

# GEM TRADE LAB NOTES

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### AZURITE and ANTLERITE Rock

Many blue and green minerals owe their color to copper, including the gem minerals turquoise (a phosphate), chrysocolla (a silicate, which may be seen as inclusions in chalcedony), and azurite and malachite (carbonates). Copper minerals of more unusual compositions often cannot be distinguished from more common species using standard gem-testing methods. For example, ajoite, shattuckite, and papagoite could be mistaken for chrysocolla, and green minerals such as brochantite, atacamite, and pseudomalachite, among others, could be mistaken for malachite.

In November 1994, the West Coast laboratory received a variegated blue and green oval cabochon (see figure 1) for identification. Microscopic examination revealed at least four different materials in the 3.33-ct cabochon: (1 and 2) blue and green opaque materials, plus (3) a gray translucent material, in the body of the stone; and (4) a very dark blue substance in surface cavities. The spot refractive index was about 1.7 (poor polish precluded more accurate measurement). A specific gravity of 2.87 was determined hydrostatically. The stone effervesced to a minute amount of dilute hydrochloric acid placed on its base, and the cavity substance melted when approached with the thermal reaction tester ("hot point"). This evidence suggested that the stone was azur-malachite; however, given the many possible blue and green minerals (see above



Figure 1. Testing revealed that this 3.33-ct oval cabochon is a rock consisting primarily of blue azurite, green antlerite, and quartz. The foreign material seen in surface cavities is probably a colored polymer.

for examples), we conducted advanced testing to identify the phases present.

X-ray powder diffraction of the blue and gray materials showed them to be azurite and quartz, respectively. However, the green material was not the more usual associate of azurite, malachite, but rather was antlerite, a copper hydroxysulfate. Azurite and antlerite may occur together in oxidized zones of copper ore deposits. The dark blue substance seen in the cavities was a colored foreign material, probably a polymer of some sort. Therefore, we concluded that this cabochon was a rock consisting of azurite, antlerite, and additional minerals. We further noted that—as is

typical for rocks—petrographic testing would be necessary to fully characterize this material, and that a colored foreign material was present in surface cavities.

MLJ, SFM, and Dino DeGhionno

## DIAMOND

### With Strain Phantom

In the Fall 1993 Gem Trade Lab Notes section (pp. 199–200), we reported on a 3.01-ct, light yellow diamond with a phantom inclusion—a sharp-edged diamond octahedron that was visible only when viewed between crossed polarizers (phantoms are usually outlined by inclusions of another substance, which makes them easy to see in ordinary light).

As crystals grow, the conditions under which they form can change. Phantoms in quartz, for instance, often represent periods when the quartz crystal stopped growing, and particles of chlorite, iron-oxide, or other minerals were deposited on the surface of the still-incomplete crystal; when crystal growth resumed, the foreign materials (now trapped inside) outlined the previously existing crystal faces. Those phantoms in diamonds that are visible only with polarized

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

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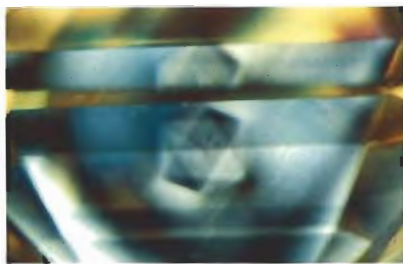


Figure 2. When viewed between crossed polarizers, this 1.42-ct Fancy Intense yellow diamond revealed a strain phantom with unusual internal strain features. Magnified 20 $\times$ .

light may have been formed by an abrupt change in the pressure or strain under which the diamond crystal was growing, without any foreign substance having coated the pre-existing crystal faces.

Last winter, the West Coast laboratory received a 1.42-ct diamond for examination. With crossed polarizers, we saw high-order strain with a particularly interesting strain phantom (figure 2): an octahedron showing a dark line through one vertex and a dark plane perpendicular to it. We do not know what might have caused these internal strain features. Note that because the strain phantom was only visible through crossed polarizers, it did not affect the clarity grade (VVS<sub>1</sub>) of the (natural color) Fancy Intense yellow diamond.

MLJ and Patricia Maddison

### Treated-Color Pink Diamond

Over the last few months, the East Coast laboratory examined three treated-color pink diamonds, one of which was mixed in with a large parcel of natural-color stones. Unlike most treatments, treated (i.e., irradiated and annealed) pink color in diamond is rarer than natural pink color. The East Coast lab examined its first treated-pink diamond about 1959 (*Gems & Gemology*, Spring 1959, p. 268), when reactor-irradiated stones first became commercially available. Renowned British gemolo-

gist Basil Anderson, to whom we subsequently sent the stone for examination, reported that this was the first reactor-treated pink diamond he had seen as well.

In diamonds, the pink color produced by treatment is usually so highly saturated that a natural equivalent was extraordinarily rare before the discovery of fancy-color diamonds at the Argyle mine in Australia. Thus, from about 1960 to 1980, we were suspicious of any intensely colored pink diamond submitted to the laboratory. Now that some diamonds from Argyle equal treated-color pink stones in saturation, it has become even more important to know the identifying characteristics of this treatment.

In our experience, all treated-pink diamonds have a characteristic strong orange fluorescence to both long- and short-wave ultraviolet radiation. In addition, they consistently show a diagnostic visible spectrum—with sharp lines at 595, 617, and 658 nm, and an emission line at 575 nm—that is readily seen with a hand-held type of spectroscope. The first treated-color pink diamond seen in the laboratory

Figure 3. Uneven distribution of color, as illustrated by the pink and yellow zones in this 0.43-ct round brilliant diamond, is characteristic of treatment. Magnified 18 $\times$ .



Figure 4. The color distribution in this 0.39-ct round brilliant is more even than that shown in figure 3. However, the diagnostic fluorescence and spectrum proved that the stone had been treated by irradiation and subsequent annealing.

clearly showed this characteristic spectrum and fluorescence, even though it weighed only 0.01 ct. Depending on the treatment procedure and the distribution of nitrogen, microscopic examination may reveal an uneven distribution of the color, with distinct zones of yellow and pink (Gem Trade Lab Notes, Summer 1988, pp. 112–113). The 0.43-ct round brilliant in figure 3 displays such color zoning, while the 0.39-ct round brilliant in figure 4 was evenly colored. Both stones, as well as a 0.47-ct round brilliant (not shown), were easily identified by their fluorescence and spectra.

Treated-color pink diamonds are uncommon because they require a rare starting material, type-Ib diamond, which contains small amounts of nitrogen dispersed as single atoms in the crystal structure [see the discussion of diamond types by E. Fritsch and K. Scarratt, in *Gems & Gemology*, Spring 1992, pp. 38–39]. Most type-Ib diamonds are small (less than 1 ct), and their natural color is usually a highly saturated orangy yellow. Such stones are rarely considered candidates for treatment because of the

value in their intrinsic yellow color. One diamond treater said that all of his treated pinks are produced accidentally, when a parcel of yellow-to-brown melee just happens to contain the needed starting material. Interestingly, most yellow synthetic diamonds are type Ib (or mixtures including a large type-Ib component), and such diamonds will turn pink to red if treated with radiation and heat (see T. Moses et al., "Two Treated-Color Synthetic Red Diamonds Seen in the Trade," *Gems & Gemology*, Fall 1993, pp. 182-190).

Another category of pink diamond sometimes shows strong orange fluorescence: pale-toned diamonds that are type IIa (containing no nitrogen detectable by infrared spectroscopy). Such natural-color pink diamonds are distinguished from treated pink diamonds by their much lower color saturation, by their diamond type, and by the fact that features in the visible spectrum are weak, usually detectable only with the extra sen-

sitivity of a recording spectrophotometer.

GRC and IR

### Unusual Diamond Crystal

Most gem-quality diamond crystals are regular or distorted octahedra, with rounded and irregular crystal forms being less common. On rare occasions, we are shown diamonds with unusual crystal forms. One such example was an aggregate of two rounded crystals, reported in the Spring 1992 Lab Notes section (p. 52).

Another unusual diamond crystal was just seen at the East Coast lab: Not only is the 13.24-ct crystal irregular in shape, but it also has a large "tunnel" etched through its center (figure 5). While our first thought was that this was another kind of intergrowth, the optical properties indicated that it was a single crystal. Careful microscopic examination of the surface in and around the tunnel revealed grooves and channels, which suggests that an etching process formed this hole. We also noted

both green and brown radiation stains at one end of the tunnel.

IR

### SYNTHETIC DIAMOND Suite

Although the trade press has warned many times over the past two years of the imminent influx of Russian gem-quality synthetic diamonds, to date the GIA Gem Trade Laboratory has not seen them in significant quantities. Nevertheless, an occasional diamond submitted to the laboratory for determination of color origin is unmasked as synthetic. Three examples were described in earlier Lab Notes: "Synthetic Yellow Diamond Crystal" (Fall 1993, p. 200), "Faceted Yellow Synthetic Diamond" (Winter 1993, p. 280), "Synthetic Diamond: Treated-Color Red" (Spring 1995, pp. 53-54). All three had properties consistent with synthetic diamonds produced in Russia (see J. Shigley et al., "The Gemological Properties of Russian Gem-Quality Synthetic Diamonds," *Gems & Gemology*, Winter 1993, pp. 228-248).

A few months ago, a client submitted two cut-corner rectangular modified brilliants (0.30 and 0.41 ct) and one round brilliant (0.30 ct) to the East Coast lab for origin-of-color reports (figure 6). All three stones had several properties in common: a saturated yellow color; a strong-to-weak yellow-green long-wave UV fluorescence in a cross-shaped pattern, seen only through the table facets (figure 7); a similarly distributed, but generally weaker (moderate-to-faint), reaction to short-wave UV; and an absorption spectrum—observed with a desk-model prism spectroscope—consisting of a vague absorption generally increasing toward 400 nm. Two stones exhibited weak green transmission luminescence, and two showed weak absorption at 527 nm when examined at low temperature. All were weakly attracted to a magnet.

In diffused light with magnification, we observed vague color

Figure 5. Although this unusual 13.34-ct rough diamond appears to be some sort of intergrowth, it is actually a single crystal with what appears to be an etched hole through the center.





Figure 6. All three of these diamonds (from left, 0.41, 0.30, and 0.30 ct), which were submitted to the laboratory for origin-of-color reports, proved to be synthetic.

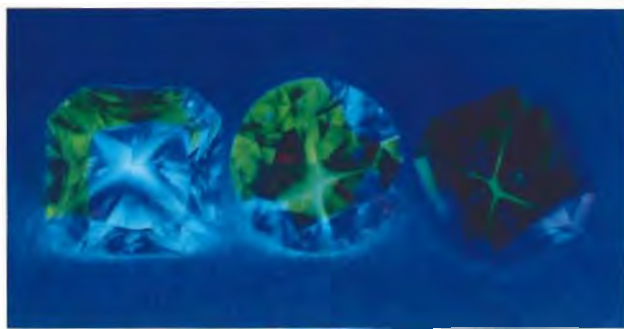


Figure 7. When examined through their tables, all of the synthetic diamonds shown in figure 6 revealed a yellow-green cross-shaped fluorescence to long-wave UV radiation.

zoning of lighter and darker yellow in all three stones. Only when the samples were immersed in methylene iodide did we also see a distinct colorless cross within a medium yellow body color in all three. All revealed extensive clouds of pinpoint inclusions as well, some in the form of curved stringers (which we have never observed in natural diamonds). One stone contained what appeared to be large globules and droplets of residual flux (figure 8). Energy-dispersive X-ray fluorescence (EDXRF) analysis of one of these inclusions by GIA Research revealed Fe and Ni. Infrared spectroscopy showed that all three stones were a low-nitrogen mixture of type Ib and Ia diamond, with A aggregates dominating B aggregates.

All these properties were consistent with those reported by Shigley et al. (1993) for as-grown Russian synthetic diamonds (that is, that had not been irradiated and annealed to alter their color). This is the first time the lab received more than one synthetic diamond from one client at one time. Furthermore, two of these were of higher quality than other Russian synthetic diamonds described to date, and many of the diagnostic properties were less distinct than those previously reported. Consequently, a thorough microscopic

examination is needed to distinguish such stones from natural diamonds.

*RCK, IR, and Emmanuel Fritsch*

#### JADEITE JADE, with Misleading Inclusions

An entry on page 117 of the Summer 1994 Lab Notes section described metallic inclusions of two types (probably pyrite and pyrhotite) in an unusually translucent jadeite cabochon. Since then, the West Coast laboratory has seen two other examples of natural-color

jadeite with potentially confusing inclusions.

The first piece (which measured approximately  $49.50 \times 27.66 \times 7.87$  mm) was an especially clear—translucent to semitransparent—mottled green-and-white carving of a woman, a child, and a fish. All of the properties were consistent with natural-color jadeite. With magnification, however, we saw small white crystals in the white areas (figure 9, left). In a cursory examination, these white crystals might be mistaken for devitrification features in glass imitations of jadeite. (By devitrification features, we mean individual crystals and crystal groups that grew after the glass cooled or from residual unmelted material [see figure 9, right].) However, examination under higher magnification revealed that they lacked the dendritic nature typical of many devitrification features; also, the surrounding aggregate material was not optically isotropic. Because none of these inclusions reached the surface of the sample, we could not determine their identity.

The second piece was a 26.70-ct translucent green oval double cabochon, with unusual darker green "inclusions" that looked like fuzzy balls of lint at high magnification (figure 10); with reflected light, we were able to see that one

Figure 8. EDXRF analysis of one of these surface-reaching droplets—which were observed in one of the stones shown in figures 6 and 7—indicated that it contains iron and nickel, elements found in the fluxes used to synthesize diamond. Magnified 30 $\times$ .



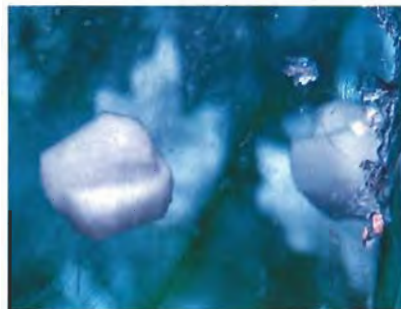


Figure 9. White crystals in jadeite (left, at 12× magnification) could be mistaken for devitrification features in manufactured glass (right.)

of them broke the surface (figure 11). The “inclusions” appeared to consist of small clusters of jadeite grains with a second substance, probably another mineral, coating the grain boundaries. Again, not enough material was present to identify the boundary mineral conclusively.

The “inclusions” in this second piece were interesting because, with only a cursory examination, they could be mistaken for selectively impregnated spots caused by some unknown (or miscalculated) treatment. However, magnification revealed that most of these spots were completely enclosed in the cabochon, with no access to its surface. Also, Fourier-transform infrared spectroscopy (FTIR) revealed no evidence of polymer impregnation.

MLJ and John I. Koivula

Figure 10. These unusual small, dark “inclusions” were found throughout a 26.70-ct jadeite cabochon. Magnified 10×.



#### OMPHACITE Rock Carving

Nephrite and jadeite, both correctly called jade, are members of two separate mineral groups that contain several other distinct minerals. However, no other members of these groups are properly considered jades, as they differ from either nephrite or jadeite in chemistry or, more importantly, structure. For example, chatoyant actinolite, which is chemically identical to nephrite, is an amphibole-group

Figure 11. When we examined one of the jadeite cabochon's dark green inclusions in reflected light at higher (40×) magnification, we found that a less reflective substance was coating the boundaries between jadeite grains in the “inclusion” regions. (Because of the light scattering, this substance appears white in the microscope.)

mineral. Although members of the trade often incorrectly call it “cat's-eye jade,” it is not jade at all, because it has a *parallel* fibrous structure and not the *interlocking* fibrous structure characteristic of nephrite jade. Similar examples could be cited for the pyroxene group, to which jadeite belongs.

Last fall, the West Coast lab received for identification an opaque, mottled green-and-white carved mask, which measured about 22.8 × 22.1 × 7.4 cm (figure 12). Only limited standard gemological tests could be performed. Because of the mask's size, determination of specific gravity was impractical. The combination of curved surfaces and a poor polish resulted in our obtaining only a vague spot R.I. of 1.62. The mask was inert to both long- and short-wave UV radiation, and magnification revealed an aggregate appearance.

Because these data were insufficient to identify the material, X-ray powder diffraction analyses were performed on microscopic scrapings from the mask. From these analyses, it was determined that the mask was composed primarily of omphacite, plus some feldspar and possibly traces of other minerals. However, we could not characterize the item completely (as would be possible with petrographic analysis), because our testing was limited to nondestructive methods.

Omphacite is a pyroxene-group mineral, intermediate in composition between jadeite and diopside; it is fairly common in Mesoamerican “jades” (see, e.g., G. E. Harlow's article in *Natural History*, August 1991, pp. 4–10, and W. F. Foshag's article—where he calls omphacite “diopside-jadeite”—in *American Mineralogist*, Vol. 40, No. 11–12, 1955, pp. 1062–1070). Although omphacite is chemically similar to jadeite, it is neither jadeite nor a jade.

MLJ and RCK



Figure 12. This mask was identified as a rock consisting primarily of omphacite (a pyroxene mineral) plus feldspar and possible additional minerals. Consequently, it is not jade.

#### CULTURED PEARL, With a Damaged Nucleus

Baroque cultured pearls often have thick layers of conchiolin between the nacre and the bead nucleus. When a gap forms in this layer, the nucleus can come loose from the nacre. Drilling such a pearl can be hazardous, as either the nacre or the bead might break. One way to work around this hazard was discussed in the Summer 1990 Lab Notes section (p. 155). In that instance, an X-radiograph was taken to determine where to drill without breaking the nacre.

Drillers are not always so fortunate. We suspect that a loose bead scenario was responsible for damage observed in a light gray baroque pearl that was part of a cultured pearl necklace tested at the West Coast laboratory last fall. X-radiographs (figure 13), taken during routine testing, revealed a large void with what appeared to be fragments of a bead nucleus in one of

the pearls. Examination through the drill hole confirmed loose pieces of shell-like material within the cavity. We could even see evidence of a drill hole in one larger fragment.

Although we can only speculate as to what happened, we believe that the bead was probably

in a void, or loosely surrounded by conchiolin, and had detached before or during the drilling process. There may even have been several drilling attempts, during which the bead moved and broke into pieces, much of it being reduced to powder by the drill bit. The remaining fragments were then free to tumble within the large void. This can be clearly seen in figure 13, from the different positions of the fragments in the two views.

Although the nacre on this pearl has lost the support provided by a bead nucleus, its shape and thickness give it enough strength to be used for a necklace.

Cheryl Y. Wentzell

#### DYED QUARTZITE, Imitating Jade

Because of its great abundance and its good durability, colorless quartz is often dyed various colors to imitate other gems. In fact, it is one of the oldest "impostors" in recorded history, with the dyeing of quartz to imitate emerald referred to as early as the first century A.D. (see, e.g., K. Nassau, "The Early History of Gemstone Treatments," *Gems & Gemology*, Spring 1984, pp. 22-33). Dyed green quartz is still commonly used as a simulant, with

Figure 13. Readily seen in these X-radiographs of a strand of cultured pearls is a  $10.10 \times 9.30 \times 8.00$  mm cultured pearl with a large void that appears to contain several loose fragments (note the different positions in the two views) from a broken bead nucleus.

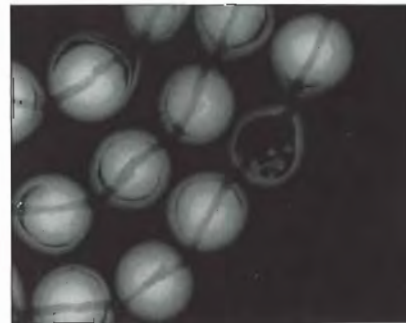
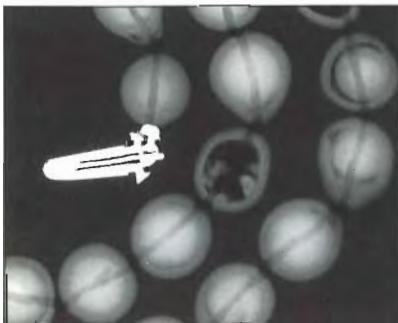




Figure 14. The approximately  $30.25 \times 15.98 \times 5.50$  mm dyed quartzite cabochon in this ring makes a convincing imitation of jadeite.

single-crystal material treated to imitate emerald and with translucent-to-nearly opaque quartz, as well as quartzite (a metamorphic rock composed primarily of quartz grains), dyed to imitate jadeite.

In November 1994, the West Coast lab received for testing a ring set with a translucent mottled-green oval cabochon, about  $30.25 \times 15.98 \times 5.50$  mm, that resembled fine-quality jadeite (figure 14). Standard gemological testing, including a 1.55 spot R.I. and the aggregate structure seen with magnification, identified the stone as quartzite. Microscopic examination also revealed dye concentrations in fractures and between grains of the aggregate structure, with the presence of dye further confirmed by the characteristic "dye band" centered at about 650 nm, which was seen with a desk-model prism spectroscope.

To learn more about the treatment used for this stone, we analyzed it with infrared spectroscopy.

This revealed key absorption features at about  $2900\text{ cm}^{-1}$  in the mid-infrared, similar to those of the synthetic resin Opticon and those documented in some bleached and impregnated "B jade" (see E. Fritsch et al., "Identification of Bleached and Polymer-Impregnated Jadeite," *Gems & Gemology*, Fall 1992, pp. 176–187). However, the absorptions in the treated quartzite were only about one-tenth as strong as those that have been documented in impregnated jadeite. This is probably because a much smaller quantity of polymer is used to carry the dye into the treated quartzite. (For more on the quantitative method used to evaluate infrared absorptions in treated jadeite, see the article "Type-B Jadeite: New Polymers and Estimating Amount of Wax," by E. Fritsch, *Jewellery News Asia*, November 1994, pp. 106–108, 110.)

RCK

Figure 15. Although this 21.28-ct "star ruby" was somewhat included, had a good color, and appeared to be native cut, gemological testing proved that it was a synthetic ruby with a diffusion-induced star and "fingerprint" inclusions.



## SYNTHETIC RUBY, With Diffusion-Induced "Fingerprint" Inclusions and Asterism

The East Coast laboratory received for identification what appeared to be a star ruby (figure 15). The somewhat included 21.28-ct cabochon had a moderate star and a color reminiscent of rubies from Burma. It appeared to be native cut, with an extremely thick girdle. The desk-model prism spectroscope revealed a ruby spectrum. When we first examined the piece with a microscope, only fingerprint inclusions were evident; at higher magnification, however, we saw obvious curved striae. The stone was really a Verneuil (flame-fusion) synthetic ruby. Therefore, the fingerprints were induced, as was the surface-diffused star. GRC

## Cat's-Eye SAPPHIRE

Although asterism is a fairly common phenomenon in corundum gems, chatoyancy is encountered only rarely (described as "extremely rare" in the 5th edition of Webster's *Gems* [edited by P. Read], Butterworth-Heinemann, Oxford, 1994). In our experience, a cat's-eye effect in corundum—natural or synthetic—is usually produced when the cutter orients the axis of the star in an asteriated stone off-center, so that only one "leg" of the star is seen across the dome of the cabochon.

Earlier this year, the West Coast lab received for identification a 1.91-ct, semitransparent, mottled greenish blue oval cabochon that displayed distinct chatoyancy (figure 16). Standard gemological testing proved that it was natural sapphire. When we examined the stone with magnification, however, we were surprised to see that it had almost no acicular rutile crystals, which are typically the cause of asterism in corundum. Instead, we



Figure 16. Chatoyant sapphire, such as this 1.91-ct ( $13.99 \times 5.19 \times 2.54$  mm) stone, is very unusual.

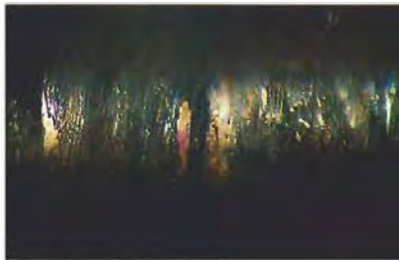


Figure 17. The cat's-eye effect seen in the sapphire shown in figure 16 is caused by the reflection of light from these numerous parallel, liquid-filled channels. Magnified 20 $\times$ .

detected a series of nearly planar, parallel, liquid-filled "fingerprints" (figure 17). Light scattering from these caused the chatoyancy. Magnification also revealed diffuse color halos around crystal inclusions, evidence that the stone had been heat treated. RCK

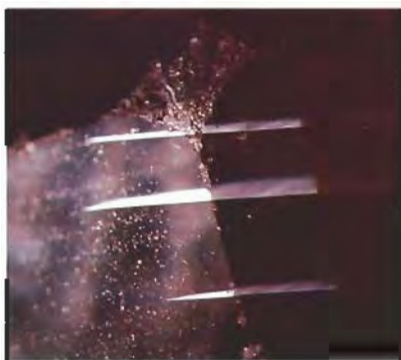
#### SYNTHETIC SAPPHIRE, Color-Change with Twin Lamellae

Probably the flame-fusion synthetic corundum seen most frequently in the GIA Gem Trade Laboratory is vanadium-doped, color-change synthetic sapphire (which appears greenish blue in fluorescent or natural light and pinkish purple in incandescent light). Many of the clients who submit such material for identification do not even suspect that it is a form of corundum: They believe we will establish whether it is natural or synthetic alexandrite (chrysoberyl). Identification of these Verneuil synthetic sapphires is generally straightforward, as they typically show (1) a single vanadium-related absorption band at about 474 nm (resolvable with a desk-model spectroscope), and (2) curved striae (when examined with magnification using darkfield illumination).

In November 1994, however, the West Coast lab received for identification a 1.43-ct transparent emerald-cut stone, which measured

about  $6.85 \times 5.73 \times 3.80$  mm. It exhibited a distinct color change, appearing bluish green in daylight-equivalent fluorescent light and pinkish purple in incandescent light. Examination with a binocular microscope did not reveal any solid (mineral) inclusions or any voids (i.e., gas bubbles or negative crystals). However, readily noted was a series of laminated twin planes, which were clearly visible through the table facet (figure 18). Although this feature is not proof of origin, it

Figure 18. A series of twin lamellae, an uncommon feature in flame-fusion synthetic corundum, can be clearly seen in this color-change synthetic sapphire, which also revealed curved striae. Magnified 25 $\times$ .



usually indicates natural corundum. Further examination with magnification—this time looking through the pavilion facets—revealed curved striae, which proved the stone was synthetic.

Descriptions of twinning in Verneuil synthetic corundums appear sporadically in the literature (see, for example, W. F. Eppler's "Polysynthetic Twinning in Synthetic Corundum," *Gems & Gemology*, 1964, Vol. 11, No. 6, pp. 169–174 and 179, as well as J. M. Duroc-Danner's "Polysynthetic Twin Lamellae in Synthetic Verneuil Sapphire," *Journal of Gemmology*, 1985, Vol. 19, No. 6, pp. 479–483). Twinning is not the only confusing feature that may be seen. In flame-fusion synthetic corundums, the gemologist may rarely come across inclusions of undissolved alumina (R. Webster [edited by P. Read], *Gems*, 5th ed., 1994, Butterworth-Heinemann, Oxford, pp. 405–406); triangular cavities containing gas bubbles (Spring 1991 Lab Notes, p. 45; Webster's *Gems*, pp. 405–406); and even needle-like inclusions (Winter 1990 Lab Notes, p. 298).

All these atypical inclusions and growth features should serve as a warning to the reader: Do not make a gem identification based on a superficial microscopic examination or on the first inclusion(s) seen. ALL internal features in the gem should be studied from a variety of viewing angles before a decision is reached. RCK

#### PHOTO CREDITS

Figures 1 and 16 were photographed by Maha DeMaggio. The photomicrographs in figures 2, 9 (left), 10, 11, 17, and 18 were taken by John I. Koivula; the photomicrograph in figure 9 (right) was by Jeffrey E. Appling, JEA Jewelry Appraisals, Salinas, California. The photos in figures 3 and 5 were taken by V. Cracco. Nicholas DelRe supplied figures 4, 6–8, and 15. Shane F. McClure provided figures 12 and 14. The X-radiographs in figure 13 are by Cheryl Y. Wentzell and Patricia Maddison.