Gems & Gemology

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ABOUT THE COVER: This exceptional conch "pearl" and diamond parure includes earrings with contrasting-color conch "pearls" for each clip and detachable drop. The pink, pear-shaped conch "pearl" in the pendant is, at 45 ct (180 grains), probably one of the world's largest. The article by Emmanuel Fritsch and Elise Misiorowski in this issue takes a comprehensive look at the history, biology, fisheries, and unusual gemological features of this rare but fascinating gem material. Jewelry courtesy of Harry Winston, Inc. Photo © Harold & Erica Van Pelt — Photographers, Los Angeles, CA.

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THE GEMOLOGICAL PROPERTIES OF THE DE BEERS GEM-QUALITY SYNTHETIC DIAMONDS

By James E. Shigley, Emmanuel Fritsch, Carol M. Stockton, John I. Koivula, C. W. Fryer, Robert E. Kane, David R. Hargett, and Clayton W. Welch

Gem-quality synthetic diamond crystals weighing up to 11 ct have been grown in limited numbers at the De Beers Diamond Research Laboratory since the 1970s. These crystals have been produced strictly on an experimental basis and are not commercially available. Examination of a group of 14 brownish yellow, yellow, and greenish yellow synthetic diamonds reveals distinctive gemological properties: uneven color distribution, geometric graining patterns, metallic inclusions, and, in most cases, fluorescence to short-wave but not to long-wave U.V. radiation.

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The GIA Research Department recently examined a group of 14 gem-quality synthetic diamonds grown during the past few years at the De Beers Diamond Research Laboratory in Johannesburg, South Africa. This article describes the distinctive gemological properties of eight crystals ranging in weight from 0.40 to 5.23 ct (figure 1) and six faceted specimens weighing from 0.27 to 0.90 ct (figure 2). It represents the first report on these gem-quality synthetic diamonds in the gemological literature. The De Beers material is transparent, free of cleavages and fractures, and is dark brownish yellow, yellow, or light greenish yellow in color. De Beers representatives state that synthetic diamond crystals such as these have been grown at their research facility in South Africa since the 1970s strictly on an experimental basis, and that none has been sold for any purpose. However, the fact that De Beers and other companies (e.g., Sumitomo Electric Industries in Japan; see Shigley et al., 1986) are able to produce synthetic diamonds of gem quality and in sizes that can be used in jewelry demonstrates that the commercial production of sizable gem-quality synthetic diamond crystals is no longer limited by technical difficulties, but rather only by production and marketing costs. At some future time, De Beers may make synthetic diamonds similar to those we examined available for certain high-technology applications.

Although De Beers representatives state that there are no plans to market this material for jewelry purposes, examination of these specimens offers us the opportunity to record the properties of a third group of synthetic diamonds suitable for use as gem material. By comparing the properties of the De Beers material with those of the General Electric and Sumitomo gem-quality synthetic diamonds (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1986), we can also document the gemological properties that are distinctive of gem-quality synthetic

Figure 1. These eight gem-quality synthetic diamond crystals (0.40–5.23 ct) were manufactured on an experimental basis at the De Beers Diamond Research Laboratory and loaned to GIA for study. They fall into three distinct color groups: dark brownish yellow, yellow, and light greenish yellow. Photo © Tino Hammid.

diamonds in general. In this article, where we mention features observed in the De Beers synthetic diamonds that we also noted previously in the General Electric and Sumitomo specimens, the reader should refer to the articles cited above for details on the earlier work.

BACKGROUND

In 1970, almost 15 years after creating the first industrial-quality synthetic diamonds (Bundy et al., 1955), the General Electric Company an-

nounced the limited production of gem-quality synthetic diamond crystals approximately 1 ct in size (Strong and Chrenko, 1971; Strong and Wentorf, 1972; Bundy et al., 1973). Since then, although General Electric eventually decided to discontinue work in this area, research on the growth of large, transparent synthetic diamonds for industrial applications has proceeded at other companies at an accelerating pace. The resulting new diamond synthesis technology has important gemological implications not only for the production of large

Figure 2. These six faceted De Beers synthetic diamonds (0.27–0.90 ct) were also examined for this study. They include the largest faceted synthetic diamonds that have ever been examined at GIA. Photo © Tino Hammid.

synthetic diamond crystals, but also for helping to clarify scientific knowledge of the conditions of diamond formation in the earth. It may also lead to a better understanding of the causes of color in colored diamonds in instances where these causes (especially when related to irradiation or other treatment processes) are still not well known.

Until recently, production of large synthetic diamonds was restricted to a small number of crystals grown only for experimental purposes, and thus there was little chance that one of them

would be encountered in the jewelry market. In 1985, however, Sumitomo Electric Industries in Japan announced the successful production of 1–2-ct gem-quality yellow synthetic diamond crystals. Sumitomo researchers have perfected a method whereby transparent synthetic diamond crystals can be grown in a quantity sufficient to meet the needs of an industrial market. Because of their commercial availability, some of the Sumitomo synthetic diamonds have already been encountered in faceted form in the jewelry marketplace
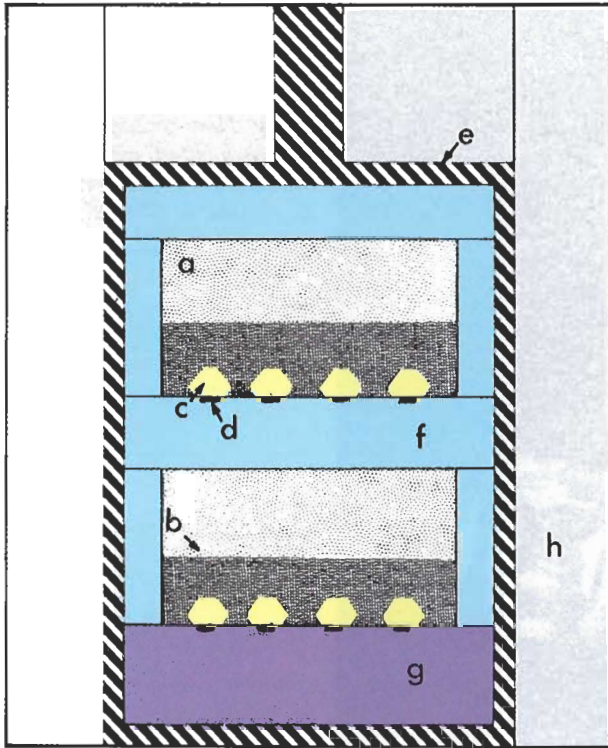
Figure 3. A reaction vessel similar to that shown in this generalized schematic drawing is used to grow single crystals of synthetic diamond by the high-pressure flux method. Temperature differences maintained within the vessel result in the carbon source material dissolving in the flux and crystallizing as single crystals of diamond on the seed crystals. In reaction vessels of this design, diamond crystals grow at several levels at the same time. Parts of the system are labeled as follows: a=carbon source material (diamond powder); b=metal alloy flux; c=growing diamond crystal; d=diamond seed crystal; e=heating unit; f=partition walls; g=bottom wall; h=insulating and pressure medium. This diagram is an idealized sketch and does not depict the actual reaction vessel used in the De Beers diamond synthesis research program. Illustration by Peter Johnston.

(Fryer et al., 1987, p. 44). Previous reports on both the General Electric and Sumitomo gem-quality synthetic diamonds revealed features that distinguish them from natural gem diamonds (Crowningshield, 1971; Koivula and Fryer, 1984; Shigley et al., 1986). The present article demonstrates that the De Beers gem-quality synthetic diamonds also have distinctive gemological properties.

The only process that has proved economical for growing large (1 ct or more) synthetic diamond crystals is a high-pressure flux method; this was first used by the General Electric scientists in the early 1970s and has since been improved (see Strong and Chrenko, 1971; Strong and Wentorf, 1972; Bundy et al., 1973; Muncke, 1979; Wedlake, 1979). The process involves crystallizing diamond from a metal alloy flux at temperatures of about 1100 to 1700°C and pressures of about 50 to 100 kbars, using a high-pressure reaction vessel (see figure 3). De Beers scientists used this same process to produce the diamond crystals provided for our examination.

SYNTHETIC DIAMOND PRODUCTION BY DE BEERS

The De Beers Industrial Diamond Division in Johannesburg began its own research program on diamond synthesis in the late 1950s. Within a few years, De Beers researchers developed techniques for making industrial-grade synthetic diamonds in large quantities. Since then, commercial production of synthetic industrial diamonds at De Beers facilities (as well as elsewhere) has steadily progressed to a level of production of several million carats annually. During the period 1961–1986, for example, 468 million carats of synthetic industrial diamonds were manufactured by De Beers (De Beers Consolidated Mines Ltd., *1986 Annual Report*).

Concurrently, the De Beers Diamond Research Laboratory has also carried out extensive research on the synthesis of larger synthetic diamond crystals for possible high-technology applications. According to the laboratory director, Dr. R. J. Caveney, De Beers has been manufacturing large synthetic diamonds since the 1970s. Dr. Caveney reports that the material loaned to us represents the various sizes, qualities, and colors of synthetic diamond crystals currently being produced.

According to Dr. Caveney, the De Beers synthetic diamond crystals are grown using a molten metal alloy flux (which acts as both a solvent and a catalyst for diamond formation) as well as a standard design reaction vessel similar to the type used to produce commercial diamond grits. Small diamond seed crystals are usually used to initiate crystal growth. Experimentation has shown that there is an optimum number and positioning of the seed crystals in the reaction vessel that will yield the largest and best-quality single crystals.

The synthesis process involves: (1) a starting arrangement of the diamond powder source material and the molten metal alloy flux, and (2) a temperature gradient imposed within the reaction vessel. This gradient causes the diamond powder to dissolve in the metal alloy flux in the hotter source region (where the molten flux is undersaturated with respect to carbon) and the carbon to crystallize as single crystals of diamond in the cooler growth region (where the molten flux is supersaturated with respect to this element). A number of diamond crystals ranging up to 6 or 7 ct can be grown in the reaction vessel during a single production run. Recently, De Beers researchers produced an 11.14-ct brownish yellow gem-quality synthetic diamond crystal (figure 4). The growth period for a 1-ct crystal is reportedly about 60 hours, and for a 5-ct crystal it is about 180 hours. The starting material, composition of the metal alloy flux, nature and positioning of the diamond seed crystals, temperature gradient, absolute temperature, and type of reaction vessel all influence the size, morphology, and yield of large diamond crystals that can be grown.

The synthesis process can be controlled from one production run to the next so that similar diamond crystals can be grown on a repeated basis. The color of a synthetic diamond depends on the type and amount of trapped impurities, which in turn can be influenced by adjusting the chemistry of the components of the growth system. According to Dr. Caveney, while a few pale yellow and colorless synthetic diamonds have been manufactured, currently they are not as easy to grow in high-quality single crystals as the brownish yellow, yellow, and greenish yellow crystals we examined. Blue type IIb synthetic diamond crystals are also more difficult to grow at the present time. However, De Beers is not growing diamond crystals to produce particular colors, but rather to obtain certain desired properties, such as high thermal conductivity, for specific industrial applications. Since the total number of crystals that can be grown during a particular time period is restricted by cost and by the limited amount of synthesis equipment available, De Beers representatives believe that the industrial use of their large synthetic diamonds will remain restricted to highly specialized applications.

RESULTS OF TESTING
Table 1 provides the color, weight, dimensions, and
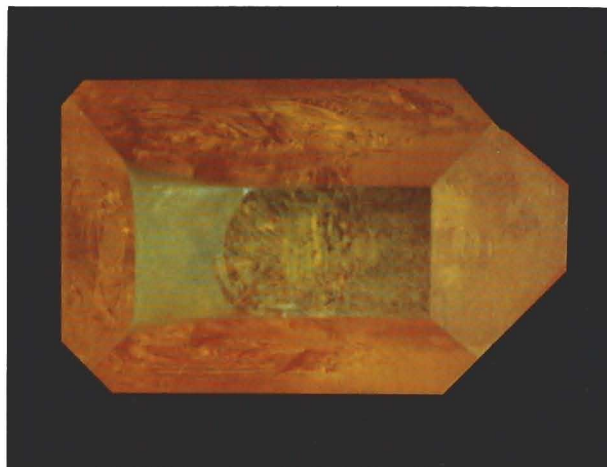
Figure 4. This 11.14-ct synthetic diamond crystal is the largest gem-quality synthetic diamond crystal grown thus far at the De Beers Diamond Research Laboratory in Johannesburg. The crystal (17 mm in its longest dimension) is an elongate octahedron modified by cube faces. Photograph courtesy of Dr. R. J. Caveney.

physical description of the De Beers synthetic diamonds we examined. The eight crystals (figure 1) were reported to be in the same condition as when grown except for cleaning to remove pieces of flux and other surface contaminants. To facilitate viewing of internal features, the upper and lower surfaces of the crystals had also been polished. The amount of material removed by polishing was reportedly limited, but the specimens as supplied to us actually represent only portions of complete crystals (although they are herein referred to as crystals). In the description of crystal morphology and surface features that follows, the characteristics given apply to all of the crystals except as indicated. No obvious differences in shape or surface features were noted between crystals of the three colors; however, the brownish yellow crystals are the largest while those that are greenish yellow are the smallest (which may just be coincidental).

The six faceted synthetic diamonds we examined (figure 2) were cut in standard brilliant and step cuts. Dr. Caveney reported that no problems or unusual behavior were encountered during the faceting of these synthetic diamonds. Table 2 summarizes the more distinctive gemological properties documented by conventional testing methods that we found in these six faceted synthetic diamonds.

Morphology of the Crystals. The synthetic diamond crystals supplied by De Beers are octahedrons modified by cube, dodecahedral, and other faces (reported to be trapezohedral faces — see Woods and Lang, 1975 — and described herein as such) in order of decreasing surface area and frequency of occurrence (figures 1 and 5). We noted the same kinds of crystal faces on the General Electric and Sumitomo synthetic diamond crystals. Some of the De Beers crystals have a square shape, but the majority are rectangular (figure 4). These crystals have relatively sharp edges and corners as well as predominantly flat faces. In contrast, although many natural gem diamond crystals also take the form of an octahedron, they often have rounded edges and corners, convex-appearing surfaces, a more complex arrangement of crystal faces, and can be less symmetrical in shape. Our observations suggest that the De Beers crystals have a simpler (and thus more recogniz-

able) crystal form than do many natural diamonds. This ideal shape results both from the controlled growth environment and from the fact that diamond crystals produced in the laboratory do not undergo the complex history of growth and dissolution stages that is encountered during the formation of many natural diamond crystals (Strong and Chrenko, 1971; Strong and Wentorf, 1972; Muncke, 1979).

Surface Features of the Crystals. A number of researchers have observed several important differences between natural and synthetic diamonds in surface features or markings on the crystal faces; they have attributed these differences to the respective conditions of crystal growth (see, e.g., Tolansky and Sunagawa, 1959; Bovenkerk, 1960; Tolansky, 1961, 1962; Patel and Ramanathan, 1963; Patel and Ramachandran, 1968; Orlov, 1977; Moore, 1979). We found the crystal faces of the De

TABLE 1. Data on the De Beers gem-quality synthetic diamonds examined for this study.

Specimen number	Color	Weight (ct)	Dimensions (mm)	Description
1	Brownish yellow	5.23	11.83 × 9.91 × 4.68	Portion of an octahedron modified by small cube and dodecahedral faces, with two polished surfaces on opposite sides of the crystal
2	Brownish yellow	4.56	12.74 × 9.35 × 4.57	Portion of an octahedron modified by small cube faces, with two polished surfaces on opposite sides of the crystal
3	Brownish yellow	4.10	10.57 × 10.06 × 4.02	Portion of an octahedron modified by very small cube and dodecahedral faces, with two polished surfaces on opposite sides of the crystal
4	Yellow	0.97	6.09 × 5.57 × 2.90	Portion of an octahedron modified by small cube, dodecahedral, and other faces, with two polished surfaces on opposite sides of the crystal
5	Yellow	0.57	5.40 × 4.51 × 2.27	Portion of an octahedron modified by small cube and very small dodecahedral and other faces, with two polished surfaces on opposite sides of the crystal
6	Yellow	1.03	5.40 × 5.33 × 2.81	Portion of an octahedron modified by small cube faces, with two polished surfaces on opposite sides of the crystal
7	Greenish yellow	0.39	4.80 × 4.32 × 1.82	Portion of an octahedron modified by small cube and dodecahedral faces, with two polished surfaces on opposite sides of the crystal
8	Greenish yellow	0.44	4.76 × 4.51 × 1.80	Portion of an octahedron modified by small cube faces and other faces, with two polished surfaces on opposite sides of the crystal
9	Brownish yellow	0.76	5.94 × 5.84 × 3.54	Faceted round brilliant cut
10	Brownish yellow	0.90	6.49 × 6.48 × 3.60	Faceted round brilliant cut
11	Greenish yellow	0.43	5.72 × 3.42 × 2.21	Faceted rectangular step cut
12	Greenish yellow	0.36	4.36 × 4.31 × 2.18	Faceted square step cut
13	Yellow	0.30	5.00 × 3.68 × 2.54	Faceted oval brilliant cut
14	Yellow	0.26	3.79 × 3.16 × 2.25	Faceted rectangular step cut

TABLE 2. Distinctive gemological properties of the brownish yellow, yellow, and greenish yellow faceted De Beers synthetic diamonds[a].

Property	Brownish yellow	Yellow	Greenish yellow
Ultraviolet fluorescence[b]			
Long wave[c]	None	None	None
Short wave	Moderate to strong intensity; yellow or greenish yellow; strongly zoned with nonfluorescing areas	None	Weak intensity; yellow; zoned
Phosphorescence to ultraviolet radiation	None	None	Weak intensity; yellow; duration of 10 seconds or more
Visible-range absorption spectrum	No sharp bands	No sharp bands	No sharp bands
Color distribution	Distinct color zoning; aligned with pattern of internal graining	Distinct color zoning; aligned with pattern of internal graining	Subtle to distinct color zoning
Graining			
Internal	Often obvious; sometimes colored; "hourglass" pattern of intersecting lines	Often obvious; sometimes colored; "hourglass" pattern of intersecting lines	Rarely visible; pattern of intersecting lines
Surface (on table)	Octagonal "stopsign" pattern	Faint lines	Faint lines
Inclusions	Dense clouds of tiny, white-appearing pinpoints; larger metallic inclusions	Clouds of tiny, white-appearing pinpoints; larger metallic inclusions	Isolated, tiny, white-appearing pinpoints; larger metallic inclusions
Crystal surface features[d]	Dendritic patterns; triangular pyramids; granular or irregular surfaces possible on faceted DeBeers synthetics		

[a]Some gemological properties noted as being prominent in the synthetic diamond crystals are less evident or are completely absent in the faceted specimens. Thus, the information provided in this table is based on observations made only on the faceted synthetic diamonds.
[b]The perceived intensity and color of the ultraviolet fluorescence of a gemstone can be influenced by the observation conditions (type and age of the U.V. lamp, condition of the short-wave filter of the lamp, viewing arrangement, brightness of the room, etc.).
[c]A weak orangy yellow or yellow fluorescence was observed in some of these samples (especially in the greenish yellow ones) with a more intense long-wave U.V. lamp (such as a GIA GEM Instruments Model No. 745 unit).
[d]Crystal surface features such as these could be retained at places along the girdle of a faceted stone where there are unpolished remnants of the original crystal faces.

Beers synthetic diamonds to display some distinctive surface features that could be retained on unpolished sections of the girdle of a faceted stone, and thus could be of use gemologically.

Specifically, the octahedral crystal faces on the De Beers synthetic diamonds have the smoothest surfaces. When observed with magnification, these relatively smooth faces can have an irregular, hillocky appearance with slightly raised or lowered areas that form a polygonal arrangement. We noted several distinctive features on these octahedral faces.

Gemologists generally use the term *trigon* to describe any triangular-shaped marking on an octahedral face of a natural diamond crystal. These trigons are sometimes seen on unpolished portions (referred to as "naturals") at the girdle of a faceted natural diamond, and they are used as a confirmation that the faceted stone is in fact a diamond. Such triangular-shaped features can actually occur either slightly above or slightly below the surrounding surface. *Trigons* correctly refer only to small triangular depressions on an octahedral face of a diamond (Webster, 1970). If they project above the surface, these features should correctly be described as triangular pyramids (Patel and Ramanathan, 1963). We observed triangular pyramids of various sizes on the octahedral faces of many of the De Beers synthetic diamond crystals (figure 6). However, we found no trigons, although other researchers have reported seeing them on synthetic diamond crystals in rare instances (Bovenkerk, 1960; Tolansky, 1962). The presence of triangular pyramids and trigons on the octahedral crystal faces of both synthetic and natural diamond crystals indicates that these features cannot be used as an identification criterion.

Other surface features occur on the octahedral faces of most of the De Beers synthetic diamond crystals. These include: (1) numerous tiny pits on the triangular pyramids and other elevated areas of a face that may have resulted from etching when the crystal was cleaned of flux and surface contaminants; (2) a slightly raised edge around part of a

face; and (3) slightly elevated dendritic markings covering portions of a face (figure 7), which is one of the most characteristic surface features seen on synthetic diamond crystals (Tolansky and Sunagawa, 1959; Tolansky, 1962; Shigley et al., 1986).

The cube faces are smaller than the octahedral faces, but they were observed on all of the De Beers synthetic diamond crystals we studied. In contrast, cube faces are not commonly seen on natural gem diamond crystals, and when they do occur, their surface texture is quite rough and pitted (Tolansky, 1961, 1962). On the De Beers crystals, the cube faces are planar but they display an irregular, polygonal, or granular appearance over their entire area (figure 8). We also observed a few square pyramids as well as some dendritic surface markings on these faces.

The dodecahedral faces are small, elongate, and have rough surfaces. They commonly exhibit striations oriented parallel to the long direction of the face and often running its entire length. These
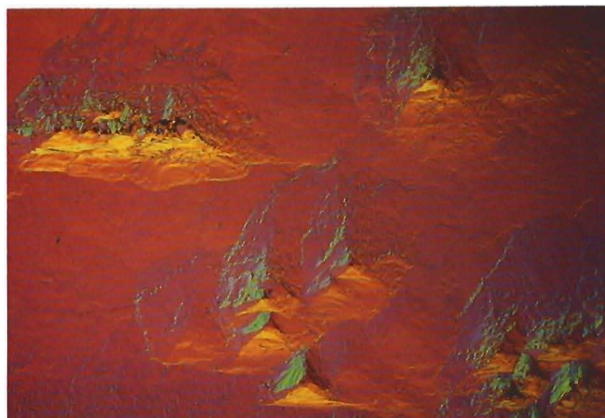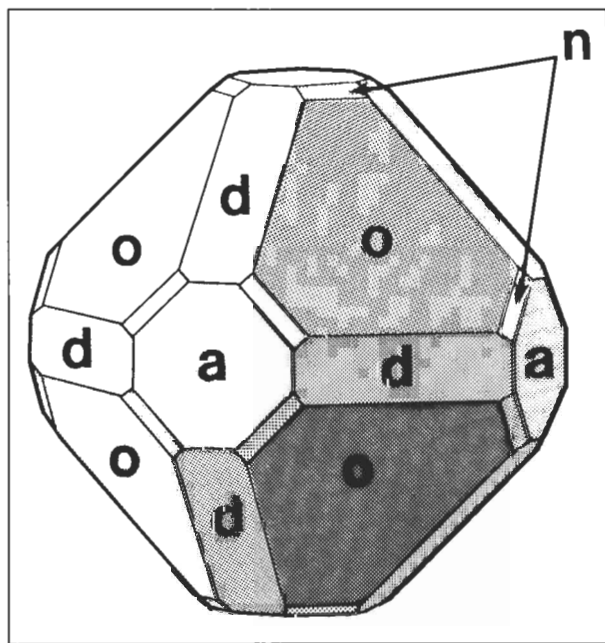

Figure 6. Triangular pyramids were observed on the octahedral faces of many of the De Beers synthetic diamond crystals. This photomicrograph was taken by the Nomarski interference contrast method, which emphasizes slight differences in relative surface elevation by the use of color. The triangular features shown here are all pyramids that project above the surrounding surface (and therefore should not be called trigons). Magnified 60×.

Figure 5. In this drawing of an idealized synthetic diamond crystal, the crystal is an octahedron modified by other smaller faces. The crystal faces are identified as follows: o = octahedral; a = cube; d = dodecahedral; n = trapezohedral. On an actual crystal like the ones we examined, the number, arrangement, and relative sizes of the crystal faces may differ slightly from what is depicted here. Illustration by Peter Johnston.

faces are unequally developed in size, and do not appear at all on some crystals.

The fourth type of crystal face (believed to be trapezohedral) almost always occupies the smallest surface area on the De Beers synthetic diamond crystals. These faces have the roughest appearance, can also be striated, and, like the dodecahedral faces, do not appear on all crystals.

Our observations on the De Beers crystals confirmed many of the surface features (e.g., cube faces, dendritic markings) that have been found on other synthetic diamonds, such as the Sumitomo material. Whether these features on the De Beers crystals are the result of growth processes or of partial dissolution is unclear. However, the absence of trigons combined with the fact that most surface features (such as the triangular pyramids) project above the surface suggests that these features result from growth processes. Nevertheless, the dendritic markings and some of the other surface features are distinctive of these and other synthetic diamond crystals, and they have not been observed on natural diamond crystals. Therefore, these features can provide useful identification guidelines.

For the most part, the girdles of the faceted De Beers synthetic diamonds we examined are either
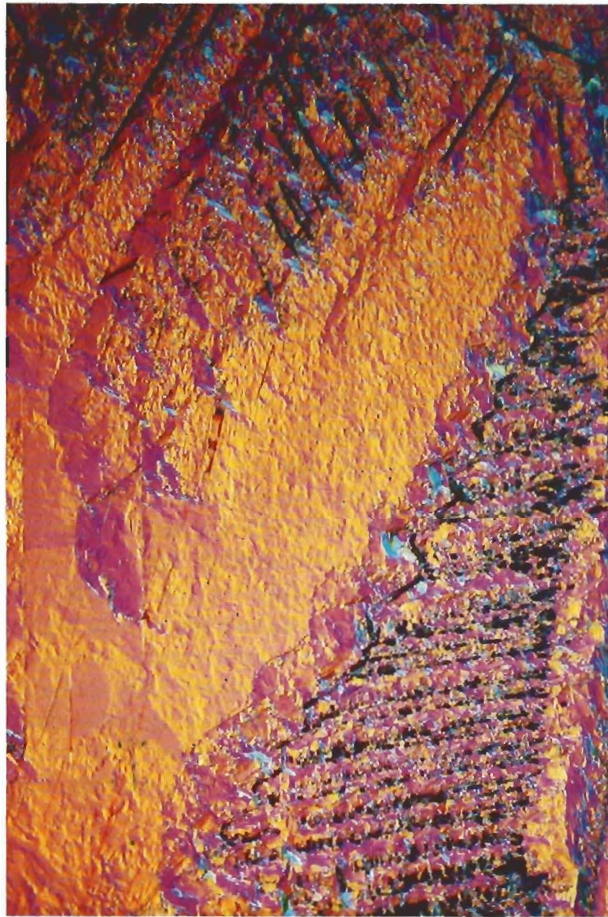
Figure 7. Dendritic surface markings on an octahedral face, shown here on a De Beers specimen, are one of the most characteristic features of a synthetic diamond crystal. Nomarski interference contrast; magnified 40×.

Figure 8. The cube faces of the De Beers synthetic diamond crystals examined all have an irregular, granular appearance. Nomarski interference contrast; magnified 45×.

polished or have a bruted appearance. We did find several small unpolished areas that display the same rough, dendritic, striated, or irregular surface features that we observed on the synthetic diamond crystals. If observed on a cut stone, such features could be useful for identification purposes.

Color. Five of the 14 De Beers synthetic diamonds examined are dark brownish yellow; this group includes the largest crystals and cut stones. Five of the synthetic diamonds are yellow, while the last four are light greenish yellow. We found the color in most of the synthetic diamonds to be unevenly distributed (figure 9) with respect to either hue or intensity. This color zonation can vary from rather subtle to quite pronounced. The boundaries be-

tween areas of slightly differing color may be sharp or gradual, and they are sometimes marked by grain planes that are themselves colored. Although uneven coloration was also noted in the General Electric and Sumitomo synthetic diamonds, the patterns of color zoning in these three instances do not correspond.

Figure 9. In this faceted yellow De Beers synthetic diamond, the unevenness of the color is quite pronounced, with both yellow and colorless areas forming a geometric arrangement. Color zonation such as this is rarely if ever seen in a faceted natural diamond of similar color. Magnified 10×.
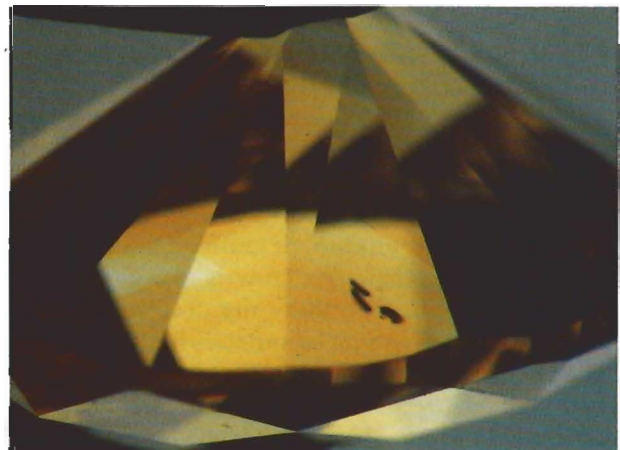
We found that this color distribution in the De Beers synthetic diamonds, although uneven, usually forms a regular geometric pattern. The pattern of color zoning can be correlated not only with the outer shape of the crystal but also, more importantly, with the internal growth structure of the diamond. An explanation of this relationship requires some brief remarks on the different mechanisms of diamond crystal growth in the earth versus those in the laboratory.

It is possible to find natural diamond crystals that are virtually free of internal structural irregularities. This is due to the fact that natural diamond crystals grow over extended periods of time in the earth by the addition of layers of material mostly parallel to the surfaces of an octahedron. This octahedral-type growth (also described as "faceted" growth because of its very planar character) produces the prominent octahedral faces that are characteristically seen on many natural diamond crystals.

In the laboratory, diamond formation takes place in just a matter of days. This rapid crystallization leads to the growth of crystals by the addition of material parallel not only to octahedral faces but also to cube, dodecahedral, and possibly other crystal faces as well (see Lang, 1979, for details). As a result, in a large laboratory-grown diamond there invariably seem to exist different internal regions, or sectors, of the crystal. Within each sector, growth parallel to a particular crystal face (octahedral, cube, or other) predominates during crystal formation. These various growth sectors can differ from one another in impurity content, in the number and kinds of structural defects, and in physical properties such as polishing hardness. Such differences provide a means of differentiating between growth sectors. As growth proceeds, the boundary zones between adjacent sectors also become the sites where impurities and defects are likely to become concentrated.

In the brownish yellow or yellow De Beers synthetic diamond crystals we examined, these growth sectors can be recognized by marked variations in their color and ultraviolet fluorescence, by the occurrence of prominent grain planes (parallel to cube faces) in the cubic growth sectors that are absent in the others, and by the occasional presence of inclusions along boundaries between some sectors. Growth sectors are also present in the greenish yellow crystals but are less easy to distinguish. Figure 10 is an idealized drawing of the arrangement of octahedral and cubic growth sectors in a brownish yellow synthetic diamond crystal. These internal growth sectors may not be as equally well developed or as centrally positioned in some crystals as is depicted here, and they may not be quite as obvious to the eye. For all of the crystals, the growth sectors were more easily visible when the stones were immersed in methylene iodide. Even in some of the faceted specimens, the growth sectors are apparent (the color zoning in the cut stone in figure 9 results from sector growth).

We suggest that this arrangement of distinct growth sectors, as evidenced by variations in color zoning and other gemological properties, is one of the most prominent characteristics of yellow synthetic diamond crystals like the De Beers material. Although not fully appreciated at the time, this sector growth is responsible for the distinctive color zoning and graining that we noted as being so prominent in the Sumitomo synthetic yellow diamonds. We should caution, however, that we have observed somewhat similar-appearing color zoning (that is perhaps due to causes other than sector growth) in faceted natural yellow diamonds, but only on very rare occasions.

Spectroscopy. The vast majority of natural yellow diamonds are classified as type Ia (for details of diamond classification by type, see Shigley et al., 1986), and they usually display one or more sharp absorption bands of varying intensity in the violet and blue portions of their visible-range spectrum (including those known as the "Cape" series of bands). When viewed with a hand spectroscope, the spectra of the De Beers synthetic diamonds exhibit no sharp bands in the visible range; there is only a gradually increasing absorption toward the ultraviolet. This was also the case for the General Electric and Sumitomo synthetic yellow diamonds. Visible-range absorption spectra of this kind are characteristic of type Ib diamonds. The spectrophotometer graphs reproduced in figure 11 confirm these observations, and also help to illustrate the differences in color among the De Beers synthetic diamonds. For the brownish yellow and yellow specimens, the spectral curves begin to rise markedly at about 560 nm. Both kinds of synthetic diamond absorb violet, blue, and some green light and transmit the remaining portions of the spectrum, which gives rise to their yellow color.

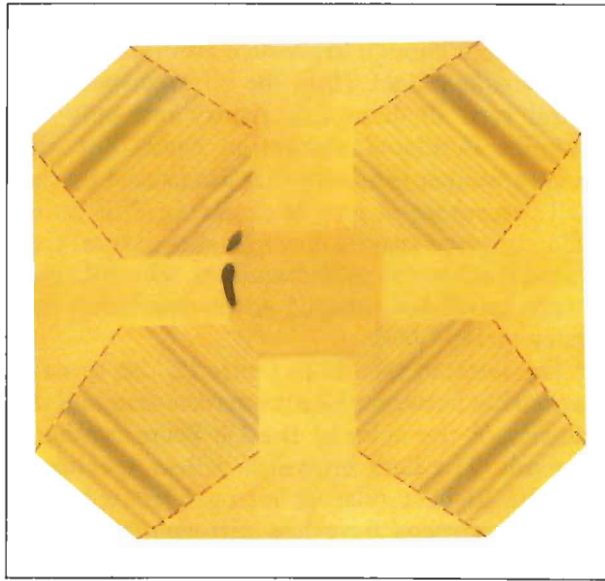The spectra of the four light greenish yellow

Figure 10. This idealized drawing of the internal structure of one of the brownish yellow synthetic diamond crystals (viewed from a direction perpendicular to a cube crystal face) illustrates the prominent internal sector growth and the resulting distinctive graining patterns and color·zoning. These features have been accentuated here for clarity and to emphasize their spatial relationship to each other. Octahedral and cubic growth sectors of similar size are arranged in cross-shaped patterns around the central core of the crystal (which is also a cubic growth sector). Crystal growth proceeded outward from the center in these sectors. Within the cubic sectors, crystal growth was accompanied by the development of colored graining. Graining is absent in the adjacent octahedral sectors. Along the edge of the central zone there are several crystallographically oriented metallic inclusions as well as additional grain lines that mark this boundary. Illustration by Robin Teraoka.

Figure 11. The visible-range absorption spectra of the three colors of De Beers synthetic diamonds exhibit no sharp absorption bands but only a gradually increasing absorption toward the violet. The spectrum of the greenish yellow material also exhibits a slight increase in absorption toward the red. The spectra were recorded at room temperature with a Pye-Unicam 8800 UV-VIS spectrophotometer from crystals that have two nearly parallel, polished sides. Absorption values along each curve were normalized for a unit path length to permit direct comparison of the spectra. Illustration by Peter Johnston.

synthetic diamonds are slightly different. Specifically, these synthetic diamonds absorb less light in the violet and blue. Their spectral curve is shifted, and begins to rise at about 520 nm, and it also exhibits an increase in absorption above 620 nm that is slight but nonetheless significant in modifying the otherwise yellow color of this material. The absorption of violet and blue, as well as some orange and red, gives rise to a transmission window in the green-yellow region between 520 and 620 nm and thus to the greenish yellow body color.
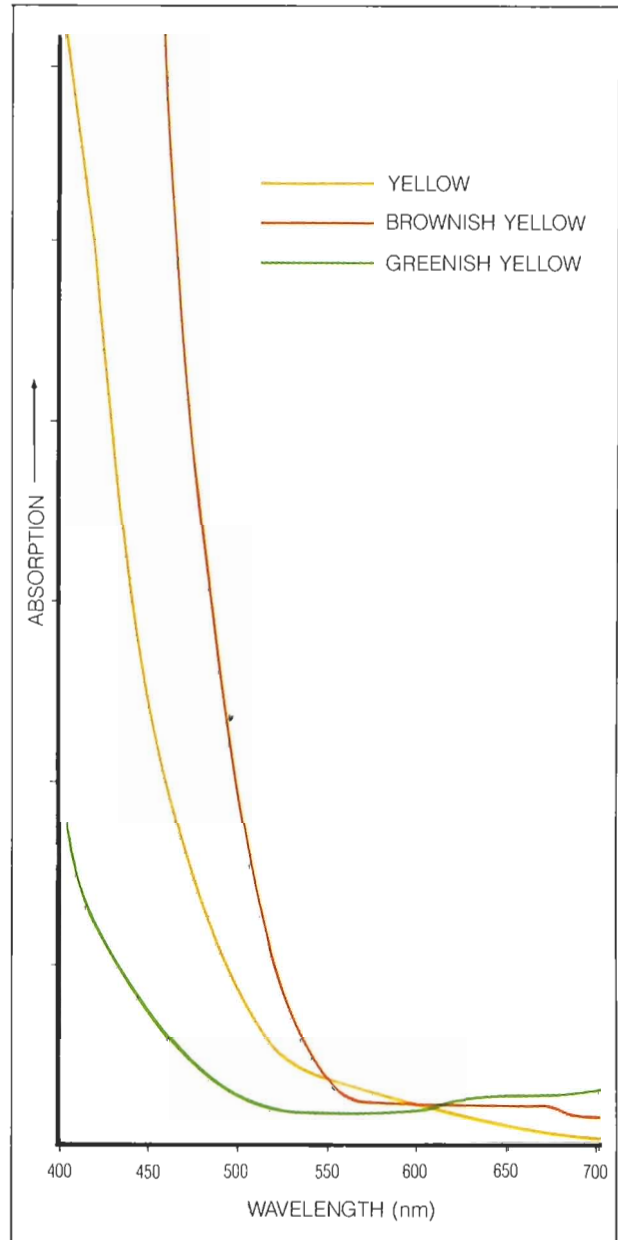
The greenish yellow color of synthetic diamonds has been the subject of other scientific studies. For instance, Collins and Spear (1982) investigated some General Electric synthetic green diamonds grown from a nickel flux. They indicated that the green color results from absorption at the violet end of the visible-range spectrum (due to nitrogen) in conjunction with a broad-band absorption centered in the near-infrared (at about 1.4 eV) and extending into the red portion of the visible spectrum (about 2.0 eV). Wedlake (1979) noted that the green color in some other synthetic diamonds is concentrated near nickel inclusions. Orlov (1977, p. 127) described experimental work in which natural diamonds had been colored green by the diffusion of nickel into their surfaces. On the basis of this circumstantial evidence, Collins and Spear suggest that the 1.4 eV broad-band absorption extending from the near-infrared into the visible range that contributes to the green color of synthetic diamonds is associated with nickel that becomes incorporated in the diamond crystal structure during crystal growth in the laboratory. They also attribute the presence of two groups of sharp absorption bands in the visible range at approximately 659 and 494 nm in this material to nickel. The fact that the De Beers synthetic diamonds display metallic inclusions that contain nickel (see later discussion) may indicate that the greenish yellow color of some of the De Beers material is also the result of trace amounts of this element.

Infrared Spectra. The infrared spectrum can be used to classify a diamond according to its type. Figure 12 shows the infrared spectra obtained with a Fourier Transform infrared (FTIR) spectrometer for each of the three colors of De Beers synthetic diamonds that we examined; these spectra indicate that the synthetic diamonds have nitrogen impurities in the form of type Ib. The yellow color of type Ib diamonds is caused by nitrogen that is dispersed as single atoms substituting for carbon atoms in the diamond crystal structure (Chrenko et al., 1971; Clark et al., 1979). Most natural yellow gem diamonds are type Ia, and they contain nitrogen in the form of small clusters of neighboring atoms. Natural type Ib yellow gem diamonds are rare. As mentioned above, such diamonds lack sharp absorption bands in their visible-range spectra. However, natural type Ib diamonds with dispersed nitrogen atoms also invariably contain a small amount of nitrogen atoms in an aggregated form (but not enough to produce absorption bands in the visible range). Thus, the infrared spectra of natural type Ib diamonds display not only the dominant Ib-related absorption bands but also bands of weaker intensity that are caused by this small percentage of type Ia character. This difference in infrared spectra distinguishes natural type Ib from synthetic type Ib diamonds, which display no type Ia–related infrared absorption bands (see Shigley et al., 1986).

The infrared spectra in figure 12 also reveal a relationship between the nitrogen content and the intensity of the color of the De Beers synthetic diamonds. The dark brownish yellow specimens have the highest relative nitrogen content, the yellow specimens have less nitrogen, while the light greenish yellow specimens contain the least nitrogen.

The infrared spectra of the De Beers synthetic diamonds exhibit an additional interesting feature. As noted above, the visible-range absorption spectrum of the greenish yellow specimens is somewhat different from that of the other two colors. Microscope examination of one of the greenish yellow faceted synthetic diamonds revealed a color zonation in which most of the internal growth sectors are yellow, a few are colorless, and some appear distinctly green. In addition to the expected type Ib absorption, the infrared spectrum of a green sector of this specimen (figure 13) displays weak bands that look very similar to infrared features characteristic of type IIb natural diamonds, which are electrically conductive because of the presence of boron instead of nitrogen and are usually blue or gray. The type IIb–like infrared absorption features that we observed in this stone (and which would not be expected in the infrared spectrum of a nitrogen-containing type Ia or type Ib diamond) are located at 4090, 2930, 2800, and 2450 cm^{-1}. Whether these bands are associated with boron or with some other defect center is currently under study.

In the previous section we briefly described a thesis that proposes that the greenish color of some of the De Beers synthetic diamonds could be due to the presence of traces of nickel in the diamond crystal structure (see Collins and Spear, 1982). On the other hand, if boron or some other defect center that gives rise to type IIb–like bands in the infrared spectrum were present in the green sectors of the greenish yellow De Beers synthetic diamonds, this
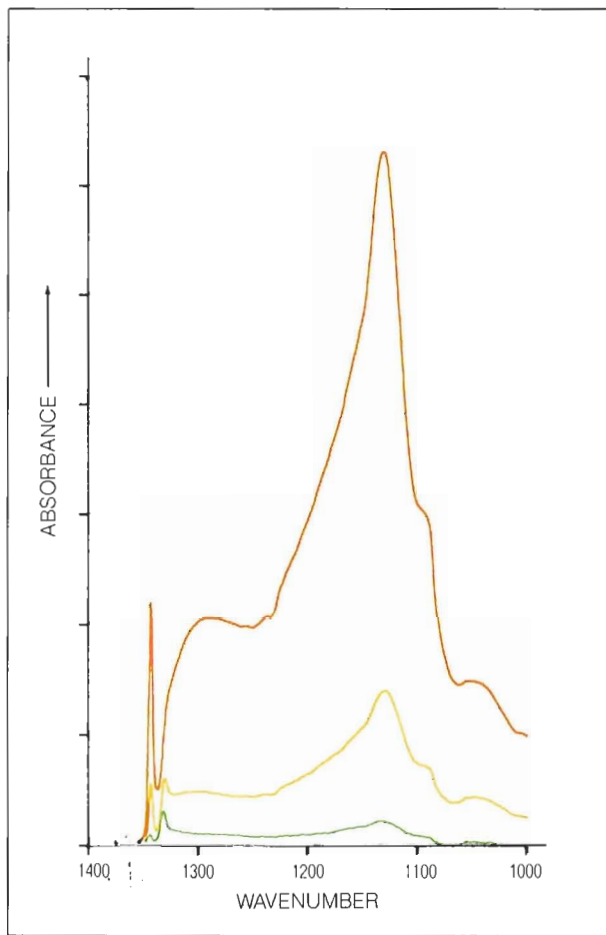
Figure 12. Features in the 1000–1400 cm^{-1} portion of the infrared spectra of the dark brownish yellow (top), yellow (middle), and light greenish yellow (bottom) De Beers synthetic diamonds indicate that they are all principally type Ib with no type Ia character. The spectra of natural type Ib diamonds invariably contain not only the dominant type Ib–related infrared bands, but weaker type Ia–related bands as well. The spectra shown here also reveal that the De Beers synthetic diamonds have different relative contents of nitrogen, ranging from relatively high in the dark brownish yellow, lower in the yellow, and lowest in the light greenish yellow specimens. The spectra were recorded with a Nicolet 60SX FTIR spectrometer system. Absorption values along each curve were normalized to a unit path length to permit direct comparison of the spectra.
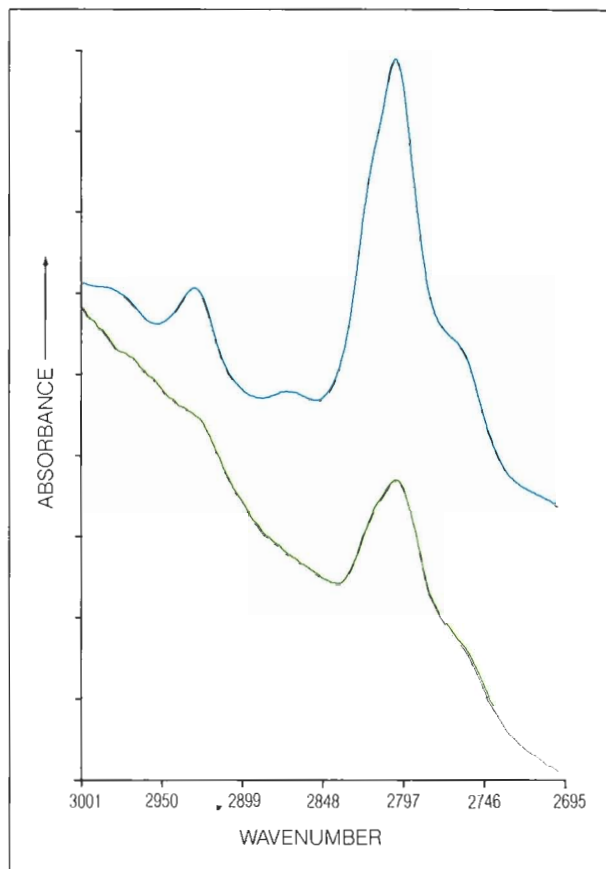

Figure 13. This portion of the infrared spectrum of a green growth sector in a greenish yellow De Beers synthetic diamond (bottom) strongly resembles that of a blue type IIb natural diamond (top), which suggests that the green sectors of this synthetic diamond have a type IIb–like character. The spectra were recorded with a Nicolet 60SX FTIR spectrometer system.

might account for some of our observations on the properties of these specimens.

If both dispersed nitrogen (type Ib) and dispersed boron (type IIb) coexisted in neighboring sites in the crystal lattice of a diamond, they could compensate for each other electrically (depending on their relative amounts), and they should not give rise to their expected yellow and blue colors simultaneously. We speculate that, in the green sectors of this synthetic diamond, these two impurities may be either dispersed as single atoms far enough apart from each other in the lattice as not to interact, or they may form a mosaic-like array of separate nitrogen- or boron-rich domains, or regions, within the diamond on an ultramicroscopic scale. Either distribution of nitrogen and boron atoms might account for the superposition of both the type Ib (yellow)– and type IIb (blue)–related features observed in the visible-range and infrared absorption spectra. This would also provide an alternative to the theory that the green color in these specimens is due to trace amounts of nickel. Absorption of violet and blue light (by nitrogen) and of orange and red light (by boron) could result
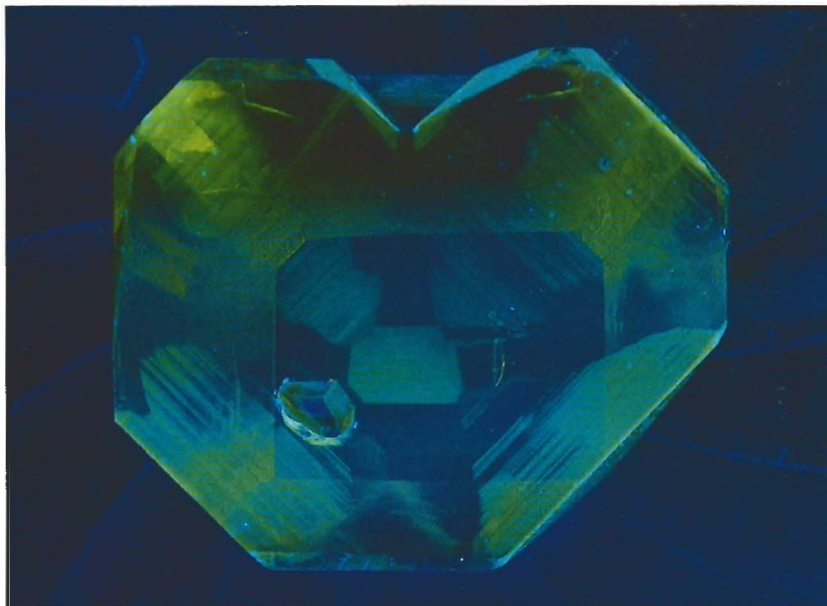
Figure 14. When this brownish yellow De Beers synthetic diamond crystal was exposed to short-wave ultraviolet radiation, the cubic growth sector in the center and the four sectors that form a "cross" pattern fluoresced intensely while the intervening octahedral sectors were inert. Parallel graining in the four outer cubic sectors was also highlighted by the fluorescence emission. The same pattern of fluorescence emission from portions of a crystal can also be seen on the crystal exterior, with the cube faces fluorescing brightly while the octahedral faces are inert. Magnified 6×; five-hour exposure.

in a diamond with a green color. Separation of dispersed boron and dispersed nitrogen atoms, or separation of type IIb domains from one another by type Ib domains, might also account for the lack of electrical conductivity in this cut stone (although such conductivity is a characteristic feature of type IIb diamonds, and was observed on the surfaces of the greenish yellow crystals).

Interestingly enough, a weak, sharp absorption band at 659 nm was recorded at room temperature with the FTIR spectrometer in all the De Beers synthetic diamonds *except* the greenish yellow specimens. Collins and Spear (1982) observed a band at this location in the spectra of nickel-doped General Electric synthetic diamonds recorded at the cryogenic temperature of 77 K (−196°C). However, our observations of this band only in the brownish yellow and yellow De Beers synthetic diamonds suggest that any relationship between the greenish color of the greenish yellow synthetic diamonds that we examined and the presence of nickel impurities from the flux metal still seems questionable.

Ultraviolet Fluorescence. We tested the reaction of the De Beers synthetic diamonds to ultraviolet radiation at room temperature with standard U.V. lamps (Ultraviolet Products models UVG-11 and UVL-11). When exposed to long-wave U.V. radiation, all 14 of the De Beers synthetic diamonds are inert. In contrast, the reaction to short-wave U.V. radiation is varied. All of the brownish yellow specimens fluoresce a moderate to strong yellow or

greenish yellow; the yellow synthetic diamond crystals fluoresce weak to moderate yellow, but the faceted specimens are inert; and all of the greenish yellow synthetic diamonds fluoresce a weak yellow. When the short-wave U.V. lamp is turned off, only the greenish yellow specimens phosphoresce, with a weak yellow color that lasts for 10 seconds or more (a common feature among the type IIb natural diamonds we have examined). This fluorescence and phosphorescence is most pronounced near the outer portions of the greenish yellow crystals.

In some cases, the short-wave U.V. fluorescence is emitted in a geometric zonal pattern that corresponds to the arrangement of internal sector growth described earlier; this is most pronounced in the brownish yellow crystals. As shown in figure 14, the cubic growth sectors of this crystal fluoresce intensely, while the adjacent octahedral sectors fluoresce little or not at all. Within the cubic sectors, parallel grain lines (see discussion below) are highlighted by the fluorescence emission. In addition, the fluorescence is frequently brighter near the edges between sectors. This zoned pattern of fluorescence was also observed in some of the faceted De Beers synthetic diamonds (figure 15).

This ultraviolet fluorescence behavior, particularly the response to short-wave U.V. radiation, is more varied than that observed in the Sumitomo synthetic diamonds. Thus, U.V. fluorescence may be less reliable as an identifying gemological property for synthetic diamonds of other than brownish yellow or intense yellow color.
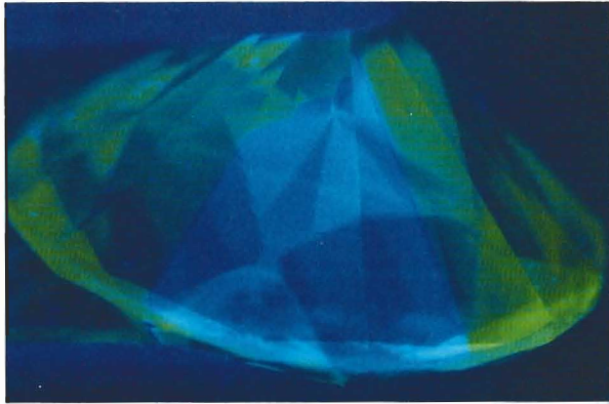
Figure 15. In faceted specimens, too, the short-wave ultraviolet fluorescence of a brownish yellow De Beers synthetic diamond shows the zoned pattern related to the internal growth sectors of the crystal. Magnified 20×; four-hour exposure.

Fluorescence to X-Rays. The De Beers synthetic diamonds were tested with a conventional X-ray unit operating at 72 kV and 13 mA for several seconds of exposure. The brownish yellow specimens fluoresce a dark yellow or greenish yellow of moderate intensity, again in a zonal pattern, with very slight or no phosphorescence. The yellow specimens fluoresce in a similar pattern and color but with greater intensity. Again, there is little or no phosphorescence. The greenish yellow synthetic diamonds fluoresce an even stronger yellow in a zonal pattern and, in addition, exhibit a strong phosphorescence that persists for more than 10 seconds. When tested in a similar manner, the General Electric synthetic yellow diamonds were inert while the yellow Sumitomo material fluoresced bluish white with no phosphorescence.

Cathodoluminescence. Diamonds will often luminesce when exposed to an electron beam, a characteristic referred to as cathodoluminescence. Previous studies of synthetic diamonds indicate that they can display intense and often geometrically zoned cathodoluminescence, and that this response usually differs from the pattern of cathodoluminescence observed in natural diamonds. As figure 16 illustrates, this markedly zoned luminescence can also be quite useful in investigating the internal growth sectors as well as in studying the differences in growth history of both natural and synthetic diamonds (see Kiflawi and Lang, 1974; Woods and Lang, 1975; Hanley et al., 1977).

Figure 16. In a natural diamond crystal (left), visible cathodoluminescence is exhibited by parallel zones on four sides of the crystal, where they mark successive positions of the outer edge of the diamond as it grew. Crystal growth occurred by addition of new material along planes parallel to the faces of an octahedron. Although this diamond crystal formed almost entirely by octahedral-type growth, the complicated pattern of visible luminescence is evidence of the complex growth history that is typical for many natural diamonds. In the faceted brownish yellow De Beers synthetic diamond (right), the pattern of cathodoluminescence reveals an internal structure consisting of cubic (luminescing a greenish yellow) and octahedral (inert) growth sectors. Photographs courtesy of Dr. G. S. Woods, C. S. O. Valuations, London (left) and Mrs. M. T. Rooney, D. T. C. Research Centre, Maidenhead (right).
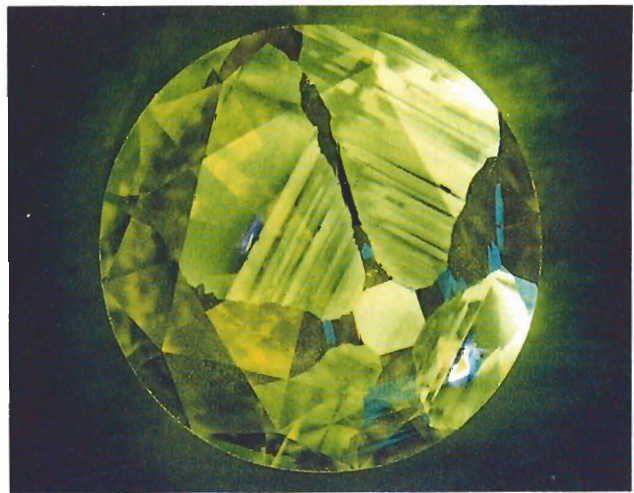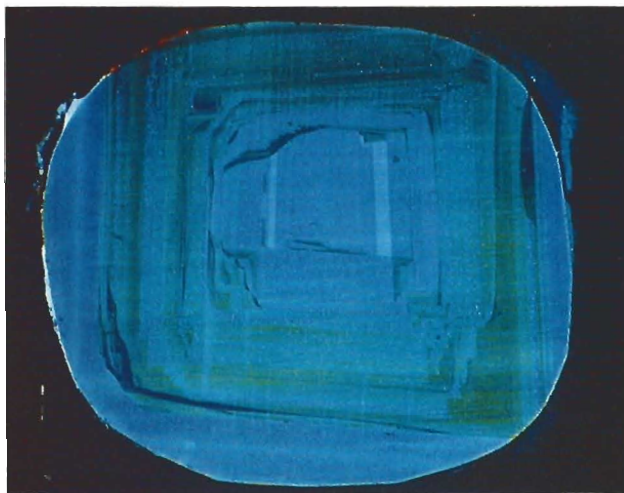
Our examination of the De Beers specimens with a Luminoscope cathodoluminescence unit revealed that the brownish yellow and yellow synthetic diamonds luminesce an orangy yellow, yellow, or greenish yellow that varies in intensity from weak to strong. The greenish yellow synthetic diamonds luminesce a weak greenish yellow. While these cathodoluminescence colors alone may not help distinguish synthetic from natural diamonds, results of the studies cited above demonstrate that observation of the zoned patterns of cathodoluminescence (as recorded, perhaps, with more sophisticated equipment) can often be significant in making this separation.

Electrical Conductivity. Each of the De Beers synthetic diamonds was tested for electrical conductivity with a gemological conductometer. All of the faceted stones are nonconductive, as are the brownish yellow and yellow crystals. However, when conductivity between two crystal faces on the greenish yellow synthetic diamonds was tested, the faces were found to be slightly conductive. Perhaps the incorporation of higher levels of impurities or defects near the outer surfaces of these crystals may explain the electrical conductivity as well as the surface ultraviolet fluorescence of the greenish yellow crystals (we have noted both features in natural type IIb diamonds).

Thermal Conductivity. When tested with a thermal conductivity meter (a GIA GEM Instruments Duotester), the De Beers synthetic diamonds (like the General Electric and Sumitomo materials) exhibit the high thermal conductivity expected for diamonds in general. Therefore, this test cannot be used to separate synthetic from natural diamonds.

Specific Gravity. The specific gravity of each of the De Beers synthetic diamonds was determined using a heavy-liquid procedure devised by Koivula and Fryer (1984). The specific gravity of these specimens was estimated to lie between 3.50 and 3.51, which is within the range of natural and other synthetic diamonds.

Examination with the Microscope. *Inclusions.* Several of the De Beers synthetic diamonds of all three colors contain relatively large, dark inclusions with a metallic luster that we presume to be particles of solidified flux material. Inclusions such as these are not found in natural diamonds.

These metallic inclusions have a tabular, elongate, or needle-like shape (figure 17). The shapes result from the inclusions filling cavities in the material that show distinct crystal faces. The inclusions occur singly or in small groups, can vary in size, and are occasionally aligned in a linear or planar fashion with their long axes parallel to grain lines or to the boundaries between internal growth sectors. They can be located either near the edge or deep within a crystal, and thus are also present in the faceted specimens. In some instances, the area immediately surrounding a group of such inclusions appears slightly lighter in color for distances of several tenths of a millimeter. These inclusions seem to be larger in the greenish yellow specimens.

Tiny, white-appearing "pinpoints" were also observed. They, too, are often arranged in a pattern along grain lines or growth sector boundaries (figure 18). In some of the faceted specimens, these pinpoint inclusions occur in such abundance that they assume a cloud-like form that imparts a haziness to the stone (figure 19).

Color Zoning. Also interesting are the narrow, near-colorless, vein-like areas (figure 20) that extend inward from the edge of a crystal, usually just beneath a cube or dodecahedral face. When these areas are clearly visible, their location is seen to correspond to that of the cubic growth sectors discussed earlier. The variation in color between the vein-like areas and adjacent growth sectors is

Figure 17. Large metallic inclusions, presumably particles of solidified flux filling cavities in the host stone, were observed in several of the De Beers synthetic diamonds. Magnified 25×.
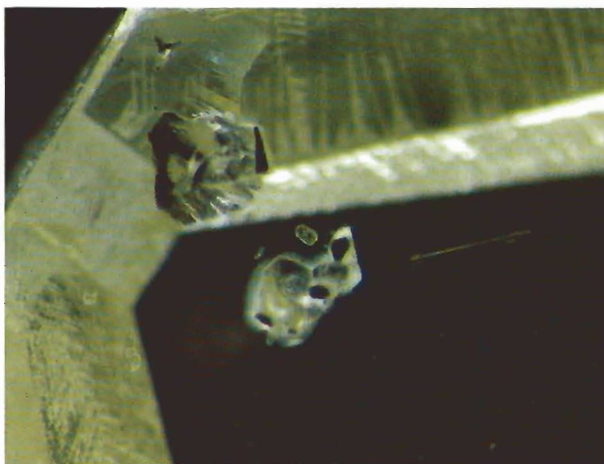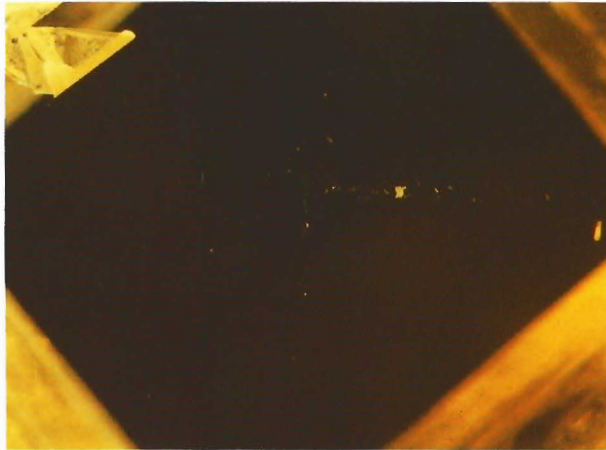
Figure 18. Tiny pinpoint inclusions arrayed in the form of a "cross" in the center of this yellow De Beers synthetic diamond crystal mark the boundaries between internal growth sectors. Magnified 20×.

Figure 19. In some of the faceted De Beers synthetic diamonds, numerous tiny pinpoint inclusions form a "cloud" that gives a hazy appearance to the stone. Magnified 20×.

likely to be related to the differences in nitrogen incorporation among sectors during crystal growth. Near-colorless, vein-like areas of similar appearance were also prominent in the yellow Sumitomo synthetic diamonds.

Graining. ·Many of the De Beers synthetic diamonds also exhibit a distinct pattern of grain lines that are seen internally and sometimes on the surface. Before we describe this feature, however, some remarks about the meaning of the term *graining* may help clarify our observations.

Graining is a general term used by gemologists to describe irregular, linear, or planar growth features visible either internally or on the surface of a diamond. When there is surface graining, it usually can be correlated with internal graining. Although graining seems to be a relatively common feature in gem diamonds, and may be an important factor in the quality grading of otherwise flawless stones, little has been written on the subject except for the articles by Kane (1980, 1982).

Internal graining has been ascribed to differences in lattice orientation, the presence of inclusions, or other structural irregularities in the diamond (Kane, 1982). Its occurrence often seems to be associated with optical birefringence, which might in turn be related to strain. Some internal graining has been correlated with twinning in diamond (J-P. Poirot, pers. comm., 1987). However, most internal graining occurs in untwinned diamond crystals. While there is probably some rela-

Figure 20. The narrow, near-colorless, vein-like areas that extend inward from the four corners of this yellow De Beers synthetic diamond crystal correspond to the cubic growth sectors. These near-colorless areas may not be as well developed or as obvious in a faceted stone, but they are commonly seen and are quite distinctive of this material. Magnified 20×.

tionship between internal graining and features such as irregularities in crystal structure, we suggest that much internal graining is due to a slight difference in refractive index between neighboring regions of the diamond that gives rise to an optical contrast between the two regions. A difference in refractive index is brought about by minor variations in composition and/or structure. In the

case of the synthetic diamonds we examined, these differences are most likely associated with variations in nitrogen content.

Internal graining in natural diamonds usually parallels the four possible octahedral planes in the crystal. As such, it provides a phantom temporal record of the crystal shape during earlier stages of crystal growth. In the De Beers synthetic diamonds, however, most of the internal graining is parallel to cube faces, and is best developed in the cubic growth sectors (but it is absent in the neighboring octahedral sectors—again, see figure 10). This may be the result of more rapid growth in the cubic sectors, which leads to a greater probability of compositional differences and structural irregularities (and thus to differences in refractive index) in these sectors.

Some graining marks the boundaries between growth sectors where interfacing of compositional or structural differences can also lead to refractive-index variations. Both the boundary- and the cubic sector–related internal graining give rise to the distinctive "hourglass" and octagonal "stopsign" patterns seen in some of these synthetic diamonds (figures 21 and 22). Similar patterns of graining were noted in the Sumitomo synthetic diamonds. Internal and surface graining of this kind has not been reported in natural diamonds, and is thus a key identification criterion.
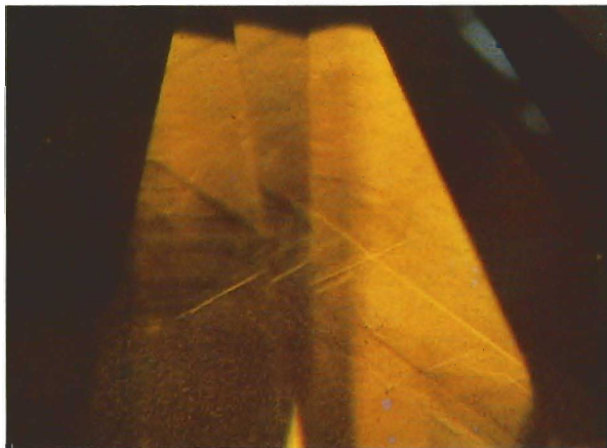
Appearance in Polarized Light. Natural diamonds exhibit linear, cross-hatched, mosaic, or inclusion-related strain patterns when observed in polarized light. In contrast, the De Beers synthetic diamonds have a distinct cross-shaped strain pattern (figure 23). Typically, this pattern is centered at the midpoint of the crystal. In a faceted synthetic diamond, the strain pattern is aligned along the same directions as the internal graining, and thus can be an aid in examining a stone for the "hourglass" graining pattern. Some strain may also be associated with large inclusions in this material.

Chemical Analysis of Inclusions. Using a Cameca MBX electron microprobe, Paul Hlava investigated the chemical composition of the large metallic inclusions exposed at the surfaces of one of the yellow and one of the greenish yellow synthetic diamonds. Because of the irregular surfaces of the inclusions, fully quantitative results could not be obtained. However, X-ray mapping of the inclusions in the two synthetic diamonds showed them to be metal alloys that are similar in composition, with close to 60 wt.% iron and 40 wt.% nickel, which is a common composition for the flux material used in diamond crystal synthesis (see

Figure 22. An octagonal "stopsign" pattern of surface graining is also visible on the polished table of the synthetic diamond shown in figure 21. Near the lower right-hand edge of the table, the central cubic-sector core of the crystal is recognizable from its octagon-shaped outline. Four narrow octahedral growth sectors extend outward from the core at right angles to one another. Also visible are the four cubic growth sectors with their parallel surface grain lines. Oblique illumination; magnified 30×.

Figure 21. The "hourglass" pattern as seen through the pavilion of this faceted brownish yellow De Beers synthetic diamond results from the development of prominent internal graining; it is a characteristic feature of many large synthetic diamonds. Magnified 30×.

Bundy et al., 1973). Inclusions of metal alloys are not found in natural diamonds. Mr. Hlava also noted in the yellow specimen that there are numerous, scattered, 1–2 μm inclusions in which only iron was detected. The arrangement of these tiny inclusions observed with the microprobe corresponds to the visual pattern of white-appearing pinpoints mentioned earlier. Again, although pinpoint inclusions are seen in natural diamonds, they do not look like those we observed in the De Beers synthetic diamonds.

Magnetic Behavior. The presence of obvious magnetic behavior in synthetic diamonds was noted in the General Electric material by B. W. Anderson (Webster, 1970) and Koivula and Fryer (1984), and was subsequently observed in the Sumitomo synthetic diamonds by Shigley et al. (1986). Natural diamonds are only weakly magnetic if at all (Rossman and Kirschvink, 1984). Because of the presence of large metallic inclusions (believed to be remnants of flux material on the basis of their appearance and chemistry), we suspected that the De Beers synthetic diamonds might be attracted by a magnet. During the specific-gravity determination, we tested this by placing a simple horseshoe magnet next to the glass container that held the synthetic diamonds suspended in the heavy liquid. The magnetic response could then be roughly gauged by the relative movement of the suspended sample toward the magnet. We found the De Beers synthetic diamonds to vary from strongly magnetic to nonmagnetic. The larger the metallic inclusions are, the stronger the attraction of the synthetic diamond is to the magnet. We noted no relationship between magnetic behavior and the color of the synthetic diamonds except insofar as the greenish yellow specimens are more strongly magnetic because, generally speaking, they contain the larger metallic inclusions.

CONCLUSION

Although large, colored synthetic diamonds in a size and quality suitable for faceting have been produced at the De Beers Diamond Research Laboratory since the 1970s, this is the first gemological examination of this material. These large synthetic diamonds have been manufactured only for scientific study and are not yet commercially available. They have not been introduced into the jewelry market, and De Beers maintains that there are no plans to do so. However, the cooperation of

Figure 23. This cross-shaped internal strain pattern, here seen in a crystal, is distinctive of many of the De Beers synthetic diamonds. Note also the pattern of graining in the four cubic sectors. Cross polarized light; magnified 10×.

De Beers representatives in providing synthetic diamonds as well as information on their diamond synthesis technology has enabled us to report on the gemological properties of this material.

The De Beers gem-quality synthetic diamonds can be easily identified in cut form by means of conventional gemological testing techniques. Table 2 summarizes the distinctive properties of the faceted specimens. Features to look for are the distinctive zoned pattern of color, ultraviolet fluorescence, and internal graining, as well as the metallic inclusions. While some of these properties are unique to synthetic diamonds (i.e., certain patterns of internal and surface graining, metallic inclusions), others may resemble those of natural gem diamonds (i.e., color zonation, pinpoint inclusions). Thus, determination of natural or synthetic origin should not be based on any one gemological property alone. In combination, however, the characteristic gemological properties of these gem-quality synthetic diamonds provide conclusive identification.

With the exception of ultraviolet fluorescence, the gemological properties of the De Beers synthetic diamonds are consistent with those noted previously for the General Electric and Sumitomo gem-quality synthetic diamonds of comparable colors. We have now examined samples of gem-quality synthetic diamonds from three different sources (two of which represent current technology), and have found them to be easily recognizable

by the gemologist. This suggests that faceted yellow synthetic diamonds will continue to be distinguishable from natural gem diamonds of similar color. Whether or not this will be the case for other colors of gem-quality synthetic diamonds, if and when they are consistently produced, remains to be seen. Among the synthetic diamonds we have examined so far, the most distinctive gemological properties (such as color zoning) present in the brownish yellow and yellow material seem to correlate with the relatively higher nitrogen content. Such properties were less obvious in the greenish yellow crystals. In the future, if gem-quality synthetic diamonds with a lower nitrogen content are produced, as is expected for colorless stones, these distinctive gemological properties may be less evident or even absent. On the basis of our observations to date, we foresee difficulties in separating natural from synthetic colorless diamonds using conventional gemological techniques.

The fact that De Beers and Sumitomo have independently developed the commercially feasible technology to synthesize yellow gem-quality diamonds as large as several carats reinforces our view that in the future synthetic diamonds will be encountered more frequently in the jewelry industry. We have now entered into a new era of commercial diamond synthesis technology. We again recommend that jewelers and gemologists pay close attention to documenting the gemological properties of gem diamonds of yellow color.

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THE HISTORY AND GEMOLOGY OF QUEEN CONCH "PEARLS"

By Emmanuel Fritsch and Elise B. Misiorowski

Conch "pearls" are calcareous concretions produced by the Queen conch mollusk, Strombus gigas, which is found in various areas of the Caribbean. Although conch "pearls" occur in a range of colors, the pink are usually the most desirable. "Pearls" over 10 ct are rare, but they have been observed as large as 45 ct. They sometimes exhibit a porcelain-like luster and an unusual characteristic called flame structure, which made pink conch "pearls" quite popular in jewelry at the turn of the last century. This article reviews the history of the conch "pearl," discusses S. gigas and its fisheries, and examines the gemological properties and other characteristics of this attractive material.

Conch "pearls," calcareous concretions produced by the Queen conch mollusk, Strombus gigas, often have a very attractive pink color that may be enhanced by a characteristic silky-looking "flame structure" (figure 1). As described by Stevenson and Kunz (1908, p. 279), many specimens "present a peculiar wavy appearance and a sheen somewhat like watered silk, a result of the reflections produced by the fibrous stellated structure." In addition, some conch "pearls" show a smooth, shiny porcelain-like luster that makes them very attractive. Because they are nonnacreous, they cannot be considered true pearls; consequently, the term *pearl*, commonly used in the trade to describe this material, appears here in quotation marks. The name of the mollusk should be pronounced "conk" and both spellings, *conch* and *conk*, are found in the literature.

Although they are truly rare gems, which are found only in the waters of the Caribbean and Bermuda and which seldom occur in a quality and size suitable for jewelry, conch "pearls" are occasionally seen in period jewelry, particularly in the Art Nouveau style. Large unmounted conch "pearls" of high quality have sold for significant prices. An oval 17-ct pink conch "pearl" went for just under US$12,000 at a Paris auction in 1984 (Federman, 1987). Last year, a 6.41-ct fine, dark pink, unmounted conch "pearl" was sold at auction for US$4,400 (Christie's London, June 24, 1987,).

Recently, Susan Hendrickson, of the Black Hills Institute of Geological Research, loaned GIA a large private collection of about 150 conch "pearls." This remarkable group, the result of 10 years of patient gathering, shows the ranges of size, color, and shape in which conch "pearls" can occur. The purpose of this article is to compile the scattered historical references to conch "pearls," review current knowledge of *S. gigas* and its fisheries, and examine the gemological and other properties of this little-known gem material.
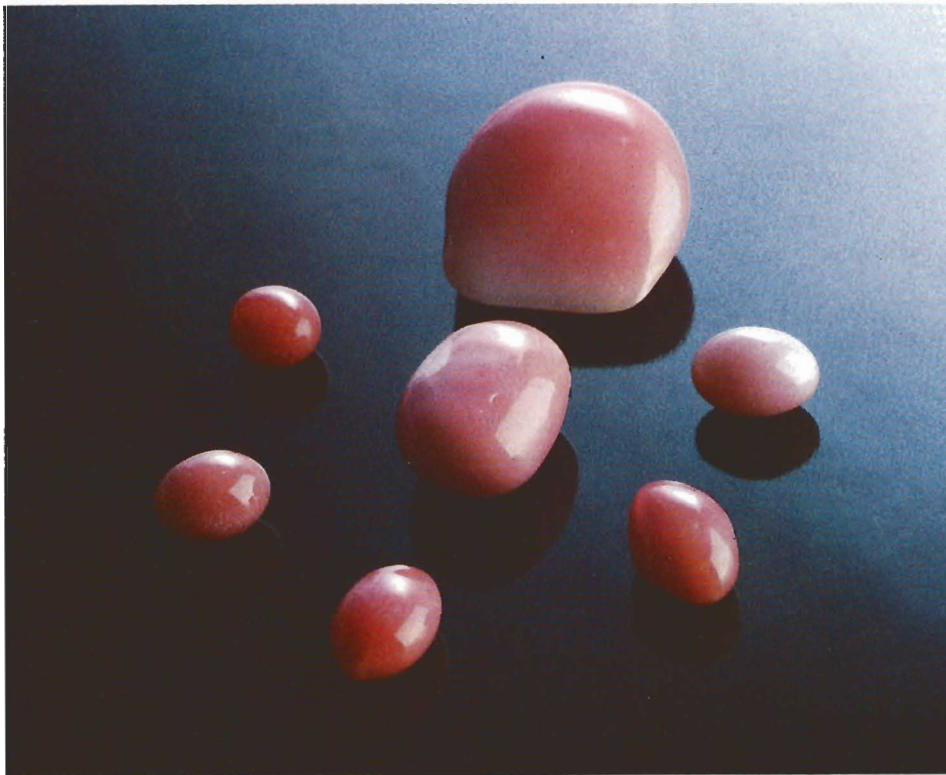
Figure 1. This group of exceptional pink conch "pearls" includes some of the finest that were studied for this article. The largest, an unusually fine porcelaneous "pearl," weighs 40.14 ct (22 × 21 × 12 mm). In some, the delicate flame structure typical of conch "pearls" is visible with the unaided eye. Specimens courtesy of Susan Hendrickson; photo by Scott Briggs.

A HISTORICAL LOOK AT CONCH "PEARLS" AND SHELL IN JEWELRY

In antiquity, the conch shell was regarded by the Incas and many early cultures as a symbolic mouthpiece of the gods. "Perhaps it was because, when held to the ear, the voice of the sea god murmured through it" (Dickinson, 1968, p. 7). Although there is no specific reference in the literature to "pearls" obtained from *S. gigas* before the mid-1800s, it is reasonable to believe that they were found and used in jewelry, along with nacreous pearls.

The earliest mention of conch "pearls," specifically from the *S. gigas* mollusk, can be found in the 1839 *Catalogue of the Collection of Pearls & Precious Stones Formed by Henry Philip Hope, Esq.* and referred to in Stevenson and Kunz (1908, p. 464). Among the 148 pearls listed are two conch "pearls": "an oval conch pearl, pink in general color and somewhat whitish at the ends, . . . and another conch pearl . . . button shaped, yellowish-white with a slight shade of pink." Streeter (1886) also mentions this collection and goes on to say that conch "pearls" were quite popular during the 1850s and 1860s, to the point that supply could not keep up with demand.

During Queen Victoria's reign (1837–1901),

the shell of the conch was imported into Europe for use in the manufacture of porcelain, to be carved as cameos, and for collecting as a curio. Italian cameo carvers preferred the *S. gigas* shell because of its delicate pink tints (Streeter, 1886). Actually, during the 19th century, conch "pearls" were often referred to as "pink pearls." Alexandra, consort to Edward, Prince of Wales, and daughter-in-law to Queen Victoria, was partial to pearls of all kinds. Edward and Alexandra were the leaders of upper-class society during the late 1800s and early 1900s; the trends that they set in fashion and jewelry came to be known as the Edwardian style. Edwardian jewelry incorporated a lavish profusion of pearls and diamonds usually set in platinum.

One example of an Edwardian piece that incorporates a conch "pearl" (figure 2) can be seen at the Walters Art Gallery in Baltimore, Maryland. This 23.5-ct conch "pearl," at the time one of the largest known, was purchased around 1900 from George F. Kunz at Tiffany & Co. in New York, where he was employed as staff gemologist (Mitchell, 1984, p. 179). Bought by Henry Walters as a gift for his niece Laura Delano, it was eventually presented by her to the Walters Art Gallery.

While the larger conch "pearls" were popular with the upper class at the turn of the century, their smaller counterparts were well suited for use

Figure 2. Large conch "pearls" were well suited to the lavishness of Edwardian jewelry. In this Edwardian piece (circa 1900), the 23.5-ct conch "pearl" is set in a hinged platinum cage of prongs with a foliate design. The top can be turned to release the prongs so that the "pearl" can be removed. Courtesy of the Walters Art Gallery.

in the Art Nouveau jewels popular among the rising middle class and artistic avant-garde during the same period. Conch "pearls" lent themselves well to the naturalistic motifs that were common in Art Nouveau jewelry (Misiorowski and Dirlam, 1986). As Art Nouveau jewels often incorporated a mixture of fine gems and metals with inexpensive materials, such as glass and horn, the smaller conch "pearls" were ideal for use as buds in floral designs (figure 3). Jewels of this sort are seen at auction occasionally.

Following the upheaval of World War I, interest in conch "pearls" waned. The Art Deco style that predominated after the war manifested itself in stark geometrics that mirrored the disillusionment of the time and the preoccupation with streamlined modernity. We can find no evidence of the use of conch "pearls" in Art Deco jewelry. Not until the current decade have conch "pearls" regained favor as unique and unusual gems in jewelry. In the last two years, the competition for

buying in the Dominican Republic has sharply increased (S. Hendrickson, pers. comm., 1987).

Recently, Harry Winston, Inc. created a few pieces of conch "pearl" jewelry intended for its very special clientèle. One magnificent suite of necklace and earrings features six pink conch "pearls," beautifully combined in size, color, and shape (see cover photograph). The necklace incorporates a deep reddish pink button-shaped conch "pearl"; its pendant contains a magnificent 45-ct (180-grain) pear-shaped conch "pearl" that is probably one of the world's largest. Strong flame structure is readily apparent in many of the "pearls" in the suite.

In conjunction with the pink color, the mysterious allure of the flame structure in conch "pearls" has traditionally added to its desirability as a gem. The rarity of the conch "pearl" precludes its extensive use in jewelry; unless a culturing operation is developed, which is unlikely, conch "pearls" will retain their exclusive status.

BIOLOGY OF THE
STROMBUS GIGAS MOLLUSK

Only S. gigas, a univalve mollusk commonly known as the Queen conch, grows the calcareous concretions known as conch "pearls." However, one must be careful because the term conch is sometimes used to describe other kinds of shell (in fact, the science of shells is called conchology). Nevertheless, fishermen and divers can easily distinguish S. gigas from other snails by its distinctive "hook" or "claw," the horny curved operculum attached to the animal's foot. All conchs are vegetarians, eating essentially algaes, and the Queen conch is one of the largest of the herbivorous gastropods (Brownell and Stevely, 1981). Unlike most mollusks, the Queen conch snail moves in a unique "hopping" style (Fleming, 1982), pushing very hard on its foot to raise its heavy shell, and then letting itself fall forward, laboriously gaining about half a body length.

The natural habitat of the conch (figure 4) stretches from Bermuda to the Caribbean (Brownell and Stevely, 1981). When L. D. Powles wrote of his experiences as a barrister in the Bahamas (1888), he titled his book The Land of the Pink Pearl. The Queen conch is also found along the southeast coast of Florida and the Keys. In 1910, Kunz wrote a slim promotional book for Tiffany & Co. in which he listed conch "pearl" as one of the state stones. This suggests that Florida also may

have been a source for those conch "pearls" used in jewelry at the turn of the century, although Sinkankas (1959, p. 587) states that "prior to 1900, the vogue for [conch] pearls was largely satisfied by specimens captured on the reefs of Eleuthera and Exuma Islands in the Bahamas and the pearls marketed primarily in Nassau." Streeter (1886), Webster (1975), and Farn (1986) also list the Gulf of California as a source of *S. gigas*. While this area might be the home of similar-looking snails, no marine biology publication mentions the presence of *S. gigas* in this location (see, e.g., Abbott, 1954). Most likely, these reports of "Queen conchs" outside their normal geographic range are just cases of confusion caused by the use of ambiguous common names (E. Iversen, pers. comm., 1987).

Although conchs may undergo minor migrations (Hesse, 1979), they usually remain in the same general area over their lifetime. They tend to inhabit stable sandy bottoms, although occasionally they settle in gravel and coral environments. They may be found in only a few centimeters of water or as deep as 75 m, but they most commonly live at a level above 30 m in depth (Brownell and Stevely, 1981).

Reproduction takes place during the warmer months, from March to September (Hesse and Hesse, 1977). After mating, the female produces an egg mass of about 500,000 units, the size and shape of a fat banana, which is camouflaged from predators by a coating of sand. Four to five days later the eggs hatch and a tiny shell-less conch, called at this stage a "veliger," emerges to drift in water for about four or five weeks, subject to currents and extensive predation, until it settles to the bottom and acquires a small white shell. The young conch, now called a "creeker," seeks protection in the sand. Over the next two years, it will grow its spiral shell, at which time it becomes a "roller." At about three years of age, the mollusk begins to build up its shell in a flared lip. At this point, it has reached breeding maturity and is at optimum size for fishing. It also seems that this is when the snails begin to produce "pearls." The "sanga" or "samba" is a fully matured conch, with a very thick, leathery-looking shell. A group of conch shells of various ages from roller to sanga is represented in figure 5; note the development of the lip and the areas of pink coloration.

STROMBUS GIGAS FISHERIES

S. gigas is fished throughout the Caribbean primar-

Figure 3. Smaller conch "pearls" can be seen in the Art Nouveau pieces that were popular with the middle classes at the turn of the century. The Art Nouveau pendant shown here has a geranium motif of pink enameled flowers with conch "pearl" buds and plique-à-jour enameled leaves. Photo courtesy of Christie's Geneva.

ily for its meat. The shellfish are found in large groups of up to several hundred individuals. The fishermen dive from small boats (figure 6) and pluck the mollusk from shallow waters or use

Figure 4. The Strombus gigas *(Queen conch) mollusk is found throughout the waters in the shaded area of this map (After Brownell and Stevely, 1981). Illustration by Jan Newell.*
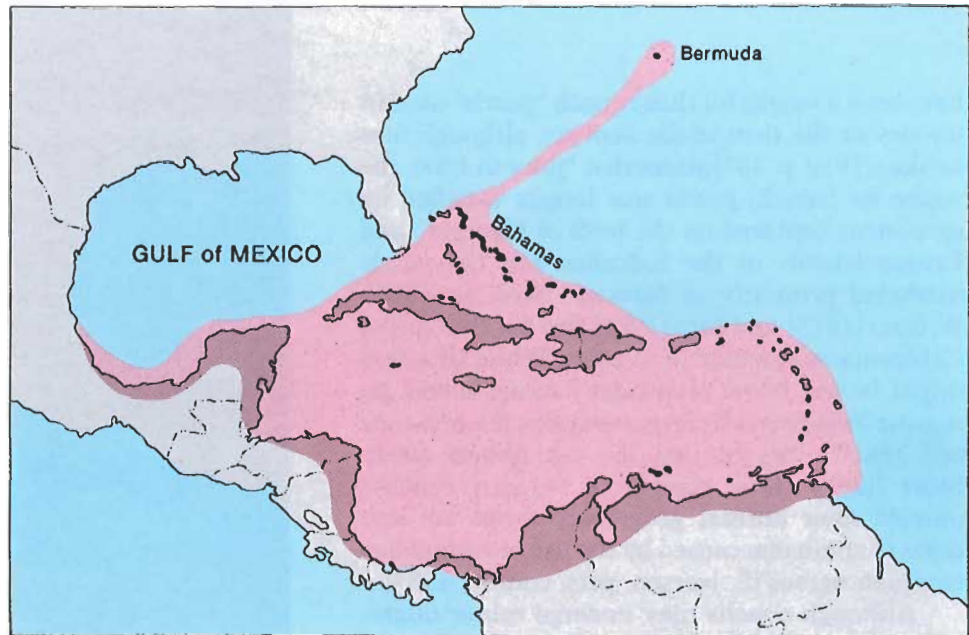
poles with a hook. The fishermen usually cut the meat out of the shell in the boat. The conch "pearls" are often found at this stage, in a pearl sac within the orange part of the mollusk, which corresponds to the mantle or skirt of the conch

(preliminary observations by B. Everett, pers. comm., 1987). They are also recovered when the boat is being cleaned. We have not been able to find any direct documentation on how the "pearl" forms in the conch, but we suspect that it nucle-

Figure 5. These shells are from Strombus gigas *of different ages, from the young "roller" on the left to the oldest "sanga" on the right. Note in the two shells in the center how the lip develops and then, in the two shells on the right, how it thickens as it is eroded over time. Photo by Robert Weldon.*

Figure 6. Fishermen from the Dominican Republic and their fishing boat, here dry-docked for maintenance, typify the conditions under which the conch shell is fished. Photo by Susan Hendrickson.

ates due to irritation from a foreign body, in much the same way pearl-like concretions form in other mollusks (Bostwick, 1936; Sweaney and Latendresse, 1984).

The meat, similar to abalone, is usually eaten locally, although during the 1970s it was frozen and exported to the United States. The conch industry benefited greatly from higher prices and improved marketing during this period, but the resulting expansion led to overfishing and the species is now seriously endangered (Hesse and Hesse, 1977; Brownell and Stevely, 1981; Fleming, 1982). Many governments have taken measures to prevent the precipitous decline of *S. gigas*. For example, it is now illegal to fish this mollusk off the coast of Florida. During the period of overfishing, many conch "pearls" (several hundreds, if not thousands) were found, but the recent measures taken to protect the mollusk are likely to reduce this number in the coming years (figure 7). A detailed review of the natural history of the Queen conch and the fishery problems can be found in Randall (1964) and Brownell and Stevely (1981).

One question often raised about conch fishing is how often a "pearl" is found. According to Kunz (1892), there is never more than one conch "pearl" in a shell. This statement has been confirmed by many modern fishermen (S. Hendrickson, pers. comm., 1986). A commercial supplier of conch meat in the Lesser Antilles recently stated that in

Figure 7. Jorge Luis, a Dominican fisherman, displays a handful of conch "pearls" that represent several months of collecting. Photo by Susan Hendrickson.

"approximately 54,000 conchs, only four large (5–10 ct) and a few dozen smaller 'pearls' were found" (Fryer et al., 1985, p. 235). The probability of finding a conch "pearl" is, then, about one in a thousand, which agrees with Streeter's indications in 1886. Ms. Hendrickson (pers. comm., 1986) put the odds even lower — around one in ten thousand to one in fifteen thousand — on the basis of personal observations and discussions with fishermen in the Dominican Republic and the Bahamas. This figure agrees with information provided by Bonnie Everett, who co-owns a fishery in the Turks and Caicos Islands (pers. comm., 1987). Ms. Everett nevertheless points out that there is no way of knowing if a "pearl" has been overlooked. In addition, only about 10% of those found can be considered gem quality. While the degree of scarcity may vary with the fishing grounds, conch "pearls" are, by any standards, very rare.

LA PLACE BOSTWICK AND CONCH "PEARL" CULTURING

The only published account of the successful culturing of conch "pearls" was written by a biological researcher named La Place Bostwick (1936). In 1933, Bostwick applied to the director of the Scripps Institute of Oceanography, requesting permission to work on culturing abalone pearls at their research facilities in La Jolla, California. In his letter, Mr. Bostwick stated that he had "also found the secret of growing round and egg-shaped pearls in the great, pink conch, *Strombus gigas.*"

Bostwick's first attempts at pearl culturing involved some 600 species of freshwater mollusks. In the course of these experiments (as reported in some pages from an undated article published in an unidentified journal that accompanied his Scripps correspondence), he harvested several black cultured pearls from the "Elephant ear" shell.

Working with biological researcher Clarence F. Hoy in Key West, Florida, Bostwick began experimenting with culturing conch "pearls" in the *S. gigas* mollusk. Two photographs and mention in two articles (Bostwick, 1936, and the article of unknown origin referred to above) suggest that the experiments were indeed successful. In 1931, an article in *The Key West Citizen* carried the triumphant title, "After two years work here, experts learn how to grow $50,000 pearls." Bostwick and Hoy, cited in the article as experts, explain the advantages of growing conch "pearls" instead of freshwater pearls. A follow-up article cited Bost-

wick on the difficulties of the undertaking ("Many Key Westers . . .," 1931). The following year, in a letter to writer Ernest Hemingway, Hoy mentions "Culture Conch Pearls" that Hoy had shown Hemingway previously. Although there is no definitive proof that Bostwick and Hoy were the cultivators, or that the "pearls" were indeed cultured, no evidence has surfaced of any other person cultivating, or attempting to cultivate, conch "pearls" in Key West at that time.

It was apparently at this point that Bostwick applied to the Scripps Institute for space in their laboratories. The correspondence begins in 1933 and suggests, ultimately, that permission was granted and Bostwick moved to La Jolla in the spring of 1934. Between 1934 and 1940, while he confidently awaited the results of his experiments, Bostwick wrote several articles about pearl cultivation, one of which was published in the January 1936 issue of *The Gemmologist*. He also carried on a lively correspondence with a writer, Catherine Meursinge, who was interviewing him for an article about his work with pearl cultivation. This article was eventually published in a Dutch periodical (Meursinge, 1937). There is no evidence, though, that Bostwick ever revealed the secret of his culturing techniques. To one inquiry regarding his methods, he denied drilling the abalone shells to introduce a bead nucleus and further replied: "I . . . hypnotize them [the mollusks] and as the mind has great effect over matter, when they understand that they must grow a pearl, they just get busy and do it. I have a very poor memory and usually FORGET to explain just how the pearls are grown" (letter to Meursinge, 1936).

Both the article by Meursinge and the correspondence leading to it mention repeatedly that a book by Bostwick titled *Pearls and Pearl Bearing Mollusks* was to be published soon by Appleton Century Publishers in New York. However, there is no mention of the book in any correspondence after 1937 and as there is no entry for such a book in the Library of Congress, it is doubtful that it was ever released.

In fact, after 1940, Bostwick himself drops out of sight. The archives at Scripps provide no clue as to the results of his abalone "pearl"–culturing experiments, which may very well have failed. At any rate, the last written record of La Place Bostwick that we were able to discover is a 1940 letter to Catherine Meursinge regarding the turbulent political situation in Europe at the time.

GEMOLOGY OF THE
CONCH "PEARL"

For this article, we examined more than 150 conch "pearls," which ranged from 0.2 to over 40 ct (2 to 22 mm). Most of the specimens had been acquired by Ms. Hendrickson directly from conch fishermen in the Caribbean. In all cases, the fishermen confirmed that the "pearls" had come from *S. gigas* specifically, although they were aware that other shells can produce calcareous concretions.

Size. Calcareous concretions from the conch shell are commonly no more than 2–3 mm in diameter, and around 0.2 or 0.3 ct in weight. Only rarely do they occur in sizes and of a quality suitable for use in jewelry (S. Hendrickson, pers. comm., 1986). Although specimens up to 10 ct are found, larger "pearls" are exceptional. Unusually fine, large examples include the 40.14-ct "pearl" shown in figure 1 and the 45-ct pendant in the Harry Winston conch "pearl" necklace mentioned earlier.

Shape. Conch "pearls" occur in a variety of shapes, ranging from extremely baroque to very symmetrical (figure 8). They are generally somewhat rounded, but only very rarely are they spherical.

Figure 8. This group of conch "pearls" illustrates the wide variety of shapes in which they occur, from pronounced baroque (brown, 18.62 ct at the bottom) to almost spherical (dark brown, 1.83 ct on the left). Probably the most sought-after shape is a symmetrical elongated ellipse, like a football, approximated by the two pink "pearls" at the upper left (6.49 and 2.48 ct). Specimens courtesy of Susan Hendrickson; photo by Scott Briggs.

Quite commonly, conch "pearls" resemble a football or a watermelon in shape. Ms. Hendrickson's collection includes a unique double "pearl." In his 1936 *Gemmologist* article, Bostwick suggested a few rules concerning the shapes of abalone pearls that probably apply as well to conch "pearls": "If a growing pearl is not located in exactly the right part of the anatomy, it will become rough or ill shaped;. . . if it is growing in a region of muscular activity, it will not grow round." He also stated that "if it touches the shell, it will become attached." A few of the samples we studied clearly show an extension, known as a peduncle, that may have been caused by the proximity of the shell.

Symmetry is a key factor in establishing the value of a conch "pearl." Irregular shapes generally do not command prices as high as symmetrical elliptic (football) shapes, particularly among Europeans. Any departure from this "ideal" oval will reduce its desirability. Other details that might have a negative effect on value are an uneven surface, flaws reminiscent of fractures, and surface blemishes. Most oval-shaped "pearls" have white ends that are often tipped with brown protuberances which can be rather unattractive.

Color Range. Conch "pearls" occur in various tones of pink, yellow, brown, and white (figure 9). In the collection provided by Ms. Hendrickson, which

Figure 9. Although most people think of them as pink, conch "pearls" may be white (1.44 ct), yellow ("golden," at the bottom, 7.23 ct), brown, or orangy ("salmon"). Specimens courtesy of Susan Hendrickson; photo by Scott Briggs.

primarily represents "pearls" found in the Silver Shoals (a region of shallow waters that is claimed by both the Dominican Republic and the Turks and Caicos Islands), more than half are light brown, sometimes with a gray or yellow modifier. Inasmuch as brownish conch "pearls" are usually discarded by the fishermen, someone who sees only what is commercially available might get the impression that they are uncommon (e.g., Streeter, 1886). However, Ms. Everett maintains that she finds mostly pinks in her conch fishery, so perhaps there is some geographic variability in the proportion of the various colors. A dark brown ("chocolate brown") "pearl" is very unusual. White conch "pearls" also seem to be rather rare, although they are mentioned by Streeter (1886), Kunz (1892, 1894), and Webster (1975). A brownish yellow conch "pearl" is referred to among collectors and dealers as a "golden pearl" (figure 10). The most highly valued hues, however, are pink and orangy-pink, also called "salmon" (Kunz, 1892; Krashes, 1986). In rare instances the color appears to be lavender. Occasionally, the pink color is so intense

Figure 10. A rare example of a fine "golden" conch "pearl" (15.56 ct) set in jewelry is this 14K gold ring. Photo courtesy of Manuel and Inge Marcial, Emeralds International Inc., Key West, Florida.

Figure 11. This 2.88-ct pink conch "pearl" of very fine color and unusual oblique flame structure, found off the San Bernardo Islands (Colombia), is set in an 18K gold pendant. Photo courtesy of Manuel and Inge Marcial, Emeralds International Inc., Key West, Florida.

that the "pearl" is described as red. Among the pink conch "pearls," a medium purplish pink is the preferred hue (see figures 11 and 12); a salmon color is considered to be slightly less desirable.

As with other pearls, the color of the conch "pearl" reflects the color of the internal surface of the shell in the region where it grows. Microscopic observation and thin sections suggest that brown is caused by the incorporation of a layer of an opaque, muddy-looking substance close to the surface of the shell. The salmon color seems to occur when a very thin layer of that substance covers a pink zone.

Figure 12. These three pink conch "pearls" represent the range of most desirable colors and flame structure. From left to right: 2.88 ct, 2.24 ct, and 4.04 ct. Specimens courtesy of Susan Hendrickson; photo by Robert Weldon.

Fading. Unfortunately, the attractive color of pink conch "pearls" is not stable. Like the shell itself, these "pearls" fade on prolonged exposure to sunlight to a much lighter pink (figure 13). This characteristic of the shell was noticed early on, as a consequence of its use for cameos (Brown, 1986).

The fading is probably related to the organic origin of the pink color. We obtained the absorption spectrum of a pink conch "pearl" on a Pye-Unicam UV-visible spectrophotometer. A broad absorption band centered around 500 nm is responsible for the pink coloration. Studies using Raman spectroscopy have demonstrated that the intensity of this visible absorption is related to the intensity of certain lines in the Raman spectrum (Délé-Dubois and Merlin, 1981). These lines are characteristic of organic compounds of the carotenoïd family, to which a large number of organic pigments belong. The exact nature of the pigment(s) is not known. Inasmuch as many organic products fade, it is not surprising to observe this phenomenon in the conch "pearl." The fading is probably caused by the decomposition of the product when exposed to the ultraviolet rays of natural daylight. There is no known method by which the color can be restored. Consequently, fine pink conch "pearls" set in jewelry should be reserved for evening or occasional, as opposed to daily, wear. With care, however, the color will remain strong, as the "pearls" in the Edwardian and Art Nouveau pieces demonstrate (again, see figures 2 and 3).

Refractive Index and Specific Gravity. The refractive indices of 16 conch "pearls," which cover the
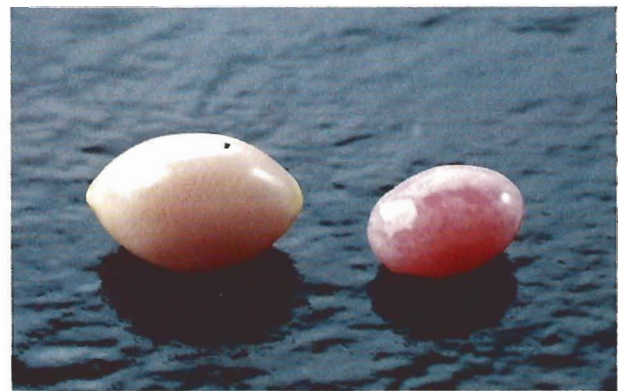
Figure 13. The color of the 3.37-ct faded conch "pearl" on the left originally resembled that of the 1.56-ct "pearl" on the right prior to exposure to sunlight. Note also the whitish protuberances on the faded "pearl"; these are a common characteristic of conch "pearls." The irregular wavy surface of the smaller "pearl" impairs its value. Photo by Robert Weldon.

full range of colors, were determined using the spot reading technique. All fall between 1.50 and 1.53, with an average value of 1.51.

The specific gravity of 12 conch "pearls" was measured using the hydrostatic method. The value obtained seems to correlate with the color. Brown concretions have the lowest values (2.18–2.77), probably because they typically contain cavities, as could be seen when the "pearls" were sawed. Intermediate values (2.82–2.86) were obtained for white and "golden" samples, which may or may not contain cavities. Our experience (both with

Figure 14. This is a fine example of a conch "pearl" (3.06 ct) of perfect form and good color. Notice how the radial flame structure creates an attractive oval-shaped pseudo-chatoyancy. Specimen courtesy of Susan Hendrickson; photo © Tino Hammid.

sawed "pearls" and as observed with X-radiography) indicates that pink conch "pearls" do not contain cavities; they range in specific gravity from 2.84 to 2.87.

The Flame Structure in Conch "Pearls." One of the most striking characteristics of the conch "pearl" is the flame structure. In some cases, the surface reveals a regular pattern of parallel elongated crystals that imparts a silky sheen to the "pearl" (again, see figure 11). In the very best specimens, the "flames" can be identified by microscopic examination as thin lamellae that are almost parallel to one another and are sometimes perpendicular to the axis of the "pearl," thereby giving rise to a rough chatoyant effect (figure 14). Flame structure has also been observed in portions of the conch shell itself, in the red and black helmet shells (Brown, 1986), and also in the *Tridacna* "pearl" (Liddicoat, 1981).

We have observed flame structure in conch "pearls" only in the pinks (and on the white parts of pink and white pearls), and not all of them exhibit

this pattern without magnification (see, e.g., the largest specimen in figure 1). A conch "pearl" in which flame structure is not visible with the unaided eye is called porcelaneous. Therefore, although the presence of flame structure helps to identify a pink concretion as a conch "pearl" (Webster, 1975; Fryer et al., 1982), its absence does not mean the contrary. Flame structure is highly desirable, however, and conch "pearls" in which it is not easily seen carry a lower value than those in which it is prominent.

The structure of the Queen conch shell has been described in great detail by Bolman (1941) and briefly by Brown (1986). Since the "pearl" is formed in the same manner as the shell, one expects to find a similar structure. We cut three thin sections, one in each of two different brown "pearls" (figure 15, left), and one in a pink "pearl" (figure 15, right). Both have basically a concentric organization (see also Fryer et al., 1985), but the layers can vary considerably in structure within the same section. The outermost layer of the pink sample exhibits a somewhat prismatic structure, constructed of rather large crystals (up to 1 mm in width). A similar layer has been found inside a brown "pearl." Other layers have a finely fibrous or a columnar structure, as described by Bolman (1941) for the *S. gigas* shell. All three sections have a very irregular brown core of unknown nature. Brown "pearls" contain intercalated layers of a brown, muddy-looking material that give them their coloration. Because there is apparently very little or no conchiolin layer, X-radiography does not reveal any structure in the "pearl."

Brown (1986, p. 157) explained that the flame structure of the conch shell is "an optical effect that was caused by sharp bending of the shell's fibrous crystals so that their orientation ran almost parallel to the internal surface of the shell." On the thin section of pink conch "pearl" with good flame structure that we studied (figure 15, right), such bending is not obvious. The flame structure seems to be apparent only when mud-like layers are not present under the outermost layer. This allows for better transparency and one sees "deeper" into the pearl. The fibrous or lamellar structure is present in all shells or "pearls" exhibiting flame structure. In polarized light, this outermost layer appears to be constructed of two sets of crystals, one lighted when the other is extinct. This suggests a fixed crystallographic relationship, probably twinning as it is commonly
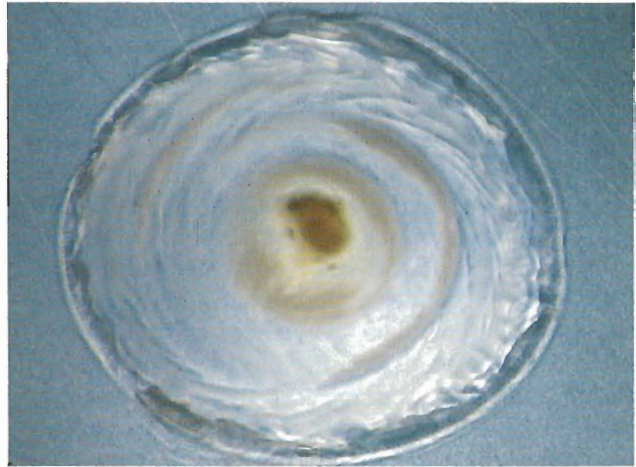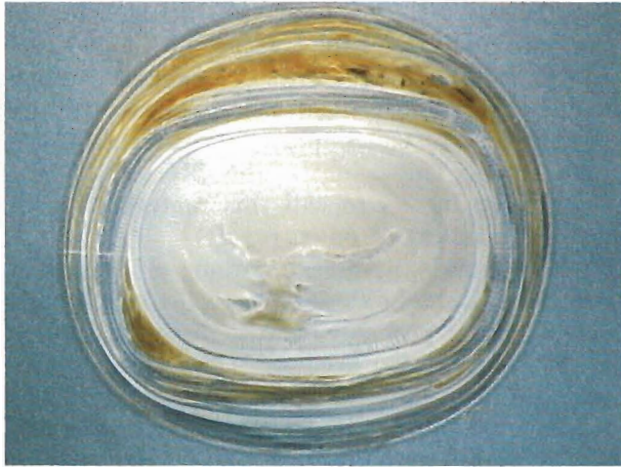
Figure 15. Thin sections (about 100 μm thick) were cut from a brown (left) and a pink (right) conch "pearl." The irregular brown core and the concentric structure are clear in both thin sections. The muddy-looking brown layers in the thin section on the left impart their color to the "pearl." Magnified 12×; photomicrographs by John I. Koivula.

seen in plagioclase. Sabatier (1953) described a calcite twin in some shells that exhibit a similar texture.· Microscopic examination of the conch "pearls" also suggests that either one set of crystals is more intensely colored than the other, or that one is fibrous while the other is not.

Unfortunately, the chemical composition of the "pearl" is not clear cut. The average refractive-index value (1.51) is lower than the range for aragonite (1.53–1.68) and within the range for calcite (1.49–1.66). This parallels the observation made on the basis of infrared spectroscopy that the surface of the shell contains some calcite (Compere and Bates, 1973). The specific-gravity values lie between those for calcite (2.71) and aragonite (2.95). If we assume an average for conch "pearls" of around 2.85, as suggested in Webster (1975), they would correspond to a mixture of about 40% calcite with 60% aragonite. Raman spectroscopy (Délé-Dubois and Merlin, 1981) also indicates a mixture of calcite and aragonite. However, X-ray diffraction on several spots of different "pearl" sections, even close to the outer surface, always matched the aragonite pattern. These measurements indicate that conch "pearls" are made up of aragonite as the major constituent, with an unknown amount of calcite and probably water, as well as a few organic products that would allow for the coloration. Therefore, the particular twinning in pure calcite described by Sabatier (1953) is unlikely to be responsible for the flame structure,

but the origin of the flame structure is probably to be found in a similar phenomenon of oriented crystal growth.

Hardness and Toughness. We found the conch "pearls" to be of surprisingly high, yet variable, hardness for their composition. Scratch tests using hardness points from two different manufacturers were consistent and resulted in values between 4 and 5 for the two brown "pearls" and between 5 and 6 for two pink ones. This resistance to scratching explains why these "pearls" keep a very high luster even when worn in jewelry. We cannot currently explain why the hardness values are higher than those of both calcite (3) and aragonite (3.5–4).

Jewelers who have drilled and set conch "pearls" have been surprised by their toughness, which can be rated as good. They report it to be much higher than that of oyster pearls (S. Hendrickson, pers. comm., 1986), making conch "pearls" relatively easy to set in jewelry.

SEPARATION FROM OTHER MATERIALS
Pink or orange coral beads are occasionally mistaken for conch "pearls" (Liddicoat, 1981; Farn, 1986). The most famous misidentification is that made by Kunz, and reported by Koivula (1987). As Liddicoat (1981) pointed out, these two materials can be separated on the basis of specific gravity, which is 2.65 for coral and 2.85 on the average for

pink conch "pearls." Also, they differ greatly in surface appearance: Coral shows distinct surface pits as well as banded striations that are much more regular than the flame structure seen on conch "pearls"; coral may also show a characteristic tree-ring structure.

Other conch "pearl" imitations appear to be rare. Pink glass beads (sometimes with a pattern that resembles flame structure) have been used (Farn, 1986). Usually a close examination reveals the presence of bubbles, swirls of color, or other inclusions in the glass sufficient to separate these imitations from the natural material. Streeter (1886, p. 274) relates how an "ingenious American" cut "out of the pink portions of the shell some very creditable imitations." To increase the confusion, those beads were implanted in a conch mollusk, which was found later, of course, to have produced a so-called "pearl." Kunz also mentions these bead imitations in 1894. Recently, a cabochon cut out of the pink part of the shell was submitted to a jeweler (D. Williams, pers. comm., 1987) by a client who indicated that it had been sold to him as a conch "pearl" in Miami some years ago. Ms. Hendrickson (pers. comm., 1987) confirmed that she had seen such imitations being sold in the Dominican Republic recently. This emphasizes that one must always be vigilant, even for old tricks thought to be long forgotten. More common, of course, are the beads cut from conch shell to imitate pink coral (R. Crowningshield, pers. comm., 1987).

THE TERMINOLOGY ISSUE

Pearls are calcareous concretions that are formed from the shell material and grown naturally in a pearl sac of a molluscan animal (Coomans, 1973). This definition implies that conch "pearls" are indeed true pearls, but that calcareous concretions formed by some other animals (*Brachopoda, Vermes, Pisces, Mammalia*) are not. In agreement with this definition, the CIBJO rules recommend that concretions from the conch shell be called "Pink Pearl"; note the capital *P* for *pink* (*Gemstones/Pearls*, 1982). However, most gemology texts emphasize that nacre or orient must be present (Liddicoat, 1981; Webster, 1983). By this definition, inasmuch as it is nonnacreous, a conch "pearl" cannot be considered a true pearl. The recommendations of the Federal Trade Commission do not specify that nacre or orient must be present for the concretion to be called a pearl

(USFTC, 1959). The definition included in the recommendations of the Jewelers Vigilance Committee requires the presence of conchiolin, which is difficult to prove, and does not recommend any specific term for conch "pearls" (Preston and Windman, 1986). The policy at the GIA Gem Trade Laboratory, Inc. is to call this material a "calcareous concretion" on its reports.

In the trade, however, common practice is to call the calcareous concretion of the conch shell "conch pearl," probably because this term is more attractive and also because "calcareous concretion" is not specific enough. "Conch pearl" makes it clear that this particular calcareous concretion was produced by a conch mollusk, and does not imply, as in CIBJO nomenclature, that the color must be pink. The CIBJO terminology has engendered some additional confusion. Farn, in his recent book (1986), reports the story of a 93-grain (23.25 ct) "Pink Pearl" found in New Jersey that later became famous as the "Queen Pearl" because it was owned by Empress Eugenie. Although the spelling with a capital *P* indicates a conch "pearl" under CIBJO terminology, the item was actually a freshwater pearl with a pink hue, which should have been called "a pink freshwater pearl" (no capital *P*).

Some confusion might still arise, though, from the appellation "conch pearl." We have discussed here only the calcareous concretions produced by *S. gigas*, from the conch family. Other shells referred to as conchs are known to produce "pearls" (Farn, 1986). Also, pink porcelaneous "pearls" are known from other shells, such as *Turbinella scolymus* (Streeter, 1886).

CONCLUSION

Conch "pearls" are truly rare and fascinating gems, which combine the still-unsolved mystery of their flame structure with their beautiful pink color and exotic origin. Apparently very difficult to culture or to imitate, never treated, they are a true natural gem. Their hardness and toughness make them easy to mount and preserve in jewelry. After years of relative obscurity, they seem to have returned to fashion, probably because more are available, although they are still quite rare. Let us hope that appropriate fishing restrictions will provide a regular supply of these "pearls" for the pleasure of gemologists and gem connoisseurs alike in the generations to come.

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TAKE THE GEMS & GEMOLOGY

<u>CHALLENGE</u>

Coming in the Spring 1988 issue

THE SEVEN TYPES OF YELLOW SAPPHIRE AND THEIR STABILITY TO LIGHT

By Kurt Nassau and G. Kay Valente

Colorless to yellow to intense orange sapphire will react quite differently to light or heat depending on the nature of the material and the origin of the color. The authors determined that there are actually seven types of "yellow" sapphire on the market today, which differ in the cause of color and the stability of the color to light: type 1 — natural, light-stable color center; type 2 — natural or irradiation-produced, fading color center; type 3 — iron containing, not heated, light stable; type 4 — iron containing, heated, light stable; type 5 — surface-diffused additive, light stable; type 6 — synthetic, light stable; and type 7 — synthetic irradiated, fading. The authors examined more than 150 samples of yellow sapphire to confirm the seven types and document their different reactions to light, heat, and/or irradiation. One unexpected finding was that type 1 material can fade on heating even below 200°C, but that the color is restored by exposure to light.

ABOUT THE AUTHORS

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Yellow sapphires have surged in popularity in recent years (figure 1), which has prompted further study into their properties and, especially, the effects of treatment by heat or irradiation. An important problem is the distinction between yellow sapphires that are color stable and those that fade under normal conditions. At present, the only practical way for the gemologist to separate these two materials is by an extended exposure to light or by some sort of heating test. Webster and Anderson (1983) suggest that three hours in bright sunlight or a few minutes of heating at 230°C will fade (and thus identify) irradiated Sri Lanka material. Dealers in the Far East routinely test yellow sapphires by heating them in the flame of a candle for a few seconds or placing them on a sunlit windowsill for a few days. A heating test that is too short, however, can be unreliable, since the stone — particularly a large one — may not reach the required temperature; partial fading can also occur with material that is stable to light, as discussed below.

In the course of testing the reaction of the color of a wide variety of gem materials with respect to light and heat, one of us (KN) came to note a simple relationship: among all the materials tested, those that fade rapidly on exposure to light also lose their color when heated at 200°C for about one hour (e.g., Maxixe-type beryl and some brown topaz), and materials that do not lose their color after one hour at 200°C also do not fade significantly in light (e.g., amethyst and smoky quartz, blue and some brown topaz, and red tourmaline). One obvious anticipated exception is chameleon diamond, in which one color component appears to fade (Nassau, 1984). As a result of the present work, another one is yellow sapphire. With these two exceptions, heating at 200°C for about one hour can be a useful test for color stability (Nassau, to be published).

When we became aware of the variable reaction of

Figure 1. Yellow sapphires have become increasingly popular over the last few years. In this suite of fine yellow sapphires set with diamonds and emeralds, the largest pear-shaped yellow sapphire is 22 ct and the largest heart shape is 17 ct. Courtesy of Harry Winston, Inc.

yellow sapphires to this test, we sought to establish the possible range of reaction of different types of yellow sapphire to light, heat, and irradiation. In the course of this research, we determined the need for distinguishing the various types of yellow sapphire, so a provisional classification system was developed on the basis of our experience and the previous literature. The proposed classification and the research study are described below. A number of yellow sapphires, natural and synthetic, treated and untreated, were tested for their reaction to heat, light, and irradiation. The research confirmed the proposed classification system; recognition of the seven types will permit the gemologist to deduce for any yellow sapphire* both the

*Note that the general use of the term yellow here is intended to cover the wide range from the palest of yellows through yellow-orange to dark orange verging on brown. This range corresponds to an intensification of the same hue, with a dominant wavelength near 580 nm.

color origin and the stability of the color to light and to heat exposure by conventional gemological testing.

A CLASSIFICATION FOR YELLOW SAPPHIRE

Early gemologists believed that there was only one type of yellow sapphire, also called "oriental topaz" or "topaz-sapphire" (Bauer, 1904). Smith (e.g., in his 10th edition, 1949) said that yellow sapphire lost its color when heated and that radium (i.e., irradiation) either deepened the color or developed it in a colorless stone. More recent studies have expanded our knowledge of this behavior (Crowningshield and Nassau, 1981; Fryer et al., 1983a, 1983b; Koivula, 1986; Nassau, 1980, 1981, 1984; Schiffmann, 1981; Schmetzer and Bank, 1980; Schmetzer et al., 1983). Some studies (e.g., Schmetzer et al., 1983) have suggested that the yellow color may arise from color centers, or iron, or both. We also know that some yellow sapphires

Figure 2. Examples of the range of colors of types 1 and 2 yellow sapphires studied; the largest stone weighs 11.80 ct. Photo © Tino Hammid.

colored by color centers fade in light, while others do not (Nassau, 1981, 1984). Synthetic yellow sapphires, too, may be colored by an impurity (usually nickel) or by a color center (Schmetzer et al., 1983). Lastly, color may be induced by diffusing iron (or nickel) into the surface of a sapphire (Nassau, 1980). On the basis of the information

Figure 3. Examples of the range of colors of types 1, 2, and 3 pale tan and brown sapphires studied; the largest piece is 6 mm long.

published to date and on experience, we propose a classification that defines seven types of yellow sapphire:

Type 1: Pale yellow to orange, with color originating from a natural stable color center. Usually from Sri Lanka. Color is stable to light.

Type 2: Pale yellow to deep orange, resulting from the irradiation of colorless sapphire, with color originating from a light-fading color center. May have been colored when found, but faded when exposed to light; color can be restored by irradiation, but will fade once again.

Type 3: Pale yellow to orange, iron containing, but has not been heated to high temperature, as in type 4. Color caused by iron (usually up to 0.8 wt.%), with other elements possibly present in smaller amounts. Typically from Thailand, Australia, or Tanzania. Color is stable to light.

Type 4: Yellow to deep orange-brown, color created by heating paler iron-containing material. Color probably caused by iron; it is stable to light.

Type 5: Yellow to deep orange-brown, containing iron (or nickel) in surface layer only; impurity has been diffused in at high temperature. Color is stable to light, but the thin colored zone may be lost on recutting.

Type 6: Synthetic sapphire with nickel and/or other elements added; may also have been subjected to heat treatment. Color is stable to light.

Type 7: Synthetic sapphire with color induced by irradiation. Fades to colorless in light.

In types 1 and 2, iron may be present (usually less than 0.1%) without affecting color. However, some stones could conceivably contain more than one type of color-causing agent. Types 2 and 7, especially, can co-exist with other types; thus, a pale yellow type 1 sapphire may be irradiated to a dark orange color, which is then type 1 + 2, but in light this will fade back to the original type 1 pale yellow. All of these types of yellow can also co-exist with a chromium-produced pink, resulting in an analogous group of seven types of "pad-paradscha" sapphire (Crowningshield, 1983).

MATERIALS AND METHODS

More than 150 colorless and pale colored sapphires, both rough and faceted, were used in this study. They came from Chanthaburi-Trat (Thailand), Sri Lanka, Umba Valley (Tanzania), Montana, and some unidentified locations. A wide range of synthetic sapphires, including Verneuil, Czochralski, and flux products, were also tested. Some of the natural gems had been heat treated while others had not, as determined by microscopic examination.

The range of colors of those gem-quality yellow sapphires studied that were identified as types 1 and 2 are illustrated in figure 2. That of the milky and clear pale tan and brown material, including types 1–3, is shown in figure 3; and typical type 4 material is shown in figure 4.

Heating was performed in resistance-heated muffle furnaces, with the samples buried in clean, acid-washed sand for the higher temperatures. Irradiations were performed in a cobalt-60 gamma cell at a rate of one Mrad per hour (Nassau, 1983). In all instances, the color reached saturation, as visually determined, in much less than eight hours (the minimum time used). A few spot checks showed that X-rays produced the same color reaction as gamma rays, as had been expected (Fryer et al., 1983a; Pough and Rogers, 1947). For exposure to unfiltered short-wave ultraviolet radiation (USW), samples were placed 5 cm from the bare bulb (4 watts) of a Mineralight fluorescent lamp.

Many of the faceted stones were matched on the GIA ColorMaster, both before and after a variety of treatments. These ColorMaster measurements were also converted to the AGMS (American Gem Market System, Moraga, CA) overall grade point scale, where 0 is colorless and 100 is the most saturated (and, therefore, most desirable) sapphire to be designated yellow (Valente, 1986). The 100 grade-point material is sold in the trade for about five times what the 60 grade-point material goes for, while the latter sells for about 50% more than the 40 grade-point material. The National Bureau of Standard ISCC/NBS collection of color chips (Kelly and Judd, 1955) was also used for visual comparison as well as inferred by computer conversion from the ColorMaster values.

The colors of the sapphires studied extend on

Figure 4. Typical heated type 4 yellow sapphires. Photo © Harold & Erica Van Pelt.

the ISCC/NBS scale from no. 263 white, through 89 pale yellow, 87 moderate yellow, 83 brilliant yellow, 82 vivid yellow, 66 vivid orange yellow, 48 vivid orange, to 51 deep orange; there are additional intermediate points. Typical ColorMaster readings (all A) are for no. 48 – 50/50/00 and 96/99/00; for no. 82 – 44/61/0 and 38/46/0; and for no. 87 – 22/42/06. The dominant wavelength is in the 575- to 587-nm range, so that an essentially single-dimensional color (hue), varying only in saturation, is being measured.

TESTING AND RESULTS

Forty gem-quality type 1 stones (group 1) were ColorMaster matched by one of us (GKV) four to eight times each, before and after a variety of tests. These tests included heating for one hour at 100°C or 200°C (abbreviated H100 and H200, respectively); exposing for one day to gamma rays, for 12 hours to unfiltered short-wave ultraviolet radiation (USW), or for one or two days in sunlight; and/or storing for three days in a dark safe. The results of the various tests for three typical stones from group 1 are shown in figure 5 against the AGMS grade point scale; approximate color descriptions are also included in this figure. Data for the H200 heating step, a subsequent USW exposure, and a subsequent H100 heating (but only if performed in this sequence) are summarized in figure 6 for all of the stones in group 1.

A second group, including 10 of the group 1 gemstones, 44 additional cut stones (including colorless type 2 and heat-treated type 4 stones), and 53 pieces of rough (including those of figure 3), were irradiated and heated, some to successively higher temperatures (at 50°C intervals), to study the formation and disappearance of types 1 and 2 color centers. Samples were also exposed to sunlight as well as to incandescent and fluorescent artificial light, some before and some after irradiation and/or heating.

All the sapphires tested, including the heat-treated type 4 stones, turned a significantly darker yellow on gamma-ray or X-ray irradiation, as much as over 90 grade points. Figure 7 shows the range of colors produced by varying amounts of gamma irradiation in type 2 colorless sapphire. The USW treatment produced a smaller darkening, as shown at *b* in figure 6, with an average of approximately 25 grade points; two 24-hour USW treatments were sometimes necessary to return a heated H200 stone to a color darker than the original.

Successive heating steps of type 1 and irradiated types 2 and 1 + 2 material showed that some color was lost on heating for one hour at as low a temperature as 60°C. More color loss occurred at 100°C, 150°C, 200°C, 300°C, and 400°C; all traces of color were lost by 500°C or 600°C. It should be noted that fractures typical of those caused by heating were seen around inclusions after expo-
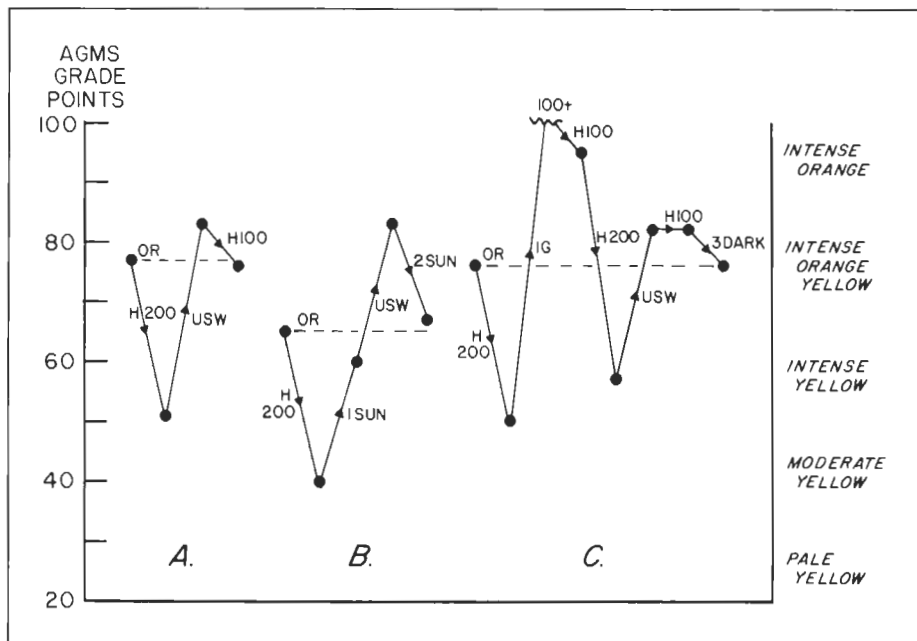
Figure 5. This graph charts, on the AGMS grade point scale, the changes in color produced by various types of treatment in three typical type 1 yellow sapphires. OR is the original color, H200 is heating at 200°C for one hour, H100 is heating at 100°C for one hour, 1SUN and 2SUN are exposure to one or two days of sunlight, 1G is exposure for one day to gamma radiation, 3DARK is storing for three days in a dark safe, and USW is exposure for 12 hours to unfiltered short-wave ultraviolet radiation.

NUMBER OF
SAMPLES

a.
N = 40
R = 0-37
A = 17.6
S = 10.6

DECREASE IN AGMS GRADE POINTS FOR H200

b.
N = 26
R = 0-65
A = 25.1
S = 15.0

INCREASE IN AGMS GRADE POINTS FOR USW

c.
N = 24
R = 0-14
A = 4.0
S = 5.2

DECREASE IN AGMS GRADE POINTS FOR H100
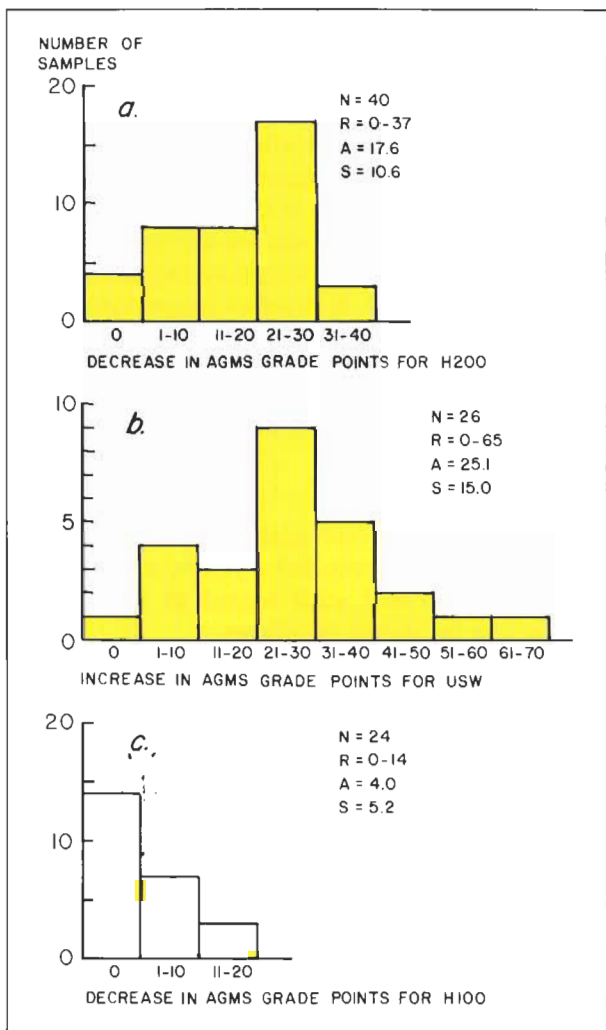
Figure 6. These statistical bar charts for type 1 yellow sapphires show (a) the loss of color (as expressed in decreased AGMS grade points) after an H200 heating, (b) the improvement in color (increased AGMS grade points) after a subsequent USW treatment, and (c) the subsequent loss of color after a final H100 heating. N is the number of samples, R the range of point values, A their average, and S their standard deviation.

sure to temperatures as low as 400°C. As seen at *a* in figure 6, 36 out of 40 light-stable yellow sapphires lost significant color with an H200 heating (17.6 grade points, averaged for all 40), while the H100 heating at *c* in this figure, which was conducted after the USW exposure, produced much smaller changes (average 4.0 grade points). Both of these bar graphs indicate that the color

change produced by the different treatments varies greatly from stone to stone. In some instances, the use of H100 after USW resulted in a return of the original color (±2 grade points), as at *A* in figure 5. At other times, H100 produced no change, as in one of the two such treatments at *C* in this figure, where a mere resting in the dark restored the original color. In all other specimens, however, the irradiation-induced color did not appear to change if the stones were stored in the dark.

Exposure to bright light, typically two days in bright California sun, or longer periods under less bright conditions (both outdoors and behind a window), was found to be the simplest and preferred way to return the original color, as at *B* in figure 5. Although this had been expected to apply to irradiated types 2 and 1 + 2 yellow sapphires, it also worked for these types of stones when faded by heating, regardless of the temperature to which they were heated and the extent of fading.

This unexpected behavior was at first attributed to the ultraviolet rays present in sunlight. However, a yellow glass filter with an optical density of 2.0 at 410 nm was used to remove the ultraviolet component from incandescent light; this slowed down light-restoration of the heat-removed color but did not prevent it. Accordingly, even visible light restores the stable-state color from either direction, both from the irradiation-produced darker colors as well as from the heat-produced lighter colors.

Figure 7. Examples of type 2 colorless sapphires irradiated to various colors; the largest stone weighs 21.34 ct.
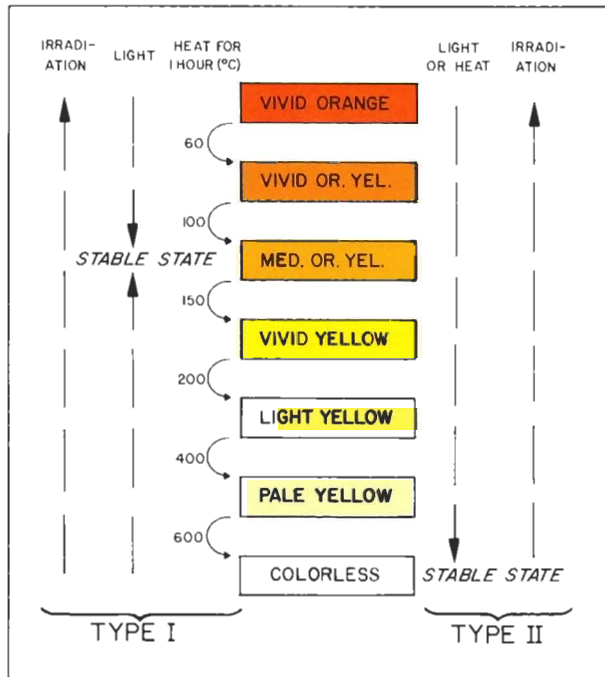
Figure 8. The behavior on exposure to light, heat, and irradiation of a specific type 1 light-stable medium orange-yellow sapphire (left) is compared to that of any type 2 colorless sapphire (right).

All of these results are summarized in figure 8 for a specific type 1 yellow sapphire (left) and for a type 2 yellow sapphire (right). The temperatures shown at the left apply only to this specific specimen, for which the stable color is a medium orange-yellow. The material is returned to this color by light from either direction, after darkening by irradiation or after fading by heat treatment. The stable-state color of another type 1 sample could be anywhere on this scale, with shifted temperatures. It can be seen that the type 2 sapphire on the right is merely a special case of the type 1 on the left, with the stable state here being colorless.

Additional irradiation experiments followed by light and/or heat exposure were performed on a variety of types 3 and 6 materials, with results analogous to those for the irradiation-induced type 2 yellow component. Heating to as high as 1700°C did not change the ability to produce type 2 color by irradiation, which also was observed in the presence of any other types of yellow color. The fading with heat or light of both types 1 and 2 colors also did not appear to be affected by a high-temperature treatment. The type 7 irradiated syn-

thetic sapphire behaved the same as the type 2 natural. Type 1 behavior was not observed in any synthetic sapphire, presumably because of the absence of the required precursor. The color of type 3 yellow sapphire is not affected by light or by heating except at the highest temperatures (approaching 2000°C), when it is converted to type 4 material. Irradiation can produce a deeper type 3 + type 2 yellow, but the extra type 2 component fades in light as expected. R. Hughes (unpublished observation, 1986) has reported that gentle heating of type 4 Sri Lanka material produces a darkening of the yellow, with a return to the original color on cooling back to room temperature.

CONCLUSIONS

This series of tests essentially confirms the proposed classification system for yellow sapphires. In simplified form and with regard to stability to light, it can be stated as follows:

Type 1: Natural stable color center

Type 2: Natural or laboratory-irradiated fading color center

Type 3: Natural iron-produced stable color

Type 4: Heat-developed stable color

Type 5: Surface-diffused additive color

Type 6: Synthetic with impurity-caused color

Type 7: Synthetic with irradiated fading color center

There have been many reports in the gemological literature on the nature and properties of one or more of these types of yellow sapphire. Some of the more relevant and/or comprehensive studies are listed here in reverse chronological order, with an indication of the specific types of yellow sapphire covered; many additional relevant references will be found cited in these studies: Koivula (1986: 1 to 4); Nassau (1984: 1 to 4); Schmetzer et al. (1983: 1 to 6); Fryer et al. (1983a: I and 2); Fryer et al. (1983b: 3); Nassau (1981: 4 and 5); Crowningshield and Nassau (1981: 4 and 5); Schiffmann (1981: 2); Schmetzer and Bank (1980: 3 and 4); Nassau (1980: 6 and 7); and Pough and Rogers (1947: 2). Recent specific locality studies include those on the Umba Valley, Tanzania (Hänni, 1986) and on Chanthaburi-Trat, Thailand (Keller, 1982).

Each of these seven types can be identified by means of routine gemological testing supported by a fade test. Details of the relevant tests may be found in various gemological texts and courses as

well as in the references cited above. Types 6 and 7 can be identified as synthetic by growth characteristics; the surface-diffusion of type 5 is evident in the localization of the color; characteristic inclusions identify that a type 4 or type 5 stone has been heated (or has not and is therefore type 1, 2, or 3, in the event that a CO_2 fluid inclusion is present, as discussed in Koivula, 1986); an "unnatural" color is a good indicator for type 4 stones, as is Hughes's heating test described above; and spectroscopy (Schmetzer et al., 1983) can be used to identify both types 3 and 4. This leaves only the question of the presence of the fading types 2 and 7. If, however, the stone loses much of the yellow color on extended exposure to light, it can be identified as either type 2 or 7. Thus, the "original" natural, untreated type 1 yellow sapphire is material that has fluid inclusions or shows no evidence of having been heated, is not synthetic or diffused, and does not fade on exposure to light.

Although heating, for example to 200°C for one hour, can add considerable information as described above, any type of heating, even as low as 60°C, is definitely not recommended for routine testing of yellow sapphire since it could alter the color of some light-stable type 1 material.

On the basis of the current study, it would seem that the fading of a supposedly heat-treated stone mentioned by Crowningshield in Fryer et al. (1982) was that of an irradiated stone, since it is shown that stones that have been heat treated to high temperatures are stable to light. Another case called into question by the work done here is that of the color center suggested by Schmetzer et al. (1983) as the cause of color in the "burnt" or "annealed" material, here type 4, produced typically by heating above 1440°C. In view of the stability of the color to the very high temperature of 1440°C, it is unlikely that the color could be due to a color center; a mere coincidence in the location of the absorption band does not prove an origin. A more probable explanation lies in the exsolution of Fe_2O_3, as suggested by Keller (1982); this could happen even if only a small amount of iron is present.

Thus, three distinct groups of color origins appear to be involved in the seven types of yellow sapphire. A color center of unknown nature appears to cause the color in type 1, which fades with heat and is restored by light. A second, different color center, again of unknown nature, is responsible for types 2 and 7, darkening with irradiation

and fading with light or heat. The colors of types 3–6 originate in impurities, such as iron, which can produce a range of colors, depending on the growth and heating history of the material.

Significant loss of color can occur in type 1 yellow sapphires at temperatures well below 200°C. Irradiation with gamma rays, X-rays, or even ultraviolet can restore the color to type 1 stones and also induces the additional but fading color of types 2 and 7, which can be present together with other types of yellow (e.g., type 1 + 2). The reaction to irradiation is not affected by heating to temperatures as high as 1700°C, although such heating may develop the light-stable type 4 yellow in a type 3 stone. The best way to restore the stable state (yellow for type 1 and colorless for types 2 and 7) is exposure to light, typically two days of bright sunlight or longer for less intense (natural or artificial) illumination.

Stable nonfading yellow sapphire clearly does not have a stable color in the absence of extended exposure to light. Exposure to light results in a change to the stable-state color, either from the darker irradiation-induced state or from the lighter heated state. From these observations, it is clear that, as mined, yellow sapphire may be darker than the stable state as the result of a type 2 color component induced either during growth or by irradiation from radioactive material in the surrounding rocks, or it may be lighter from a subsequent heating in the ground, as from a metamorphic process or from intense solar heating. That appears to be the reason that exposure to light is routinely used to establish the stable-state color of yellow sapphire after it is removed from the ground (R. Vinyard, pers. comm., 1986).

The important behavior of the types 1 and 2 yellow sapphire with respect to light, heat, and irradiation is summarized in figure 8. Type 2 yellow sapphire is seen to be merely a special case of type 1 in which the stable state is colorless. Both the stable color of type 1 yellow sapphire as well as the exact temperature for a specific color change in this material can vary from specimen to specimen; presumably it depends on the quantities and types of the color-center precursors present. Even blue sapphire and ruby contain this precursor, and therefore can form some type 2 fading yellow color centers, resulting in green if the blue is fairly pale or "padparadscha" if the red is pale. Nothing definite is known about the precise nature of the defects, which could involve impurities or point

defects such as vacancies, other than their stability, even at temperatures up to 2000°C. A possible explanation for the differences between types 1 and 2 yellow sapphires is given in the Appendix.

APPENDIX: COLOR CENTER THEORY APPLIED TO YELLOW SAPPHIRE TYPES 1 AND 2

The color of type 2 yellow sapphire is caused by a light-fading color center that consists of an electron donor and an electron acceptor of the usual type (see Nassau, 1983, pp. 192–195). On an energy-level scheme, only one absorption level, such as that marked *Abs. 1* in figure 9, is involved. Absorption of irradiation energy (ultraviolet, X-ray, and gamma ray) occurs at this level, with the system falling down into the trapped state via process *A*. Once in the trapped state, the absorption of light produces color via processes *C*, *D*, and *E*. When barrier *B* is relatively close in height to the trap level, as drawn in this figure, the energy of light (added to that of room temperature) results in the light-bleaching of type 2 fading yellow sapphire by process *F*. Note that light absorption simultaneously produces color (process *C*) as well as bleaching (process *F*). For further details on the processes summarized here, see Nassau (1983).

This standard color-center scheme will not, however, explain the behavior of type 1 stable yellow sapphire with respect to heat and light. One possible scheme that can explain this unusual behavior involves an additional, low-energy absorption level, such as *Abs. 2* in figure 9. This absorption can be activated by light, probably by the more energetic light at the blue end of the visible spectrum, ending up in the trapped state with the formation of the yellow-producing color. Presumably this involves a hole precursor different from the one that produces absorption level 1.

In the proposed type 1 yellow sapphire scheme, the absorption of light is involved in three processes: production of the color center (process *LIGHT*), production of color (process *C*), and bleaching by the destruction of the color center (process *F*). The intensity of the yellow color will depend on the relative efficiency of the three processes as well as on the concentrations of the different types of precursors present. Even though heat produces bleaching at a relatively low temperature in type 1 stones, light can repopulate the trap and thus restore the color. One consequence is that such a stone will not have a definite color in the absence of extended
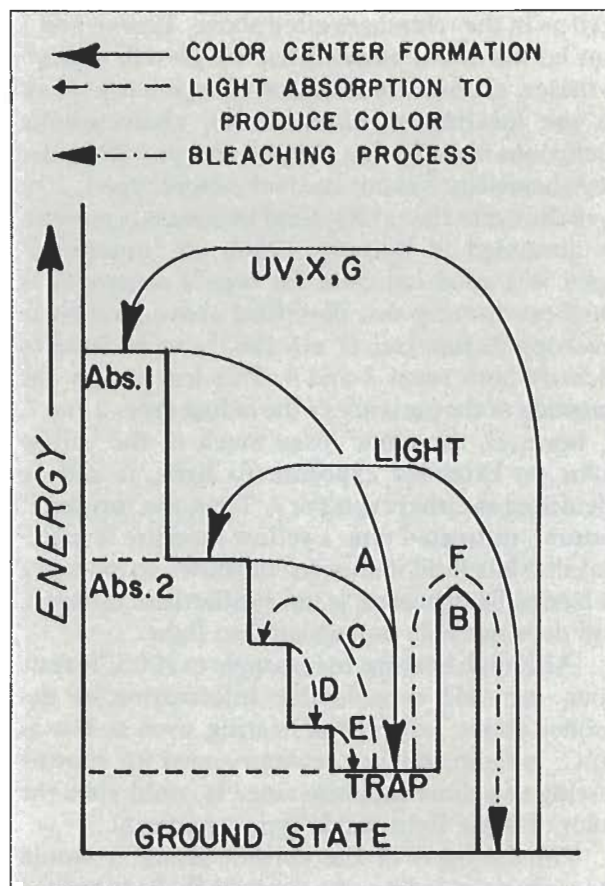
Figure 9. Energy schemes for the color centers of type 1 stable yellow sapphire and type 2 fading yellow sapphire. UV = ultraviolet; X = X-ray; G = gamma rays; Abs. = absorption level; TRAP = trapped state.

exposure to light. Another interesting consequence of this scheme is that light of different energy distributions (sun, bright sky, incandescent lamp, fluorescent tube lamp, etc.) could produce slightly different trap concentrations, since the three processes involving light can be expected to have different spectral energy efficiencies. Accordingly, a careful but rapid measurement of the color of a type 1 yellow sapphire may produce slightly different results from the preceding measurement depending on the type and amount of light to which the stone was last exposed for an extended period.

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Gem Trade LAB NOTES

AMBER

Faceted

The New York laboratory was recently privileged to see part of a collection of uncommon faceted stones. This collection features minerals that are not frequently used as gems, and gems that are usually encountered as beads, tumbled stones, cabochons, or carvings. For example, the yellow pear-shaped modified brilliant-cut stone shown in figure 1 is actually amber. Although amber is frequently encountered as faceted beads, it is rarely seen as a single faceted stone. The low hardness $(2-2 \frac{1}{2})$ not only makes it difficult to get sharp facet junctions on amber, but also makes the facet junctions extremely susceptible to abrasion. Although this attractive collector's piece does not look very much like amber (the bubbles seen in the photograph are only obvious under photographic lighting), the identification was routine.
Clayton Welch

Imitation

Many times when a piece is submitted to the lab for testing to see if it is amber, it turns out to be plastic. A 22.50-ct drilled tablet submitted to the New York laboratory was no exception. The tablet, which has a beveled edge, measured 18.4 mm

Figure 1. Amber is seldom seen in faceted form, like the stone shown here, because the low hardness makes it difficult to produce sharp facet junctions and the facets abrade easily.
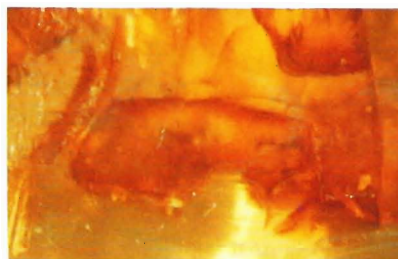
Figure 2. This plastic imitation of amber appears to contain fragments of amber beads. Notice the partial drill hole in one of the pieces. Magnified 10×.

square and 11.3 mm thick. When viewed from a distance, it has the variegated appearance of amber. However, the refractive index of 1.56, the relatively high specific gravity,

the chalky blue fluorescence to long-wave ultraviolet radiation, and the acrid odor produced when a thermal reaction tester was applied to an inconspicuous spot all easily proved that the item is plastic.

The piece is unusual, however, in that it contains fragments that appear to be amber. Unfortunately, since none of the fragments reached the surface, we could not identify them. These fragments are undoubtedly pieces of broken beads; figure 2 shows one that even has half a drill hole! *David Hargett*

CALCIUM CARBONATE Beads

The continuing popularity of bead necklaces has brought an increasing diversity of materials to the gem market, some of which are not readily identifiable. The strand of 12- to $12\frac{1}{2}$-mm variegated light brown beads in figure 3, which were submitted to the New York laboratory for identification, had been sold as "Riverstone." Testing one of the beads, we obtained indistinct refractive indices of approximately 1.55 and 1.65, with high birefringence, a specific gravity (by hydrostatic method) of 2.72, and effervescence to hydrochloric acid—proving that the material is a calcium carbonate. The bead fluoresced a strong orange to long-wave, and a strong yellow to short-wave, ultraviolet radiation. There was a fair degree of persistence to the phosphorescence from both wavelengths.

Although it was easy enough to

establish that the material is a carbonate, determining which carbonate is not so easy. The structure is a mixture of sections that are transparent and coarsely crystalline with others that are massive and almost coral-like in appearance. Several of the beads even have what appear to be fossil inclusions. However, the material is not coral and the texture is not that of limestone or marble. Perhaps "Riverstone" is not such a bad name after all.   *RC*

CORUNDUM Doublets

Because the identification of doublets is one of the first things a gemologist learns, doublets are seldom sent to the lab. Therefore, we at the New York lab were surprised to find that the "ruby" and "sapphire" center stones in the rather important looking gold and diamond rings shown in figure 4 are in fact assembled, consisting of synthetic ruby and synthetic sapphire pavilions with natural sapphire crowns. These stones are fairly large, with the oval red one measuring approximately 11 mm × 8 mm × 6 mm deep and the antique cushion-cut blue one measuring approximately 14 mm × 12

Figure 4. These attractive cocktail rings contain corundum doublets that consist of synthetic ruby and synthetic sapphire pavilions with natural sapphire crowns.

mm × 7.5 mm deep. These rings were part of a group of 30 that were being offered for sale. Most of the center stones, like these two, were bezel set so that the separation planes were carefully concealed. Curved growth features were readily visible in the pavilions of both stones, while the sapphire crowns showed prominently the hexagonal growth structure inherent in natural corundum.   *David Hargett*

Figure 3. These 12–12 1/2-mm beads, sold as "Riverstone," are actually a type of calcium carbonate.
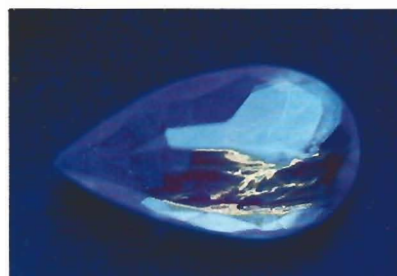
Figure 5. Most synthetic emeralds fluoresce red to long-wave ultraviolet radiation. However, the yellow fluorescence of the flux inclusions in this synthetic emerald is similar in appearance to the yellow-fluorescing oil often seen in natural emeralds and occasionally in some synthetics.

Synthetic EMERALD

The red fluorescence of most synthetic emeralds to long-wave ultraviolet radiation is well illustrated in figure 5. Although not all synthetic emeralds fluoresce — and, occasionally, fluorescence may be observed in a very fine natural stone — anytime an emerald does fluoresce strongly to long-wave U.V., it should be a warning signal that the stone is probably a synthetic.

Emeralds that are replete with

thready veins of yellow-fluorescing oil usually turn out to be natural, although synthetics with fractures that reach the surface may also be oiled. An unusual aspect of the synthetic emerald received by our New York office is the yellow fluorescence of the flux inclusions (again, see figure 5). Because the inclusions do not all reach the surface, it is obvious that their fluorescence is not due to oiling. In addition to the flux inclusions, this stone had the diagnostically low refractive index and birefringence of flux-grown synthetic emeralds.   *Clayton Welch*

Imitation JADE

The strand of variegated green-and-white beads shown in figure 6 had been offered for sale as jade in one instance and as aventurine in another. When we examined the 8-mm beads in the New York lab, the refractive index of 1.55 and the structure proved the material to be quartzite that had been selectively dyed by an unknown process. The resulting

Figure 7. These beads, 9½–10 mm in diameter, are unusually fine examples of quartzite dyed to resemble fine jadeite.

product is reminiscent of the jadeite called "moss-in-snow" by one Chinese classification. Unlike most dyed jadeite we have tested in the past, these beads did not appear red when examined with the color filter. Also,

Figure 6. These 8-mm quartzite beads were selectively dyed to simulate the appearance of "moss-in-snow" jadeite.

they did not show the absorption band centered at 650 nm that is typically seen in dyed material when examined with a hand-held type of spectroscope. Dye in the cracks was readily discernible with magnification and appeared on a cotton swab moistened with acetone that was rubbed on the bead.

By coincidence, the strand of 9½- to 10-mm beads shown in figure 7 was submitted at the same time we were photographing the dyed beads mentioned above. These beads also proved to be dyed quartzite, but they were dyed so well that they closely resemble fine chrome green jadeite to the unaided eye. The beads lack the crackled and dyed appearance that is usually obvious in this type of imitation. In fact, even under magnification the resemblance to jadeite persists. However, the refractive index of 1.55 and the evidence of dye seen in the spectroscope proved the true identity.   *RC*

PEARLS

Cultured Black Pearl

In recent months, the staff at the Santa Monica laboratory have noticed quite an increase in the number

of black pearls—both loose and in jewelry—submitted for testing. One item, a loose, undrilled "black pearl" (reported by the client to have come from Tahiti) was of special interest because of its size, approximately 20 mm × 18 mm in diameter. As seen in figure 8, the pearl is fairly symmetrical in shape and is free of any blemishes except for one circular growth line. The color varies from light to dark gray, with areas that have a distinct greenish overtone. The X-radiograph showed a rather large bead nucleus, proving that the pearl is cultured. When examined with long-wave ultraviolet radiation, the pearl fluoresced a weak red, proving that the color is natural. This is certainly one of the largest Tahitian cultured black pearls the laboratory has encountered to date.   *KH*

Figure 8. This 20 mm × 18 mm cultured black pearl is one of the the largest ever seen in the laboratory.

Another Large Cultured Pearl

The New York laboratory also received recently one of the largest (18 × 22 mm) bead-nucleated cultured pearls they have ever encountered. The X-radiograph (figure 9) clearly shows the bead nucleus. An observation that suggests, but does not prove, freshwater origin of the pearl is that the bead nucleus is predrilled—which growers say is a requirement for manipulating the nucleus during its implantation in a freshwater mollusk. In fact, the

strong X-ray fluorescence of the pearl proved its freshwater origin. However, both the fact that the pearl fluoresced stronger at the edges than in the center and the large size (12 mm) of the nucleus suggest that the bead used for the nucleus was probably of saltwater origin.   *RC*

An Oyster "Pearl"

The Santa Monica laboratory had the opportunity to examine the unusual nacreless calcareous concretion seen in figure 10. In appearance, this concretion resembles a typical cone shell with its aperture closed. It is chalky white, evenly colored, and measures approximately 35 mm long × 17.5 mm in diameter. The flame-like structure commonly seen in calcareous concretions from *Tridacna* clams or conch shells was readily visible with the unaided eye, especially on the broad side of the piece (figure 11). Our client informed us that this particular concretion had come out of a thorny oyster from the Pacific coast of Costa Rica. It has been identified by zoologists as *Spondylus calcifer carpenter.*

                                                            KH

RUBY, Heat-Treated Natural and Synthetic

Some of the heat-treated natural rubies that have been submitted to the New York laboratory show one or

Figure 9. The X-radiograph of another unusually large, 18 × 22 mm, cultured pearl shows that the nucleus is 12 mm in diameter.

Figure 10. This large, 35 mm long × 17.5 mm in diameter, calcareous concretion is from a Pacific Ocean thorny oyster.

Figure 11. Note the flame-like pattern easily visible in the concretion shown in figure 10. Magnified 10×.
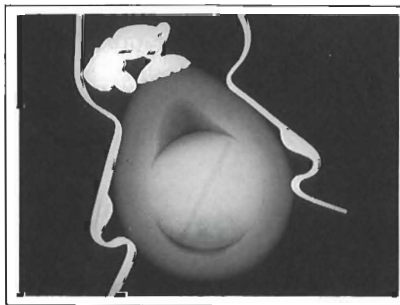
more shallow depressions that we call spall cavities. Spalling occurs when rubies are heated to high temperatures in the attempt to improve their appearance. A few such cavities even show signs of partial melting. Most spall cavities are rounded pits ranging in diameter from a fraction of a millimeter to a little over one millimeter. Very rarely, one may be quite a bit larger. These cavities are almost always shallow relative to their diameter.

Ideally, these blemishes should be polished out after heat treatment. However, because weight retention is so important, they are often left untouched. Sometimes the laboratory encounters spall cavities that have been filled with a glass-like substance to improve the appearance

of the stone (see, e.g., R. E. Kane, "Natural Rubies with Glass-Filled Cavities," *Gems & Gemology*, Winter 1984).

The New York laboratory recently examined a mounted stone with a very unusual filling in such a cavity. The natural pink sapphire shown in figure 12 has a small spall cavity that has been filled with gold! This was almost certainly the accidental by-product of the jewelry-fashioning process, since it draws attention to, rather than away from, the cavity.

Although spall cavities are usually observed in natural corundum, the one illustrated in figure 13 is in a quench-crackled flame-fusion synthetic ruby. This type of synthetic is sometimes heated and cooled rapidly to create the appearance of natural fractures and to make the detection of the curved striae more difficult. Notice the spall cavity, as well as the numerous tiny pits (or "fire skin") in the girdle that are the result of the
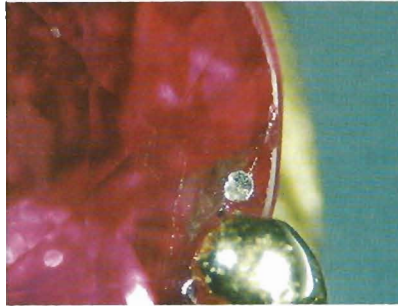
Figure 12. The spall cavity in this natural pink sapphire was probably accidentally filled with gold when the ring was manufactured.

Figure 13. Although synthetic corundum usually is not heated, the spall cavity (top center) and pits in this synthetic ruby are undoubtedly the result of heat treatment.

heating. It is possible that they were not polished out in order to enhance the illusion that the stone is natural. Other than the stress cracks, which are created intentionally, most quench-crackled synthetic corundums do not show any signs of heat treatment.

Clayton Welch

A HISTORICAL NOTE

Beginning with this issue, we are adding a new feature to the Gem Trade Lab Notes. Clayton Welch, a staff gemologist in the Gem Identification Section of the New York Gem Trade Laboratory, thought our readers would be interested in learning what was examined in the earlier days of the GTL. We agreed and decided to publish a recap of the items discussed in this section 25, 15, and five years ago.

The Lab Notes actually debuted 29 years ago, in the Winter 1958–59 issue of *Gems & Gemology*, as two sections: "Highlights at the GEM TRADE LAB in New York" and "Highlights at the GEM TRADE LAB in Los Angeles." G. Robert Crowningshield provided the items from New York, and Lester B. Bensen, Jr., contributed from Los Angeles. However, the section had as a precursor an article by Crowningshield that appeared in the Summer 1957 issue, titled "New or Unusual Gem Materials Encountered in the Institute's Gem Trade Laboratories." The success of this concept is evident in the fact that this section continues to be one of the most highly regarded features of *Gems & Gemology*.

Since this is the first issue to have this historical addition, it seems only appropriate that we start with a recap of some of the things discussed in Crowningshield's original article. We will then cover the items that were included in this section 15 and five years ago.

We hope that you enjoy this brief look at developments in gemology over the past quarter century. For many of us, it seems like only yesterday.

C. W. Fryer

SUMMER 1957

A number of rocks consisting of two or more different minerals were submitted for identification. These include lazurite in diopside and sodalite with pyrite veins (both had been confused with lapis); a mixture of pink thulite, zoisite, and nephrite that would probably now be called saussurite; and a mixture of ruby and zoisite from Africa. Sillimanite from Idaho, cat's-eye ulexite, several varieties of synthetic spinel, a natural green gahnospinel, and high-refractive-index glasses were also seen and are discussed in this article.

Crowningshield comments on the limited usefulness of the so-called emerald filter, inasmuch as not all natural emeralds appear red under the filter although all synthetic emeralds do. He suggests that the filter simply be called a color filter, since it does have some use for spinel separations. Dyed green jadeite is singled out as one of the most commercially significant stones to have been identified by the GTL in 1956. Jadeite triplets are also described.

WINTER 1972–1973

The Los Angeles GTL discusses the appearance of true synthetic alexandrite produced by a flux-growth method, and provides a detailed description of the inclusions and other properties of this material. Umba River corundums had recently appeared in the lab, as had the relatively new grossularite garnets that would soon be known as tsavorite. A strongly banded type IIb diamond is described, as are seven large diamond and quartz doublets that had been bezel set in a bracelet. The fact that the pavilions seemed to be doubly refractive and one showed a bull's-

Normal color of this 2.5-ct "chameleon" diamond.

The stone shown in figure at left after heating and before exposure to light.

eye optic figure indicated that rock crystal quartz had been used for this part of each stone. A glass cat's-eye is also mentioned.

Maxixe-type beryls are reported by the New York GTL. Several carvings made from serpentine, nephrite, quartzite, and a material later to be known as saussurite are covered as well. A new "jade" cat's-eye proved to be actinolite, which could not properly be called jade because of its structure. Cat's-eye chrysoberyl and apatite were also encountered. A 4-mm-deep laser drill hole in a diamond graded at the lab seemed to be a record depth at the time. Other oddities include a botryoidal diamond crystal and a fingerprint-type inclusion in synthetic ruby. The section concludes with an illustration of the scratches that appeared on the table of a strontium titanate as a result of contact with ordinary kitchen cleanser, vivid evidence of the inferior hardness of this diamond substitute.

WINTER 1982

By this time, as it had since Spring 1981, the reports of all the GTL offices were combined in a single section that was organized alphabetically by gem material.

One of the most unusual diamonds seen in the GTL is the "Crusader" diamond, a seven-sided modified brilliant that had been cut in the shape of a crusader's shield, with a frosted cross on the table. Also reported in this issue is a "chameleon" color-change diamond. If examined while warmed by a flame or after being in the dark for several days, this chameleon-type diamond appears to be a beautiful intense orangy yellow. After brief exposure to light, however, the stone reverts to its usual grayish green color.

The properties of Zambian emerald and Colombian parasite are given. A beautiful star quartz, heat-treated sapphires, and cobalt-colored spinel and sapphire are discussed. Photographs show a spinel that exhibits both four- and six-ray stars. The last item discussed is the identification of the rarely encountered man-made materials lithium fluoride and potassium chloride.

GEM NEWS

John I. Koivula, *Editor*

DIAMONDS

Brazilian diamond find. A diamond-rich kimberlite pipe is currently being worked in the state of Mato Grosso, Brazil, approximately 20 km from the commercial center of Julina. The diamond find was made by Sopemi, a Brazilian mining company that is closely associated with De Beers and Anglo American. The mine is currently producing about 300,000 ct of diamonds per year. The stones are reported to be of excellent quality, comparable to material from South Africa and the Soviet Union. This, the first productive in-situ diamond deposit in Brazil, is a significant development for the country, since diamond mining has heretofore been confined to secondary alluvial workings.

Remarkable morphology. The magnificent 4.98-ct diamond crystal shown in figure 1 has a complex and rare morphology. The ball-like structure shows the development of numerous oriented octahedral faces replete with trigons. The trigon-decorated faces are separated by length-striated grooves, which are the reentrant-angle manifestations of a complex system of twinning. GIA's Dr. Emmanuel Fritsch, an expert on twinning, recognized this form as a type described by Goldschmidt and Von Fersman that is known as a Mohs-Rose twin.

A follow-up. The 64.83-ct D-internally flawless diamond described in this section in the Fall issue sold at auction at Christie's in New York on October 21, 1987, for US$6,380,000. Please note that this diamond was graded at the GIA Gem Trade Laboratory, Inc., in Los Angeles, not in New York as we originally reported.

COLORED STONES

The 21st International Gemmological Conference. The invitation-only 21st International Gemmological Conference was held in Rio de Janeiro, Brazil, September 20–25, 1987, with representatives from over 20 different countries. Dozens of gemological papers were presented. In addition, field excursions to the major mining areas of Minas Gerais were held immediately after the conference. The alluvial diamond mining operations around Diamantina were explored, as were a number of gem-producing pegmatites in the areas of Araçuaí, Teófilo Otoni, and Governador Valadares. Special permission was obtained from the Brazilian government to visit the newly discovered alexandrite chrysoberyl deposit near Itabira (see below). The highly sophisticated Belmont

Figure 1. This 1-cm diamond crystal shows the rarely encountered Mohs-Rose twin morphology. From the collection of Jack Greenspan; photo © Harold & Erica Van Pelt.

emerald mine, also near Itabira, was examined from the point of extraction of the ore all the way through to the final emerald-recovery process.

A conference of this magnitude takes a great deal of planning, and Elizabeth and Ian MacGregor of Teresopolis, Rio de Janeiro, Brazil, deserve credit for the smooth operation of the 21st IGC. New gemological information reported at this event will appear in the Gem News section over the next few issues.

More on Brazilian alexandrites. "Arabian Night"–like stories of exotic locales, spun together with tales of gems just waiting to be picked up by the handful, always have a way of making such places seem larger than life. Such is the case with the new alexandrite mine located near Itabira in Minas Gerais, Brazil. This locality has already produced an impressive quantity of fine gem-quality alexandrite, and promises to be prolific for the next several years. The rough material yields beautiful faceted and chatoyant cabochon gems. In appearance,

Figure 2. Delegates from the 21st International Gemmological Conference inspect the new alexandrite mine near Itabira in Minas Gerais, Brazil. Photo by John I. Koivula.

however, this may also be one of Brazil's least-interesting mining areas (figure 2). The "mine," still in the early stages of development, consists of a roughly rectangular patch of barren reddish brown earth that is surrounded by trees and brush. It measures approximately 180 × 120 m (600 × 400 ft). Beneath the earthy overburden is a layer of white, fine-grained, clay-like material a few feet thick, below which the alexandrites are found. Several gem pits have been dug haphazardly within this area. Thus far the alexandrites have been recovered from these crude, water-filled pits by local miners using simple hand tools. At the time of our visit, in September 1987, no mining was being done and the area was under military control (figure 3) because several miners had

Figure 3. An armed military policeman stands guard over the Brazilian alexandrite deposit as a group of hopeful would-be miners wait for a chance to dig. Photo by John I. Koivula.

been killed over property disputes. However, would-be miners still show up at the site on a daily basis, hoping to be allowed to dig for alexandrites. A detailed article on this locality, and the alexandrites from it, is scheduled to appear in a future issue of *Gems & Gemology.*

Colorado amethyst find. A major new find of fine-quality "Siberian" amethyst has been made at the Rainbow Lode amethyst mine in the Red Feather Lakes area of Larimer County, Colorado. As reported by Mr. Mark Jacobson of Littleton, Colorado, in the September 1987 issue of *Mineral News,* this discovery has yielded a significant quantity of doubly terminated crystals, some as large as "softballs" (10 cm [4 in.] in diameter). Multi-crystal matrix specimens of up to one foot in length have also been recovered. In July and August 1987, the mine owners, Nick Finnel of Fort Collins and Bohn Dunbar of Akron, Colorado, dug a 12 to 18 m (40 to 55 ft.) deep pit into the amethyst-bearing vein. From this operation they recovered approximately 900 kg (about 2000 lbs.) of unsorted matrix specimens and another 450 kg of single crystals. Some of the matrix specimens weigh as much as 45–55 kg (100–125 lbs.); the largest doubly terminated single crystal weighs 1 kg. Most of the crystals are undamaged and make excellent display specimens. One 7–9 kg cluster on matrix has eight amethyst scepters. Although most of the crystals are cloudy and internally fractured, the color is still dark and brilliant, and a small percentage of the find is of high gem quality. Several 1- to 9-ct stones have already been faceted from this material.

The "Lowell" effect in amethyst. Jack Lowell, of the Colorado Gem and Mineral Company, Tempe, Arizona, has identified an unusual, previously unreported, phenomenon in amethyst from Artigas, Uruguay. This adularescence-like phenomenon (figure 4) is strictly confined to the area in, and immediately around, the minor rhombohedral faces of the amethyst that show it; it may be related either to twinning or to ultra-fine growth structures within these zones, or both. GIA will continue to study this "Lowell" effect and would welcome any information from Gem News readers regarding previous publications on this phenomenon or observations of it in amethyst from other localities.

Trapiche emerald crystal. The 59.09-ct gem-quality trapiche emerald shown in figure 5 is remarkable in that it exhibits not only the classic six-rayed figure at the bottom of the crystal, but also the tapered hexagonal core that is associated with the trapiche variety but only rarely seen. Evidence of this core appears at the top of the crystal in the form of a hexagonal depression.

"The Stellenbosch Gem Index." At the 21st International Gemmological Conference, Mr. Herbert S. Pienaar, professor of gemology in the De Beers Laboratory for Gemmology at the University of Stellenbosch,

Figure 4. The adularescence-like effect observed by Jack Lowell in some amethysts from Artigas, Uruguay, has never been described before. Magnified 15×; photomicrograph by John I. Koivula.

Figure 5. This exceptional trapiche emerald crystal from the Muzo area of Colombia measures approximately 22 mm × 16 mm and exhibits a clear hexagonal core in addition to a six-rayed figure similar to that on the accompanying the cabochon (10.03 ct). Crystal courtesy of Colombian Emeralds Co., Los Angeles; photo © Harold & Erica Van Pelt.
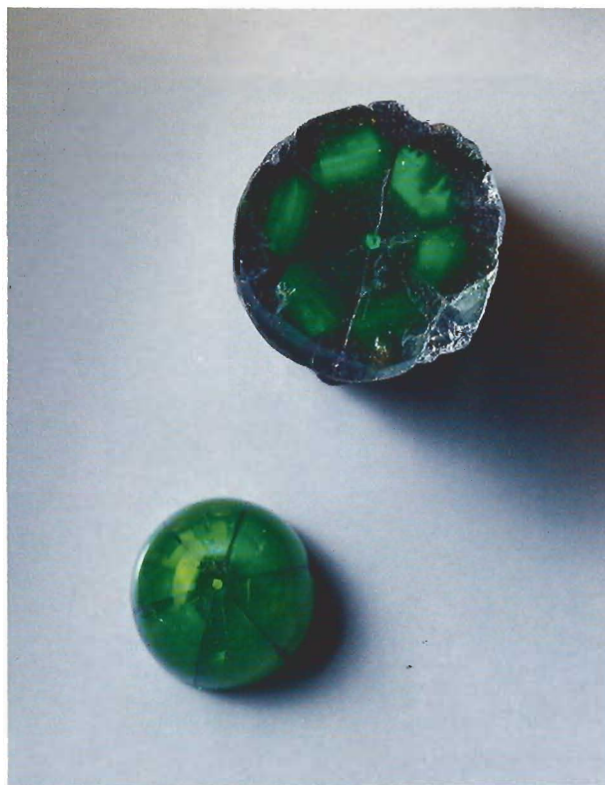
South Africa, described a method that he uses to teach beginning students of gemology the basics of gem identification. Called "The Stellenbosch Gem Index," or SGI, this teaching method is designed to narrow the identity of an unknown stone to a few possible choices using a minimal number of tests. Mr. Pienaar combines the specific gravity and mean refractive index of the unknown stone in a mathematically simple formula to come up with a single SGI number. Mr. Pienaar, together with D. A. Glenister, has prepared a booklet that describes this approach to gem identification. The booklet also contains the tables required to match the SGI of an unknown stone to a specific gem or group of gem materials.

Editor's note: This is an excellent way of showing students the close relationship that exists between the properties of specific gravity (density) and refractive index, which, for any gem material, are inseparably linked to structure and chemical composition. For further information, and to obtain a copy of "The Stellenbosch Gem Index," write Professor Pienaar, University of Stellenbosch, Stellenbosch 7600, South Africa.

Double phenomenon in sapphire. The 21.53-ct star sapphire shown in figure 6 is unique in that it also shows a distinct change of color from bluish purple in incandescent light to blue in fluorescent light. The natural star sapphire, an oval double cabochon that measures 14.52 × 12.88 × 10.87 mm, is from Sri Lanka.

Tausonite: A new mineral. Also at the recent 21st International Gemmological Conference held in Rio de Janeiro, Brazil, it was reported that strontium titanate $(SrTiO_3)$, one of the older diamond substitutes, has been found as a naturally occurring mineral. This new mineral, called tausonite after a Russian geochemist, was found in Mongolia. It is listed in the fifth edition of the *Glossary of Mineral Species*, by Michael Fleischer. Usually, synthetics are manufactured to mimic a natural material, but in this instance the synthetic was known first.

Transparent gem thaumasite. As reported in *Mineral News*, the very rare mineral thaumasite, $Ca_3Si(CO_3)(SO_4)(OH)_6 \cdot 12H_2O$, has been found as facet-quality pale yellow crystals as large as 5 mm in diameter and 15 mm in length. Mr. Mike Haritos of S.T.D. Mineral Company, Hyde Park, Massachusetts, received the thaumasites in a June 1987 shipment of minerals from South Africa. He said that, in external form, the hexagonal crystals resemble apatite or yellow beryl. Since thaumasite is listed in mineralogical texts as being colorless to white, with a habit that is acicular to filiform and usually massive and compact, the identity of these transparent yellow crystals was at first in doubt. Subsequent testing, including chemical and X-ray diffraction analysis,

Figure 6. Two separate phenomena can be seen in this 21.53-ct color-change star sapphire from Sri Lanka, shown here in incandescent light. Courtesy of Trent West Jewelry, Capitola, CA; photo by Shane McClure.

proved that the original thaumasite identification was correct. With a Mohs hardness of 3.5, thaumasite is not useful for jewelry.

Topaz from New Hampshire. In the last issue of Gem News we made brief mention of a new find of gem-quality topaz from New Hampshire. In the August 1987 issue of *Mineral News*, Mr. Ken Hollman of Center Rutland, Vermont, provided additional details on this deposit, which has become known as the Rainbow Pocket. It was initially discovered in the Conway granite on October 19, 1986, by Mr. Peter B. Samuelson of Conway, New Hampshire. The contents of the naturally opened pocket, which measured approximately 2.4 × 1.0 × 0.6 m (8 × 3 × 2 ft), were found scattered as far as 60 m down the side of a talus slope. No other significant pockets have been found within the half-mile radius that has been investigated to date. Thus far, the find has produced a total of 122 topaz crystals with a combined weight of approximately 8.2 kg (18 lbs.). The crystals have been described as a "rich brown sherry" and blue; in addition, some are bicolored. They are reportedly striated as a result of etching and are of "facet quality." The largest topaz crystal recovered from this locality to date is blue and weighs 1975 grams. In addition to topaz, this pocket has produced 100 kg of smoky quartz, 900 grams of citrine, siderite crystals as large as 2 cm, corroded crystals of microcline feldspar, and muscovite mica.

SYNTHETICS

Check your filter. Gem-quality synthetic yellow diamonds have been on the market for about one year now.

As pointed out in the reports published thus far in *Gems & Gemology*, one of the most important characteristics used to separate natural yellow diamonds from the new synthetics is fluorescence. All of the synthetic yellow diamonds tested to date have been type Ib. They fluoresce a greenish yellow to yellow in response to short-wave ultraviolet radiation (253.7 nm) but are inert to long-wave U.V. radiation (366.0 nm). The vast majority of natural yellow diamonds are type Ia; if a type Ia diamond fluoresces to short-wave U.V. radiation, it will react even stronger to the long-wave lamp. Even natural type Ib diamonds can be distinguished in this way because, while they may fluoresce to short-wave U.V. but not to long-wave U.V., like the synthetics, the fluorescence color is orange rather than greenish yellow. The relative simplicity of the test makes this difference in fluorescence an important means of distinction when dealing with a possibly synthetic yellow diamond. Unfortunately, though, when a test is easy it is often taken for granted, and proper attention is not paid to the equipment used.

During a recent lecture, Mr. Gary Roskin, assistant executive director of GIA's Alumni Association, attempted to demonstrate the short-wave fluorescence of a faceted Sumitomo synthetic yellow diamond set in a gold ring. When the lamp was activated, however, he was surprised to see that the diamond did not fluoresce. At first he thought that perhaps the mounting was in some way either blocking the radiation or masking the fluorescence, but even in a completely darkened room, no fluorescence was observed. He then obtained a new short-wave ultraviolet unit to check the reaction; this time the diamond fluoresced as expected.

The failure of the first unit was caused by the short-wave filter. The newest short-wave lamps have a "lifetime filter" that does not need changing, but in all older units the short-wave filter deteriorates with time and eventually needs to be replaced. It is important, therefore, that you check your lamp filter periodically. This can be done by using a test stone such as scheelite, benitoite, or even a small synthetic yellow type Ib diamond.

ANNOUNCEMENTS

The Natural History Museum of Los Angeles County celebrates its Diamond Jubilee in 1988 with dazzle, as a spectacular selection of world-famous diamonds from the Smithsonian's collection goes on display in the gem vault. The museum begins the year with the opulent Victoria-Transvaal necklace, featuring a stunning 67.89-ct stone surrounded by 108 smaller diamonds, which will be on display until March 13, 1988. Following this will be three other special diamond sets: the Napoleon necklace with the Empress Marie Louise diadem, March 14–June 12; the Oppenheimer and the Portuguese diamonds, June 13–September 11; and the Eugenie Blue diamond in conjunction with the Marie Antoinette earrings, September 12–December 31, 1988. For information on the museum's hours and location, please call (213) 744-3466.

The World Gems Expo will be held June 3–6, 1988, in Hong Kong. Co-organized by the Hong Kong Diamond Bourse and Headway Trade Fairs Ltd., this is the only international specialized fair on gemstones. For further details, please contact: Headway Trade Fairs Ltd., 9/F Sing-Ho Finance Building, 168 Gloucester Rd., Wanchai, Hong Kong.

The Commission on Gem Materials of the International Mineralogical Association met in Brazil in September 1987 immediately following the 21st International Gemmological Conference. The meeting was chaired by E. Ralph Segnit of Australia; others in attendance were Secretary Henry O. A. Meyer (United States), Pieter C. Zwaan (the Netherlands), Alan Jobbins (United Kingdom), Herbert S. Pienaar (South Africa), Nikolai V. Sobolev (Soviet Union), Margherita Superchi (Italy), and D. P. Svisero (Brazil). The main topic of discussion was the commission's preparation of a detailed *Atlas of Worldwide Gem Deposits*. When completed, this atlas will be indispensable to all gemologists, mineralogists, and any others involved in the earth sciences. To ensure its accuracy, the IMA invites individuals with first-hand knowledge of gem deposits anywhere in the world to contribute. To obtain or provide information concerning the atlas, please write to the project coordinators, Dr. James E. Shigley and Dr. Emmanuel Fritsch, in care of the Research Department at the Gemological Institute of America, 1660 Stewart St., Santa Monica, CA 90404. Your participation in this project is vital for its successful completion and will be greatly appreciated.

QUARTZ

By Michael O'Donaghue, 110 pp., illus., publ. by Butterworths, London, 1987. US$29.95*

Quartz, in both its single-crystal and cryptocrystalline forms, has been an important gem material for centuries. It is also one of the most common gem materials, because of the abundance of the elements silicon and oxygen (the major components of quartz) in the earth's crust. To condense the gemological significance of quartz into one small volume of 110 pages is, to say the least, a formidable task. However, O'Donoghue has managed successfully to provide the information concisely and in a well-organized fashion.

First, he discusses the igneous, hydrothermal, and metamorphic origins of quartz. He follows with a detailed description of the mineral, including chemistry, crystal structure, and inclusions. He then reviews causes of color in quartz and various methods of synthesis. Next, the significant gemological properties are presented, followed by three chapters on occurrence, and concluding with chapters on testing and on the lapidary fashioning and historical uses of gem-quality quartz.

Perhaps the only weakness in this book is the lack of adequate descriptions of the various occurrences, and the omission of some localities altogether. For example, with the exception of Libya, no mention is made of any other African sources; both the Soviet Union and China are neglected.

The book does contain a four-page spread of attractive color plates, primarily of chalcedony and the internal characteristics of single-crystal quartz gems such as amethyst. A useful bibliography, a glossary of terms, and an index of unusual names for various quartz varieties are also provided.

Quartz is enjoyable, accurate, easy to read, and within the budget range of most gemstone enthusiasts. It is a good introduction to this broad family of gems, and makes an excellent companion monograph to the more technical third volume of Dana's *System of Mineralogy.* This

BOOK REVIEWS

Elise B. Misiorowski, Editor

book is recommended to all gemologists and jewelers who have an interest in quartz.

JOHN I. KOIVULA
Chief Gemologist, GIA

LE MONDE MINERAL VU PAR LES TIMBRES
The World of Minerals through Postage Stamps

By Jean-Michel Autissier, photographs by Nelly Bariand, 128 pp., publ. by Atelier JMA, Saint-Amand-Montrond, France, 1987. 120 FF*

This beautifully illustrated volume, written in both French and English, represents a thorough documentation of gems and minerals that are depicted on postage stamps. This work was inspired by the publication of the first French mineral stamps in September 1986 and the mineral-related stamp exhibit that followed at the Sorbonne in Paris. The first of its kind, this book is an attempt to provide a complete international catalogue of stamps featuring various forms of minerals, from polished gems to ore specimens.

One hundred and five mineral species are covered, and 425 stamps are described with full philatelic references. After a short introduction to the mineral world, the presentation follows a classification by mineral species: gems and ornamental stones first, followed by other minerals classified according to the type of deposit in which they are found. The text is illustrated with fine color photographs of the stamps taken by renowned gem and mineral photographer Nelly Bariand. In total, 283 stamps are illustrated.

The overall quality of the paper, printing, and color reproduction is

excellent. The bilingual text, together with philatelic references to French, German, and American classifications, gives this work a broad international audience.

This little book can easily be used in sales to illustrate the geographic origin of a stone or the official recognition of an unusual species. It is an intriguing and fascinating introduction to the important role that gems and minerals play in everyday life.

EMMANUEL FRITSCH
Research Scientist, GIA

A GUIDE TO FOSSICKING IN THE NORTHERN TERRITORY
2nd Edition

Revised and updated by Dick Thompson, 74 pp., illus., publ. by the Northern Territory Department of Mines and Energy, Darwin, Northern Territory, Australia, 1986. A$9.00*

Twice the size of the state of Texas, the Northern Territory of Australia is a vast, sparsely settled region of legendary natural beauty in which a great variety of interesting mineral deposits, some of which produce gem materials, have been found. For the amateur field collector, or "fossicker," the Northern Territory represents a most appealing destination, offering an enormous field for exploration along with the ever-present prospect of new discoveries. This book is an authoritative guide to many of the region's localities that are accessible to collectors. It contains superb, colorful maps and a wealth of other useful information such as practical facts on mineral identification, detailed directions for finding locations, tips on traveling, names of local gem and mineral clubs, and a bibliography of suggested references. This book is well illustrated, with many color photographs of gems, mineral specimens, and localities. Its lively, attractive format could well serve as a model

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for those contemplating the preparation of such a guide for other regions.

Most of us can only dream about visiting some of the remote locations described in this book. Yet locality guides like this can act as useful references on gem and mineral occurrences for the curator and private collector. They can also suggest deposits and areas for further exploration and possible commercial development. Thus, they are valuable additions to any library regardless of whether one is ever fortunate enough to visit the location.

ROBERT MIDDLETON
Collections Manager,
Earth Sciences Division
Los Angeles County
Museum of Natural History

OTHER BOOKS RECEIVED IN 1987

The Collector/Investor Handbook of Gems, *by John L. Ramsey and Laura J. Ramsey, 300 pp., illus., Boa Vista Press, San Diego, CA, 1985, US$16.95.* * This is a very earnest endeavor on the part of two well-respected members of the trade to address a subject that most gemologists try to avoid, that of gemstone investing. The book is divided into three sections. The first, "Gems and the Economy," takes a long look at inflation and deflation and the performance of gems in this unpredictable economic climate. The second section discusses the more practical aspects of buying and selling gems: appraisals, treatments of and inclusions in gemstones, where to go for gemological instruction, and the types of equipment used for gem identification and evaluation. The third section discusses another current gemological quagmire: the description and evaluation of color in gems. This section includes a "Color Guide and Gemological Reference" to 24 popular "investment" stones, with full-color examples of each stone provided together with their properties, lo-

calities, and comments by the authors regarding positive and negative characteristics. The book closes with tables of gemstones listed three ways: alphabetically, by refractive index, and by specific gravity. Also included are a glossary, a section on suggested books and periodicals, and an index. Much useful information is compiled in this deliberately "pocket-sized" handbook, augmented by many bold color photographs of the gems.

EBM

Minerals of Mexico, *by William D. Panczner, 459 pp., publ. by Van Nostrand Reinhold Co., New York, 1987, US$44.95.* * This book represents a tremendous amount of painstaking research, both in the field and in libraries, that has culminated in a current catalogue of minerals and their locations throughout Mexico. It begins with a historical overview of the important mining districts, followed by a chronology of discoveries and developments related to mining in Mexico and a 20-page bibliography that is itself a noteworthy accomplishment. The bulk of the text is the catalogue, which is arranged alphabetically by mineral, and by state and county within each mineral entry. Although the emphasis is on minerals in general, rather than on gems in particular, any gemologist interested in Mexican gem materials will find this a useful addition to their library.

EBM

The Dow Jones–Irwin Guide to Fine Gems and Jewelry, *by David Marcum, 213 pp., illus., publ. by Dow Jones–Irwin, Homewood, IL, 1986, US$25.00.* * This book provides helpful information for any consumer interested in buying gems. Topics covered include the gems themselves, how to read lab reports, types of appraisals, and a variety of tips and insights into

the jewelry and gem trade based on the author's experience. Although the term *gem investment* makes most gemologists cringe, it continues to be a concern with the public and is addressed here as well. For a book about gems and jewelry, it is sparsely illustrated, with only eight color pages showing the principal varieties of colored stones.

EBM

Guide des Pierres de Rêve (Guide to Dream Stones), *in French, by Anne de Tugny, 239 pp., illus., publ. by Editions Flammarion, Paris, 1987, 130 FF.* This small-format, well-illustrated book is an introduction to the science and magic of gemstones for the enlightened amateur. The first and major part of the book is a simple dictionary of gemstones. Each stone is described in terms of color, clarity, internal characteristics, history, cut, care, sources, and possible imitations. The remaining parts are devoted to synthetics, practical tips for buyers, and, finally, a short section on lore. Altogether, this is an attractive and handy little book that can be used in sales to show the customer "a little bit more" about a stone, without delving into the technicalities of refractive index and specific gravity.

EMMANUEL FRITSCH

Editor's Note: In response to reader demand, the "Gemological Guidelines for Gemstone Durability in Jewelry" chart that appeared in the Summer 1987 issue of Gems & Gemology *is being reissued in a laminated version suitable for display. The chart can be purchased for US$9.95, plus postage and handling, from the GIA Bookstore (1660 Stewart St., Santa Monica, CA 90404; 800-421-7250, x282). Discounts are available to members of the GIA Alumni Association and for orders of 10 or more.*

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Blue and yellow sapphire from Kaduna Province, Nigeria. L. Kiefert and K. Schmetzer, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 427–442.

Nigerian sapphires have been known for about 15 years and are now appearing on the gem market in significant amounts; most are dark blue although a small quantity are yellow. The authors provide a thorough description of this gem material that is based on their examination of 38 crystals and 31 cut stones from alluvial deposits in Kaduna province, about 45 km northeast of Jos. The tests

revealed typical physical properties for corundum. Optical spectra indicate the presence of Fe^{3+}, $Fe^{2+/3+}$, Fe^{2+}/Ti^{4+}, and, in some cases, Cr^{3+} absorption bands in the blue sapphires, with changes in relative band strengths along different axes that correlate with observed pleochroism. The yellow sapphires revealed only Fe^{3+} and Ti^{3+} absorption features.

Detailed descriptions are provided for a variety of typical corundum inclusions, that is, unhealed plane fissures, hexagonal platelets, zircons surrounded by stress cracks, and rounded prismatic albites associated with fluid inclusions. Another type of inclusion, red to reddish brown uranpyrochlore grains, indicates that the Nigerian sapphires originated in alkali basalts.

Two color and 33 black-and-white illustrations, including 27 photomicrographs of inclusions and five absorption spectra, accompany this article.   *CMS*

Dark blue aquamarines from Sambia with high refraction of light indices. H. Bank, *Gold und Silber*, Vol. 40, No. 3, March 1987, pp. 101–102.

Bank briefly describes the dark blue aquamarine that is occasionally found in Zambia. The aquamarines occur near Lundazi in pegmatites intruding into the gneisses and schists of the basement complex; gem-quality aquamarine generally occurs as fragments of broken crystals. Beryl has also been found further south, near the Mozambique border.

Bank recently tested the refractive indices of the Zambian aquamarine and reports that the ordinary ray ranges from 1.590 to 1.596 and the extraordinary ray from 1.581 to 1.586, with a birefringence of 0.009 to 0.010. These indices are similar to those reported for Nigerian aquamarine and are higher than average for beryl.

Because references to Zambian aquamarine are scarce, the author advises readers to look at his article in the February 1984 issue of *Gold und Silber* for further information on this material.   *BCC*

Gemmological jottings. G. Brown and J. Snow, *Australian Gemmologist*, Vol. 16, No. 7, 1987, pp. 267–270.

This brief article reports on a number of interesting items: (1) turquoise beads that have been treated with both dye and wax; (2) a plastic imitation of a walrus tusk scrimshaw; (3) Japanese-manufactured synthetic jelly opal with a rather natural-appearing play-of-color; (4) a bleached and plastic-impregnated cabochon of coral (presumably black) made to imitate golden coral; and (5) a new thermal diamond probe, the Diamond Beam, now being marketed in Australia. Each subject is covered in some depth, and the first four items include a concise synopsis of the examination and what it revealed. All subjects are well illustrated in color.   *RCK*

Pronounced flow structure in an Australian opal. J. I. Koivula, *Australian Gemmologist*, Vol. 16, No. 7, 1987, pp. 257–258.

This brief article begins with an overview of the formation of gem-quality Australian opal, with particular emphasis on the mechanisms producing flow structures. The author notes that these structures, while somewhat common, are not particularly prominent and are often quite difficult to see. He then proceeds to describe a 12.80-ct white boulder opal from Queensland, noting its prominent flow features—visible both microscopically and to the unaided eye—and explains clearly the cause of these features. The accompanying photomicrograph amply illustrates the author's points.
RCK

DIAMONDS

Anomalous occurrences of diamonds. P. H. Nixon and S. C. Bergman, *Indiaqua*, Vol. 47, No. 4, 1987, pp. 21–27.

The Gem News section of the Summer 1987 issue of *Gems & Gemology* reported the discovery of a 14-ct diamond in Trinity County, California. This is exciting because the surface texture of the diamond suggests that it has not been transported far from its source on the surface; yet there are no known diamond "pipes" in California or anywhere else along western North and South America.

It is generally accepted that natural, terrestrial diamonds form under high pressure in the mantle of the earth at depths of at least 150 km. It is thought that explosive volcanism in the form of kimberlites (as in Africa) or lamproites (as in western Australia) is the only mechanism capable of exhuming samples of such deep-seated mantle. These volcanoes are restricted to regions that are in or near Precambrian continental shields, such as the interior of the North American, African, and Eurasian continents. How, then, do we account for diamond occurrences such as those in the Trinity district that are far removed from such sources?

Drs. Peter Nixon and Steve Bergman discuss a number of "anomalous" occurrences of diamonds and show that nearly all of them are found at the distal regions of the earth's lithospheric plates. Examples include regions where continental plates move against oceanic plates, such as along the San Andreas and related fault systems in California. In such areas, deep-seated peridotites and other rocks of the oceanic crust and mantle are thrust up near the plate margins, forming the so-called ophiolite complexes such as in the Trinity Alps and at Point Sal, both in California. Nixon and Bergman suggest that the diamond-bearing peridotites may have been buried originally at depths as great as 150 km. The apparent absence of other high-pressure minerals such as pyrope garnet, which is common in kimberlites and lamproites, suggests that the "anomalous" diamonds may have crystallized metastably at shallower depths and lower pressures, but this negative evidence is not convincing.

Similar upthrusting can occur when two continental plates collide, as is the case with the Indian continent and the Eurasian plate, which has produced the Himalayas. The Chinese reportedly have found diamonds near this continental suture in Tibet. Diamond-bearing upthrust zones also occur at oceanic–oceanic plate boundaries, such as near the New Hebrides trench and elsewhere in the South Pacific.

The Nixon-Bergman model is of interest to diamond enthusiasts, but it also provides food for thought for earth scientists concerned with processes at the boundaries of lithospheric plates. In addition, it also offers a testable model for diamond exploration. *Art Montana*
Professor of Geochemistry and Chairman of the Department of Earth & Space Sciences UCLA, Los Angeles, CA

Damage to cut diamonds. H. A. Hänni and G. Bosshart, *Journal of Gemmology*, Vol. 20, No. 6, April 1987, pp. 339–343.

Messrs. Hänni and Bosshart review a wide variety of causes for damage to cut diamonds. Since diamonds are highly resistant to acids and corrosive agents, damage at normal temperatures from chemical attack is quite rare. However, damage during jewelry repair may occur if, for example, a diamond is not thoroughly degreased before the borate fire coating is applied. In such incidents, the

jeweler's torch may scorch the surface of the diamond. Mechanical damage or damage due to wear includes blows that can extend existing cleavages (rare) as well as facet-edge abrasions or girdle chips (more common). Diamonds may also abrade one another when more than one diamond ring is worn on the same finger. Damage during polishing includes girdle feathers from rough bruting and pressure cracks and burn marks from the mechanical dop. Reportedly, 90% of the stones that do not receive a culet during polishing sustain minor damage. Setting damage is chiefly limited to chips to thin areas of a girdle.

While minor damage can usually be repaired by repolishing (with little loss of weight), the authors correctly point out that repairing a 1-ct stone that has sustained extensive damage could cause it to drop below its critical weight. This article concludes with the observation that since gemological laboratories can often assess the causes of various kinds of damage, insurance companies and others may find this service of value.   *James R. Lucey*

Diamond mining since 1914. J. Roux, *Diamond World Review,* No. 42, 1987, pp. 14, 16, 52, and 54.

In this article, Johnny Roux relates fluctuations in world diamond production to political and economic factors that influence supply and demand for gem-quality and industrial diamonds. Supply-side factors include: new discoveries, mine productivity, and political climate. Factors influencing demand include: world economic conditions, advancing technology, and marketing.

World production was erratic until 1948, when annual increases began their long, steady journey upward. Post–World War I economic conditions in Europe and the Depression in the United States slowed production. Both world wars forced mines in South Africa (the major producer) to close. De Beers's stockpiles, however, continued to feed the demand for diamonds during those years. The independence of African nations such as the Belgian Congo (Zaire) in 1960 and Angola (Angola People's Republic) in 1975 nearly halted production in those countries. Subsequent recovery was slow, and increased smuggling began to decrease official production figures.

Favorable factors outweighed the unfavorable, however, and worldwide diamond production grew tremendously from 2.9 million carats in 1914 to 63 million carats in 1984. One reason for this is the increasing demand, which began in the 1940s, for industrial diamonds. In addition, new discoveries and production in the USSR, Zaire, Angola, Botswana, South Africa, and, most recently, Australia have greatly added to the figures. In 1986, Australia's first year of full production, it accounted for 29 million carats of the world total of 88 million carats. It is interesting to note that Australia's 1986 output alone is equivalent to 10 times the total world production in 1914.

Roux presents this material chronologically, by selected one- to three-year spans. He also includes a graph of production from 1914 to 1986, which dramatically illustrates the increases during this period.
                                        Gail Kirchner

Exciting signatures from the earth's mantle. J. Bristow, H. Allsopp, C. B. Smith, and E. M. W. Skinner, *Indiaqua,* Vol. 47, No. 2, 1987, pp. 31–38.

The authors trace the history of the use of isotopic ratios between long-lived radioactive elements, such as samarium-neodymium and uranium-lead, in the age determination of kimberlites, lamproites, and other associated rock types related to upper mantle activity. With the technical advances made in the field of mass spectrometry over the last few years, scientists have been able to apply this same technology not only to the rocks themselves, but also to individual crystals within rocks and to inclusions within the crystals.

A tremendous time discrepancy was obtained when the ages of the host rocks were compared to those of the inclusions found in diamonds frozen within the rocks. Inclusions in diamonds from the Kimberley and Finsch mines were dated at 3.2 to 3.3 billion years, but the kimberlites are of Cretaceous age (70–130 million years). This age difference supports the conclusion that diamonds are xenocrysts derived from other mantle sources, not phenocrysts crystallized from kimberlite.

The article is illustrated with several helpful black-and-white and color photographs and drawings, including one of a garnet inclusion in a diamond and a cross-sectional model of a kimberlite pipe. A comprehensive list of 41 additional references is also provided.
                                        John I. Koivula

GEM LOCALITIES

Geological setting of Zambian emerald deposits. A. S. Sliwa and C. A. Nguluwe, *Precambrian Research,* Vol. 24, 1984, pp. 213–228.

Emerald mineralization is reported from at least 10 occurrences along a linear zone extending on both sides of the Kafubu River in north-central Zambia. These occurrences are found in quartzites and various schists of the Muva Supergroup that were originally deposited as sediments between 1635 and 1300 million years ago. Within the rocks of the Muva Supergroup are persistent linear bands of talc-chlorite-amphibole-magnetite schist, which are intruded by small veins and dikes of feldspar-quartz-tourmaline pegmatite. The emeralds are found in the schist host rock along altered contact zones that rim the pegmatites. The emeralds sometimes also occur within veins of quartz-tourmaline pegmatite. Distribution of the emerald mineralization is erratic, but the richest areas seem to form around flat-lying, undulating pegmatite veins. The beryllium necessary for beryl formation is thought to have been supplied by

the pegmatites. The chromium needed to produce the green color of the emeralds was derived from the schist host rocks, which were found by chemical analysis to contain concentrations of the element.

The Zambian emerald fields are considered comparable in quantity and quality of material to the well-known Colombian emerald occurrences, but their geologic setting differs considerably. However, striking similarities were found between the Zambian occurrences and other African deposits of emerald at Sandawana (Zimbabwe), Gravelotte (South Africa), and Lake Manyara (Tanzania). This suggests that these African occurrences have a common type of origin. The authors conclude that emerald formation cannot be correlated with particular periods of geologic history or types of tectonic settings. The sole factors that seem to control emerald mineralization are the presence of beryllium-rich pegmatites and chromium host rocks combined with a suitable temperature/pressure regime during the crystallization period.   *JES*

Minerals from the pegmatites of the Crystal Mountain District, Larimer County, Colorado. M. I. Jacobson, *Rocks and Minerals*, Vol. 62, No. 4, 1987, pp. 230–239.

The pegmatite district of the Crystal Mountain area remains one of the few pegmatite districts in Colorado that has not yet been fully explored. Located about 13 miles west of Fort Collins, the Crystal Mountain District has been known to produce crystals of blue apatite, chrysoberyl, beryl, tourmaline (schorl), topaz, and many other minerals of interest to collectors.

Jacobson describes the location, access and collecting conditions, regional and pegmatite geology, and mineralogy of the area. A historical overview, location and geologic maps, and three tables are also featured. Jacobson encourages amateur mineralogists who want to contribute to pegmatite mineralogy to continue the investigation of this district.   *BCC*

Die Smaragde der Belmont-Mine bei Itabira, Minas Gerais, Brasilien: Vorkommen und charakteristika. (The emeralds from the Belmont mine at Itabira, Minas Gerais, Brazil: Occurrence and characteristics). H. A. Hänni, D. Schwarz, and M. Fischer, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 1/2, 1987, pp. 33–49.

The authors describe the production, occurrence, and characteristics of emeralds found in the Belmont mine, which is located at Itabira in the state of Minas Gerais, Brazil. The mine was discovered in 1978 during the construction of the main railway that extends from Belo Horizonte to Vitoria. Early mining methods at the locality were primitive, although nearly 40 kg of emeralds were recovered within an area of 20,000 m². Since 1981, however, production has been modernized and heavy machinery is being used. The emerald concentra-

tion in the biotite schist is estimated to be 165 grams per ton, which makes the Belmont mine the richest emerald-producing area in Brazil.

The authors review the regional and local geology of Itabira and include a detailed map of the region. The emeralds, which very rarely occur with chrysoberyl and alexandrite, are found within Precambrian schists, former pegmatites, and quartz masses of the "Supergrupo Minas." The FeO, MgO, and Na$_2$O contents in the emeralds from the Belmont mine are relatively low.

Several inclusions have been identified: mica, quartz, tremolite, dolomite, andesine, apatite, and "hematite/molybdenite." Mica is the most common, with a large diversity of forms and colors; the high fluorine content (2–3 wt.%) is consistent with emerald formation in rocks associated with pegmatites. For the most part, these mica inclusions are members of the biotite-phlogopite series. Growth tubes are frequently arranged either as single tubes parallel to the c-axis of the host gem or in layers, and exhibit different kinds of fillings: one or two fluids possibly combined with a gas bubble and/or a solid. Most numerous are growth tubes consisting of a birefringent white crystal (probably apatite) associated with a usually rectangular cavity that has a two-phase filling. Multiphase inclusions are common. Also characteristic are disc-shaped tension cracks with fluid-filled cavities at their center.

The Itabira emeralds are typical of the association of mafic-ultramafic rocks with pegmatites. Studies of the fluid and gas inclusions indicate that the minimal temperature and pressure conditions of emerald formation are 380°C and 1400 bars.   *MG*

INSTRUMENTS AND TECHNIQUES

Assembling a microscope illuminator for micromounts. S. Leber, *Rocks and Minerals*, Vol. 62, No. 1, 1987, pp. 31–33.

Leber's article outlines the construction of a microscope illuminator to supplement or augment the existing lighting systems in a microscope. Typical applications include overhead, oblique, and horizontal illumination situations as well as situations where additional light is required, such as for photomicrography. The author provides a detailed description of various bulb types, the advantages of each, and how to build the case. He also supplies a detailed schematic of the circuitry, including wiring for a two-level illuminator and for one with continuously variable intensity. This article is high in solid engineering information.   *Bill Videto*

A cheap dichroscope. N. Grist, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, p. 485.

This half-page note simply and clearly describes how to make your own dichroscope using two pieces of Polaroid sheet and a glass slide (or two, for the extravagant). This simple apparatus can be used even on small stones in conjunction with a microscope.   *CMS*

Further development of a computer program for gem identification. P. G. Read, *Journal of Gemmology,* Vol. 20, No. 7 and 8, 1987, pp. 467–473.

The computerization of gemology continues to develop, as illustrated by Peter Read's work on gem identification programming. Using a 16-bit Amstrad computer (IBM-compatible) with 512K of memory, Mr. Read has updated his GEMDATA program. As it is now configured, GEM-DATA includes data for over 200 gem materials. Input criteria accepted include color, transparency, refractive index, specific gravity (hydrostatic or heavy-liquid estimated), optic sign, optic character, reflectivity, critical angle, and Brewster's angle. Twelve figures, mostly computer menu screens, accompany the text. *CMS*

Monolight 6000 series optical spectrum analyzer. P. G. Read, Editor, *Gem Instrument Digest,* Vol. 3, No. 3, 1987, p. 34.

This brief report covers the capabilities of an optical spectrum analyzer, which can be used as a single-beam spectrophotometer over the range of 210 nm–4700 nm. Features include a remote optical head, enabling "in situ" measurements of large or difficult-to-access materials; with a special processor, it can plot transmission/reflection characteristics, calculate CIE chromaticity coordinates, and plot the coordinates as a point on a CIE chromaticity diagram. Read also describes how to measure birefringence. One photograph of the system, two diagrams of the components, and three graphs are included. *RCK*

The separation of natural from synthetic diamonds using the Barkhausen effect. D. Minster, *Journal of Gemmology,* Vol. 20, No. 7/8, 1987, pp. 458–459.

The author describes a simple apparatus to detect ferromagnetism as a means of separating natural from synthetic diamonds. If a ferromagnetic material is in motion between a fixed magnet and a detector coil connected to headphones, a sound is produced which is known as Barkhausen noise.

Although tests were conducted only on industrial-grade synthetic diamonds, Minster believes that gem-quality synthetic diamonds should produce the same results. However, this reviewer questions whether this method would be effective for material such as the Sumitomo synthetic diamonds, which are virtually free of metallic inclusions. *EF*

JEWELRY ARTS

The Sarah Bernhardt snake bracelet. V. Becker, *Christie's International Auction Catalog,* Geneva, Thursday, November 12, 1987, item no. 603.

Auction catalogs are becoming increasingly important sources of historical information on period jewelry. Here, Vivienne Becker concisely describes the details surrounding the celebrated snake bracelet (actually a bangle and ring joined by a fine double chain) that was designed by Alphonse Mucha and fabricated by Georges Fouquet as a commission for Sarah Bernhardt in 1899. Becker, author of *Art Nouveau Jewellery,* artfully presents brief sketches of both Sarah's personality and theater roles, and of the brief partnership between Art Nouveau artists Fouquet and Mucha. She also discusses the influence of Greco-Roman and Mughal Indian jewelry on the bracelet's design, and vividly describes the piece itself. Characterized as "arguably the most famous and historically important jewel of the Art Nouveau period," the snake bracelet embodies three recurring elements of Art Nouveau jewelry: the snake motif, the use of opal, and the use of enameling.

This booklet, prepared by Christie's International especially for the November 12th auction in Geneva, presents the salient facts of this amazing piece together with two color photos and a detailed illustration from 1906. There is also a dramatic portrait of Sarah Bernhardt by Georges Clairin. *EBM*

Editor's Note: The Sarah Bernhardt bracelet sold for US$757,500 at the auction.

Vanity to valour: the complex motives for personal adornment. P. Daniels, *Ornament,* Vol. 10, No. 4, 1987, pp. 22–27.

Personal adornment has been "an integral part of human life" since the earliest civilizations. The subject of personal adornment and the reasons for it was the theme of a recent exhibition, "Eye of the Beholder: Objects for Personal Adornment," held at the Royal Ontario Museum (ROM) in Toronto.

In this overview of the exhibit, the author discusses some of the motivations for personal adornment, many of which are found cross-culturally: marriage, religion, warfare, and to designate wealth and power. The ROM exhibit incorporated examples that span centuries as well as cultures, from Egypt in 1450 BC to Brazil in 1967 AD. The objects on display ranged from simple feathered hair ornaments worn by Indians in Paraguay to the fabulous diamond necklace given to Marie Louise of Austria by Napoleon Bonaparte on the birth of their first child.

Daniels closes the article by emphasizing the common bonds between cultures and across time that are expressed by the way people adorn themselves. Eleven photos accompany the text. *EBM*

JEWELRY RETAILING

Insurance replacement: Why jewelers are losing business. R. Shore, *Jewelers' Circular-Keystone,* Vol. 158, No. 7, July 1987, pp. 126–128.

Yet another way that established jewelers are losing sales to "discount wholesale" jewelers is through insurance claim replacements, discussed in this insightful article by Russell Shor, senior editor of the *Jewelers' Circular-Keystone.*

Rather than steer customers back to the original

stores of purchase, insurers often pressure them into replacing their jewelry at discount stores. Not only is the customer not given the option of making his/her own choice, but the established jeweler loses the sale and, often, his credibility. He may ultimately lose the customer as well. The reasons for this and the ramifications of these sales are discussed. Essentially, this is a battle of wits between the established jeweler, the insurance companies, and the discount operations. Shor has taken care to outline various perspectives, and concludes by offering a list of suggestions on how to "educate" customers while fulfilling their jewelry needs.   *RW*

Is greed ruining the used jewelry market? D. Federman, *Modern Jeweler*, Vol. 86, No. 9, September 1987, pp. 51–59.

In an effort to combat unethical practices in the jewelry industry, this article points out that jewelers usually have an advantage over the public in the selling and buying of second-hand jewelry.

Too often consumers find themselves at the mercy of jewelers when they try to liquidate items into cash. In the past, it has been common practice for jewelers to offer extremely deflated prices for pre-owned jewelry, while consumers have been unaware of the various options available that would give them the maximum return on their pieces.

The author interviewed several experts in estate jewelry for their opinions on the selling of used jewelry, and explores the choices that are available to the customer: consignment, classified advertising, auction houses, and pawn shops. An interesting chart compares these resale options for four different pieces of jewelry. In most cases, however, the experts agreed that regardless of the option a consumer chooses, it would be wise to consult an independent appraiser first to avoid undervaluations.

General consensus among the experts indicates that many jewelers have become better educated in matters of estate valuation and more knowledgeable about the state statutes that bear on the conduct of buyer/seller contracts, thus bringing a new sense of fairness to the industry.   *JLC*

SYNTHETICS AND SIMULANTS

Methods for the distinction of natural and synthetic citrines and prasiolites. K. Schmetzer, *Gold und Silber*, Vol. 40, No. 6, June 1987, pp. 57–58.

Dr. Schmetzer describes the diagnostic features of natural and synthetic citrines and prasiolites; the most important are structural characteristics and features in the visible and ultraviolet spectra.

Because most natural citrines and prasiolites are the result of the heat treatment of amethyst, polysynthetic twinning on the Brazil law (found in natural amethyst and retained after heating) is the main determining

characteristic. At this time, this phenomenon is not found in the synthetic counterparts.

In addition, synthetic citrines and prasiolites are generally colored by iron or traces of cobalt and iron. Synthetic analogs of these gem materials show a number of distinct absorption bands in the visible and ultraviolet range that have not been seen in natural stones. Although the absorption bands are not given, the author refers to a more detailed article to be published in the future.   *BCC*

Nach dem Hydrothermalverfahren Hergestellte synthetische Smaragde aus der UdSSR (Synthetic emeralds made after hydrothermal process from USSR). Th. Lind, U. Henn, and H. Bank, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 1/2, 1987, pp. 51–60.

During the last few years, many publications have presented the characteristics of synthetic emeralds made in the USSR. Although these reports stated that the synthesizing process is hydrothermal, some of the stones exhibited inclusions similar to those observed in flux-grown synthetic emeralds. For the study reported here, the authors investigated synthetic emeralds marketed as "Vasar emeralds" (manufactured in the city of Tallin, of the Estonia Republic) which contain these "flux-like" inclusions. The authors confirm, by means of infrared absorption spectroscopy, that these synthetic emeralds are of hydrothermal origin.

The refractive indices of the "Vasar emeralds" are $n_o = 1.578–1.584$, $n_e = 1.571–1.581$, with a variable birefringence of 0.005–0.008. The specific gravity is 2.68–2.70. The growth phenomena in these synthetic emeralds play an important part in identification. Spindle-like, sometimes wavy, growth features are observed parallel to the c-axis. Under crossed polarizers the effect is much more distinct and assumes a zig-zag pattern when viewed perpendicular to the c-axis. Absorption spectra in the visible range show, in addition to the Cr^{3+} spectrum, Fe^{2+}, Fe^{3+}, and $Fe^{2+/3+}$ charge-transfer bands, which cause a strong pleochroism.   *EF*

Eine neue Generation synthetischer Rubine von P. O. Knischka unter Verwendung natürlicher Nahrsubstanz (A new generation of synthetic rubies made by P. O. Knischka by the use of a natural source material). W. Galia, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 1/2, 1987, pp. 19–31.

Under U.S. patent no. 4,525,171, P. O. Knischka of Austria is now commercially producing a new type of synthetic ruby. The spontaneous nucleation from a flux (i.e., without the use of a seed crystal) is achieved by recrystallizing natural rubies. A prismatic ruby crystal weighing 382.50 ct was reportedly grown by Knischka over a one and one-half year period; the largest synthetic crystal made thus far weighs 1100 ct. In the course of

this study, the author investigated crystals ranging in weight from 0.13 to 38.56 ct.

The crystals currently being produced vary considerably in morphology and inclusions as compared to Knischka's previous production or the products of other manufacturers. Microscopic examination is the best method of identifying this new synthetic ruby. The most typical inclusions are pinpoints of an unidentified substance which give a distinctive milky or cloudy appearance depending on the illumination technique. Platinum inclusions further prove the synthetic origin of the new production, although the manufacturer claims that there are no platinum inclusions in those crystals grown after December 1986. "Zig-zag" growth lines and irregular growth striae are also observed.

Chemical analyses contributed to the detection of platinum in a number of samples. Further, Na, W, and Ta were found, but no Pb. The flux inclusions were found to contain $Na_2W_2O_7$ (sodium wolframate) and Ta_2O_5 (tantalum oxide) by X-ray fluorescence, microprobe, and X-ray diffraction analyses. The U.V. absorption spectra of these synthetic rubies were studied with two different instruments: a dual-beam spectrophotometer and a Kruss U.V. spectroscope. Twenty illustrations, including four color photographs, are provided, but the fact that they are not in numerical order adds some confusion to the reading.   *MG*

Synthetische Lechleitner-rubine mit natürlichen kernen und synthetischen uberzugen (Synthetic Lechleitner rubies with natural seed and synthetic overgrowth). K. Schmetzer and H. Bank, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 1/2, 1987, pp. 1–10.

Drs. Schmetzer and Bank report on a new type of Lechleitner synthetic ruby which consists of a natural corundum seed from Sri Lanka with a flux-grown synthetic overgrowth. The inclusions observed are typical for Sri Lankan sapphires: negative crystals, various patterns of liquid "feathers," and crystals of various minerals. Typical flux residues were also apparent in the synthetic overgrowth. The color of the six faceted samples described in this article resembles that of Sri Lankan rubies and pink sapphires, with a characteristic violet tint. Angular color zoning was also observed. Chemical analyses (electron microprobe and X-ray fluorescence) revealed Li_2O-MoO_3-PbF_2 and PbO in the overgrowth. Spectrophotometry revealed absorption spectra almost identical to those of pink sapphires from Sri Lanka; the authors mention the difficulty of obtaining two different absorption curves for the seed and the overgrowth. Four of the 21 illustrations are printed in color.   *MG*

New investigations of synthetic amethysts produced in Japan. Th. Lind and K. Schmetzer, *Journal of Gemmology*, Vol. 20, No. 5, 1987, pp. 274–277.

This article addresses further separations of natural versus synthetic amethyst. The authors focus specifically on the diagnostic properties of the synthetic amethyst produced in Japan, which differs from the Russian synthetic amethyst used in earlier studies.

Japanese synthetic amethyst is characterized by feathers consisting of fluid inclusions and two-phase inclusions, sharp lamellar structures connected with distinct color zoning (observed parallel to one rhombohedral face of the synthetic amethyst), and twinning confined to distinct areas of the synthetic crystal. Furthermore, there is an additional (albeit sometimes lower intensity) absorption band in the infrared area of the spectrum.

According to Lind and Schmetzer, the distinction of natural and synthetic amethyst is based on microscopic study of the specimen under immersion. Therefore, detailed knowledge of the various properties of polysynthetic twinning in natural amethyst based on the Brazil law is recommended.   *Deborah Jean Martin*

TREATMENTS

Goethite inclusion alteration during the heat conversion of amethyst to citrine. J. I. Koivula, *Australian Gemmologist*, Vol. 16, No. 7, 1987, pp. 271–272.

The brownish yellow mineral goethite, in the form of radiating tufts or broom-head-shaped groups of acicular crystals, is a common inclusion in amethyst and in the rarer natural citrine quartz. Similar-appearing inclusions, but of a reddish brown color, are found in citrines produced by heat treating amethyst. The author theorizes that the treatment causes the goethite inclusions to alter to hematite, releasing water in the process and causing fracturing around the inclusions.

To confirm this theory, Mr. Koivula heat treated four amethysts, documenting alterations in the inclusions with before-and-after photomicrographs. Streak tests were also performed on the inclusions, the results of which were consistent with his theory. From this experiment, the author concludes that "broom-head-shaped pseudomorphs of hematite after goethite, together with associated dehydration fracturing, when observed in citrine quartz, are evidence of amethyst-to-citrine heat treatment."   *RCK*

The plastic coating of gemstones. R. W. Hughes, *Australian Gemmologist*, Vol. 16, No. 7, 1987, pp. 259–261.

The author reports on his examination of three plastic-coated gems, all believed to have come from Burma.

One was a near-colorless faceted quartz with a red plastic coating. The enhancement was easily identified because the coating was confined to the pavilion facets. The plastic had also worn away in areas, and gas bubbles were seen between the plastic coating and the quartz.

The second specimen was a very translucent, white jadeite cabochon with a thin layer of dark green plastic

on its upper surfaces. The enhancement gave the gem the appearance of "imperial" jadeite. Examination revealed two dark spots near the setting edge where the plastic had separated from the jadeite; magnification revealed plastic peeling away at the girdle and gas bubbles between the plastic and jadeite.

The last gem was a native-cut, near-colorless star sapphire that was completely coated with red plastic, giving it the appearance of a star ruby. The author's first clue to an enhancement was a slight warm feeling to the touch. Magnification revealed breaks in, and gas bubbles beneath, the surface of the coating, as well as color swirls in the plastic.

Nine color photographs illustrate the latter two specimens discussed.   RCK

Topazes bleues après traitement (Blue topaz after treatment). D. Robert, *Revue de Gemmologie a.f.g.*, No. 91, 1987, pp. 17–20.
This highly technical article begins with a description of the various trade names used to describe and market treated blue topaz. The effects of neutron, gamma, and electron irradiation are very effectively explained in relation to the final color. Apparently, residual radioactivity arises from trace elements such as tantalum and scandium in the topaz itself; therefore, topazes of different origin might represent different levels of danger after radiation. The author discusses radiation regulations and emphasizes how measurements of residual radioactivity should be made. He recommends radioactivity levels less than 75 Becquerel/gram (Becquerel = 1 disintegration per second) as safe for handling.

This article also includes some short comments about the irradiation of diamond, quartz, tourmaline, beryl, corundum, and fluorite, as well as technical comments on irradiation units. A note at the end states that the Centre d'Études Nucléaires de Grenoble, in France, has developed an instrument that can measure the residual radioactivity of large quantitites of gemstones.   EF

MISCELLANEOUS

Mineral art today. S. Robinson, *Rocks and Minerals*, Vol. 62, No. 5, 1987, pp. 328–343.
There are only a handful of artists worldwide who dedicate themselves to painting, sketching, or etching images of mineral specimens. Photography, a less expensive and usually faster medium, has largely replaced the depiction of minerals by hand illustration. Before advances in photography, however, accurate, hand-rendered images were invaluable to illustrate the ever-proliferating books on mineralogy, geology, and gemology. Robinson, herself a mineral artist, describes the various forms of mineral art that have existed, including some of the forms that are still popular today.

The main part of the article covers 26 mineral artists throughout the world, including a short biography for each, and, in most cases, a sample of their work. Four pages of the most prominent examples are in full color, an exciting compendium of mineral art.

This is an overdue yet timely portrayal of artists who have used their talent to provide images that we can both learn from and admire.   RW

The sale of the Windsor jewels. A. Gray, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 423–426.
The April 1987 sale of the Windsor collection of jewels by Sotheby's, Geneva, was one of the most widely publicized auctions of recent years. The author describes some of the most notable pieces sold at that event, including the 31.26-ct McLean diamond, a ruby-and-diamond brooch that was one of the first pieces made with invisible-set stones, and a 206-ct sapphire set as a pendant/brooch, purportedly purchased for actress Joan Collins. Vivid descriptions of other fascinating jewels make one wish that more than five illustrations accompanied this article.

Ms. Gray also cites a few examples of the prices paid for these beautiful but, more importantly, historically significant pieces. Instead of the total of £5 million expected from the auction, the collection fetched £31 million. As the author concludes, this illustrates how "the history outweighed the intrinsic value."   CMS

What's new in minerals? W. E. Wilson, Ed., with S. Cisneros, G. W. Robinson, and V. King, *Mineralogical Record*, Vol. 18, No. 5, 1987, pp. 359–368.
This column, a regular feature of the *Mineralogical Record* for some years, is devoted in this issue to the 14th Annual Rochester Academy of Science Mineralogical Symposium, which was held April 9–12, 1987, in Rochester, NY.

The first piece, by Sharon Cisneros, is a short introduction to the symposium in general. She points out that since this show occurs only two months after the February Tucson show, it has become a combination of ideas being exchanged and a forum for East Coast mineral dealers.

The main body of the column supplies information from a discussion held each year on "What's New in Minerals" that focuses on mineral discoveries made during the previous year. Panel chairmen George Robinson (National Museums of Canada, Ottawa) and Vandall King (Ward's, Rochester, NY) prepared a handout for the audience, much of which is reprinted here. The information is listed in alphabetical order by geographic locality in three sections: the United States, Canada, and "other world occurrences."

The information is a bit dated since it was not published until the September/October issue. However, such a thorough listing of new localities is very valuable, and could settle many disagreements, including when a particular material first came to light.   PASG

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SUBJECT INDEX

This index gives the first author (in parentheses) and the *first page* of the article, Editorial Forum (EF), Gem News (GN), or Gem Trade Lab Notes (GTLN) section in which the indexed subject occurs. The reader is referred to the author index for the full title and the coauthors, where appropriate, of the articles cited. The pages covered by each issue are as follows: Spring (1–62), Summer (63–124), Fall (125–186), Winter (187–256).

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joint authors.

Indexes prepared by Dona Dirlam