jewels and jewelers. Specifically focused on the production of fine jewelry (primarily signed jewels), it is richly illustrated with David Behl's photographs of jewelry and the jewelry renderings of notable designers, interspersed with pictures of famous personalities such as Greta Garbo and Shirley Temple displaying the pieces. Drawing from personal communications, magazine articles, and company archives, the authors have compiled a virtual encyclopedia of information.

In the first chapter, Proddow and Healy introduce American jewelers of the late 18th century, describing their rise in a historical context. Then, beginning with the founding of Shreve, Crump & Low Co. of Boston in 1869, they proceed to recount the early years of companies such as Frost of New York, Bailey, Banks & Biddle of Philadelphia, Greenleaf & Crosby of Jacksonville (Florida), C. D. Peacock of Chicago, and Gump's of San Francisco. In this concise overview, one also glimpses the interrelationships of various jewelers as they combine to form companies, separate, and then recombine to create new partnerships—many of which are still in existence today. This first chapter ends with a paragraph announcing the introduction of *Jewelers' Circular and Horological Review*, one of the first jewelry magazines, in 1874.

The following chapters focus on a variety of topics, including specific jewelry companies in the context of historical events and groups of jewelers within a particular period of time, such as the 1960s. The authors begin with the establishment of Tiffany & Co. and emphasize how its success was aided by the many international world expositions that were held during the 19th century. One chapter, devoted to Art Nouveau jewelry, mentions many of the new gem materials (such as Montana sap-

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Elise B. Misiorowski, Editor

phires or Arizona turquoise) popularized during this period. In another chapter, the emphasis is on changing technology and specifically the importance of the metalsmith's ability to unleash the beauty of platinum as a metal. It should be noted that these and subsequent chapters, which take place primarily in the 20th century, focus on New York. There is, however, one chapter devoted to Texas and the West.

The important role that jewelry and fashion magazines have played in the development of the U.S. jewelry industry becomes apparent when the sources of information cited by the authors in the notes and general bibliography are examined. Quotes from jewelers and fashion experts, as well as from jewelry ads, are peppered throughout the text, adding a historical dimension that is not often found in jewelry books.

As a gemologist, however, this reviewer would like to have seen more from the authors—more detail, more footnotes, more figure explanations. For example, only one paragraph is devoted to William Ruser, a major West Coast jeweler. Sizes and weights of the gemstones illustrated would have been helpful, as well as more information on the individual designers and metalsmiths, particularly the women involved in the earlier years (pre-World War I). For example, any discussion of Louis Comfort Tiffany should include the role of Julia Munson Sherman (a designer of studio jewelry for the company). Not mentioned among Chicago jewelers is Clara Barck Welles, who contributed greatly to the Arts and Crafts movement in that city.

All in all, though, the authors have done an amazing job of balancing readability and visual beauty with content. Coupled with Rizzoli's care in choosing a heavy paper stock and proper binding, this major reference work will withstand the test of time.

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## INTRODUCTION TO LAPIDARY

By Pansy Kraus, 196 pp., illus., publ. by Chilton Book Co., Radnor, PA, 1987. US\$19.95\*

Readers with any gemological experience might, at first, think that this book is too elementary, given the very simple language and style of the first chapter. This does not mean that it is poorly written. Rather, the author may want to familiarize her audience with the various gemological terms used throughout the book, as well as make the hobby accessible to young people, whose involvement is needed to keep it alive and active. This book imparts its information in such a way that anyone from beginner to graduate gemologist can learn about the various aspects of the lapidary hobby.

The first chapter starts with the most basic of the techniques—tumbling stones. In this chapter in particular, Ms. Kraus explains the various processes and precautions using the simplest of language. In the following chapters, which describe such topics as making spheres and cabochons, drilling beads, and carving, the terminology gradually becomes more advanced, as the skills required become more technical. The final chapter, on faceting, is the most thoroughly covered subject in the book, as well as the most readable.

The author includes many sidebars about the people important to the lapidary arts, giving a personal

\*This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone: (800) 421-7250, ext. 282.



touch from her long involvement in the hobby and her many years as the editor of the *Lapidary Journal*. There is also a section of color photographs to show the beautiful results of the techniques.

This book is not a specialized manual but, as the title indicates, an introduction to the hobby of lapidary. However, if the more sophisticated reader can endure the first few chapters and the obsessive dragging out of the metric conversions (to four decimal places!), he can find a wealth of information in this book, as well as possibly expand his visions about the various forms of lapidary.

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## JET

*By Helen Muller, 149 pp., illus., publ. by Butterworths, Great Britain, 1987. US\$29.95*

Although I started this review with a strong bias toward transparent or translucent gems, I came out of it surprised . . . and educated. Helen Muller begins her introduction with the following words: "Few people know much about jet." My own knowledge of the material was limited to the basic properties needed for identification, and the fact that jet came from Whitby in North Yorkshire. I thus began researching jet, since to do a review, a reviewer must know the subject. I soon discovered that, with the exception of a few scattered paragraphs in some gem texts and journals, very little had ever been written about it. Yet Ms. Muller has provided a comprehensive examination of this elusive topic.

This volume is well organized with a detailed table of contents. Culminating each chapter is a selection of useful references. The book concludes with a series of appendices, including what seems to be an exhaustive historical listing of jet manufacturers and merchants and an index to the volume itself. Four

pages of appealing color plates show a variety of jewelry and decorative jet items, such as pendants, lockets, and necklaces, that are hand painted, carved, or inlaid with other gem materials such as turquoise. Such decorations add color and variety to this black material.

This sturdy monograph is both accurate and educational. Ms. Muller deserves credit for what must have been an exhausting research exercise. She has provided gemology with a first—a volume on jet. If you are fond of ornamental materials, if you enjoy history, or if you just want to expand your gemological knowledge, *Jet* is the book for you.

One concluding comment aimed at the publishers: this reviewer assumes that Helen Muller is the same H. Muller, M.Sc., F.G.A. who won the Tully Memorial Medal in 1974 and then became an instructor with the Gemmological Association of Great Britain. Yet, an author's profile seems to be missing from all of the Butterworths Gem Books. Including a profile is not just a courtesy to the author; it also helps the would-be buyer judge the credentials of the author as they relate to the subject(s) discussed in the book.

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## AMBER

*By Helen Fraquet, 176 pp., illus., publ. by Butterworths, Great Britain, 1987. US\$29.95*

Like all the books published thus far in the Butterworths Gem Books series, this volume about amber begins with a chapter listing the basic properties a gemologist needs to make routine identifications. The author then discusses amber and its various uses. All of the major localities are profiled in separate chapters, including a welcome chapter on Asia.

Basic gemological testing procedures—including the use of a saturated saline solution, reaction to heat, and surface resistance to or-

ganic solvents—are covered. More sophisticated means of testing amber are also introduced. Two of the most useful chapters for the gemologist are the one on plastics and their properties and the one covering resins, both of which are sometimes confused with amber. Culminating each chapter is a selection of useful references; the book concludes with a helpful information index. Eight pages of appealing color plates, showing amber jewelry, in carvings, as art objects, and even photos of amber mining as well as a few inclusion photos, are provided.

It is not clear, however, why appendix 2, "Amber in the USA," is sandwiched between appendix 1 "Geologic Ages," and appendix 3 "Infrared Spectra of Amber Samples." "Amber in the USA" seems to be an afterthought and totally out of place. It would have been better placed as a separate chapter in the main body of the book along with the other localities.

One other drawback is the limited coverage given to the various types of inclusions found in amber. Inclusions in amber not only make the material more valuable commercially, but they also provide unparalleled information to scientists on past life forms, their environment, and evolution. As an example of this oversight, no bibliographic reference could be found in this book to the classic German work by Dr. Adolf Bachofen-Echt on inclusions in Baltic amber.

Although there is really no information here that cannot be found in a number of other sources, *Amber* is nonetheless enjoyable and easy to read. In her own words, the author considers it "an amber primer." Aside from the one out-of-place appendix, the book is well organized. It is accurate in content, and makes an excellent source book that should satisfy the curiosity of most gemologists about amber.

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