

Gems & Gemology

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Gems & Gemology

TABLE OF CONTENTS

FEATURE ARTICLES	187	Natural Rubies with Glass-Filled Cavities <i>Robert E. Kane</i>
	200	Pyrope-Spessartine Garnets with Unusual Color Behavior <i>D. Vincent Manson and Carol M. Stockton</i>
	208	Gem-Quality Red Beryl from the Wah Wah Mountains, Utah <i>James E. Shigley and Eugene E. Foord</i>
NOTES AND NEW TECHNIQUES	222	An Extraordinary Calcite Gemstone <i>C. S. Hurlbut, Jr. and Carl A. Francis</i>
	226	Green Opal from East Africa <i>John I. Koivula and C. W. Fryer</i>
REGULAR FEATURES	228	Gem Trade Lab Notes
	234	Gemological Abstracts
	242	Gem News
	247	Book Reviews
	249	Index to Volume 20, Numbers 1-4

ABOUT THE COVER: This late 19th century pendant is a fascinating representation of the wide variety of gemstones featured in every issue of *Gems & Gemology*. The 17.75-ct yellow sapphire is framed by demantoid garnets and accented by diamonds. The 10.25-mm pearl is joined to the sapphire above and the 2.67-ct demantoid garnet below by two red spinels. Yellow sapphire is discussed in the *Gem News* section of this issue, pearls and spinel appear in the *Gem Trade Lab Notes*, and the series on garnets continues with the article by D. Vincent Manson and Carl M. Stockton. The pendant is courtesy of Gleim Jewelers, Palo Alto, California. Photo ©Harold & Erica Van Pelt—Photographers, Los Angeles.

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NATURAL RUBIES WITH GLASS-FILLED CAVITIES

By Robert E. Kane

During recent months, natural rubies with surface cavities filled with glass-like substances that may influence both the appearance and weight of the faceted stone were examined by gemological laboratories in Thailand and England and by GIA's Gem Trade Laboratories in both New York and Los Angeles. This article reports on the examination and analysis of 15 natural rubies with notable glass-filled cavities and simple methods for identifying the presence of such filled areas. In most cases the cavities were readily detected by their distinctive luster and other visual characteristics. X-ray diffraction and chemical analysis indicated that the filler was indeed a glass; it was probably added in conjunction with heat treatment.

ABOUT THE AUTHOR

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An apparently new means of enhancing the appearance of natural rubies by lessening the visibility of surface flaws has recently been encountered in gem markets worldwide (figure 1). Gem ruby rough commonly exhibits a multitude of cavities or other surface irregularities, apparently as a result of the crystallization process, resorption after crystallization, or weathering effects, including solution of, or removal from, the matrix in which the corundum initially grew. Because of the importance of weight retention for this often very valuable gem material, some of the finest faceted gem rubies commonly exhibit naturally occurring surface cavities and pits. These surface features are generally confined to the pavilion of the gemstone, so that they do not affect the "face-up" beauty of the stone while the weight of the gem is maximized.

For example, the left view of figure 2 shows two of several large cavities on the pavilion of this 4.02-ct Burmese ruby; as is evident in the right view, however, these cavities are not easily visible from the crown when the stone is examined with the unaided eye. If this ruby were recut to remove the surface cavities, approximately 10% to 15% of the current weight of the stone would be lost. Even though the per-carat price might increase as a result of the improved appearance and clarity, the total value of the faceted ruby would actually be much less because of the weight loss. Consequently, many ruby cutters have chosen to produce a stone of greater weight and lower clarity by leaving the often unsightly surface cavities on the faceted gem rather than grinding them away.

Recently, however, it appears that a clever third alternative has been implemented that can greatly improve the appearance of the faceted ruby without sacrificing valuable weight; in fact, this procedure adds weight to the faceted gemstone. This treatment involves the filling of these surface cavities with a transparent, colorless glass. The result when viewed with the unaided eye is a ruby that appears to



Figure 1. These two heat-treated Burmese rubies contain surface cavities filled with glass that influences both the appearance and weight of the gemstones. The ruby in the upper portion of the photo weighs 7.01 ct, and the other 5.01 ct. Photo by Tino Hammid.

be cleaner and of much greater clarity than it originally was—and thus seemingly more valuable.

Following are some of the major problems inherent in this form of treatment:

1. Because the glass fillings are softer and less durable than the surrounding ruby, they are susceptible to breakage and chipping, particularly at the girdle edges. The result is often a damaged stone. For example, the Los Angeles lab was asked to assess a damaged area on the pavilion of a 2.5-ct Thai stone that our client, who had received the stone

on memorandum, had been accused of chipping. The laboratory not only established that the cavity in question had been present the last time the ruby was polished, but we also observed under magnification several very small areas of a foreign glassy substance in and at the cavity edges. These areas led us to surmise that the cavity had probably been filled with a glass that was inadvertently chipped out by our client.

2. If they are large enough, the glass fillings can be seen easily with the unaided eye, in

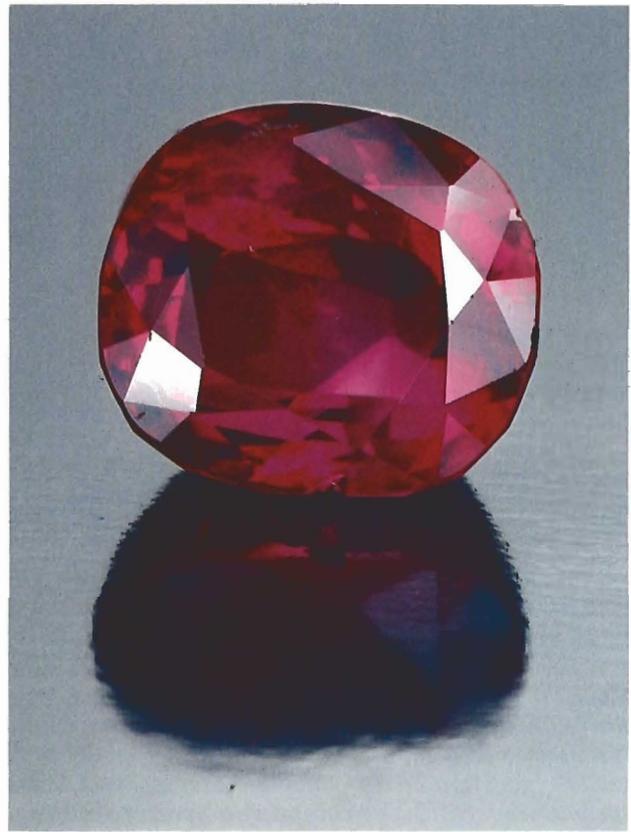
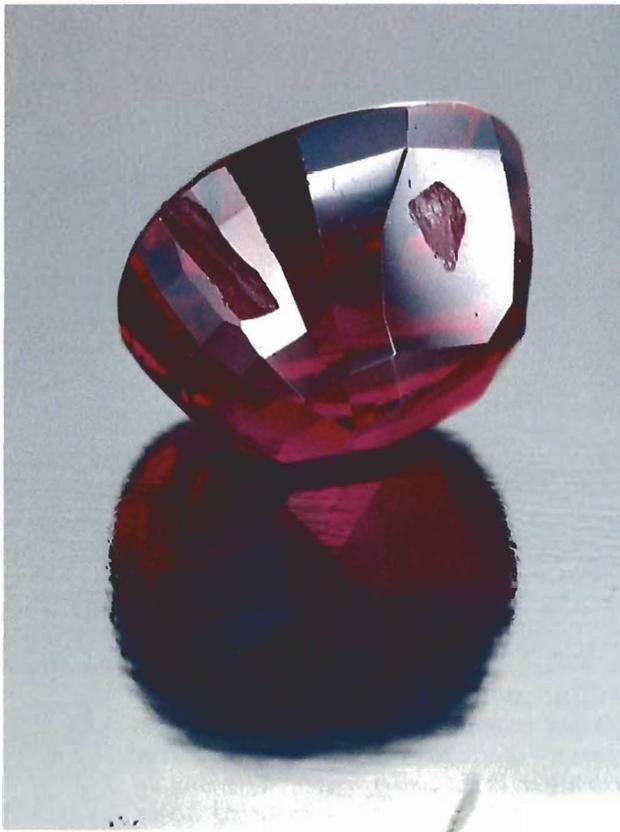


Figure 2. A 4.02-ct untreated Burmese ruby: the view on the left shows two of several large surface cavities present on the pavilion; the crown view on the right reveals that most of these cavities do not detract from the "face-up" beauty of this faceted ruby. Photo ©1984 Tino Hammid.

part because of the difference in surface luster from that of the surrounding ruby.

3. Perhaps most importantly, in extreme cases the glass fillings can account for a significant percentage of the total weight of the "ruby" (we examined one 12.78-mm-long stone with a 7.40-mm-long glass-filled cavity); thus, the potential buyer would be paying a per-weight ruby price for a stone of which a significant portion might be glass. In these cases, the treated stone should be considered a ruby-glass composite.

Failure to disclose this form of treatment when it influences the appearance or weight (or both) of a faceted ruby should be considered fraudulent and should always be identified to potential buyers.

The use of this treatment on rubies no longer appears to be isolated to only a few cases, as originally believed. Gemologists at the Asian Institute of Gemmological Sciences (AIGS) in Bangkok, Thailand, recently encountered a parcel of nine Thai rubies (each weighing around 1 ct) that all had surface cavities or pits filled with a transparent,

colorless material (Henry Ho, pers. comm., 1984; Hughes, 1984). At approximately the same time, Kenneth Scarratt, director of the London Chamber of Commerce Gem Testing Laboratory, described "two sets of natural rubies . . . which contained cavities that had been infilled with an artificial substance (possibly plastic or glass?)" (Read, 1984). A few months later, Robert Crowningshield, of GIA's Gem Trade Laboratory in New York, was shown a 2.5-ct Thai ruby that had a large cavity filled with a foreign glassy substance (pers. comm., 1984). Within a few days of this incident, the author examined over the course of one week three "fine-quality" Burmese rubies ranging in weight from over 4 ct to slightly over 7 ct (from two different clients) that each contained large cavities filled with a glass-like substance (again, see figure 1).

A few weeks later a 6.71-ct Thai ruby that contained the largest glass-filled cavity to date (7.40 mm long) was submitted to GIA's New York Gem Trade Laboratory and subsequently forwarded to the Los Angeles laboratory for further examination. At about the same time, a client submitted for identification to the Los Angeles

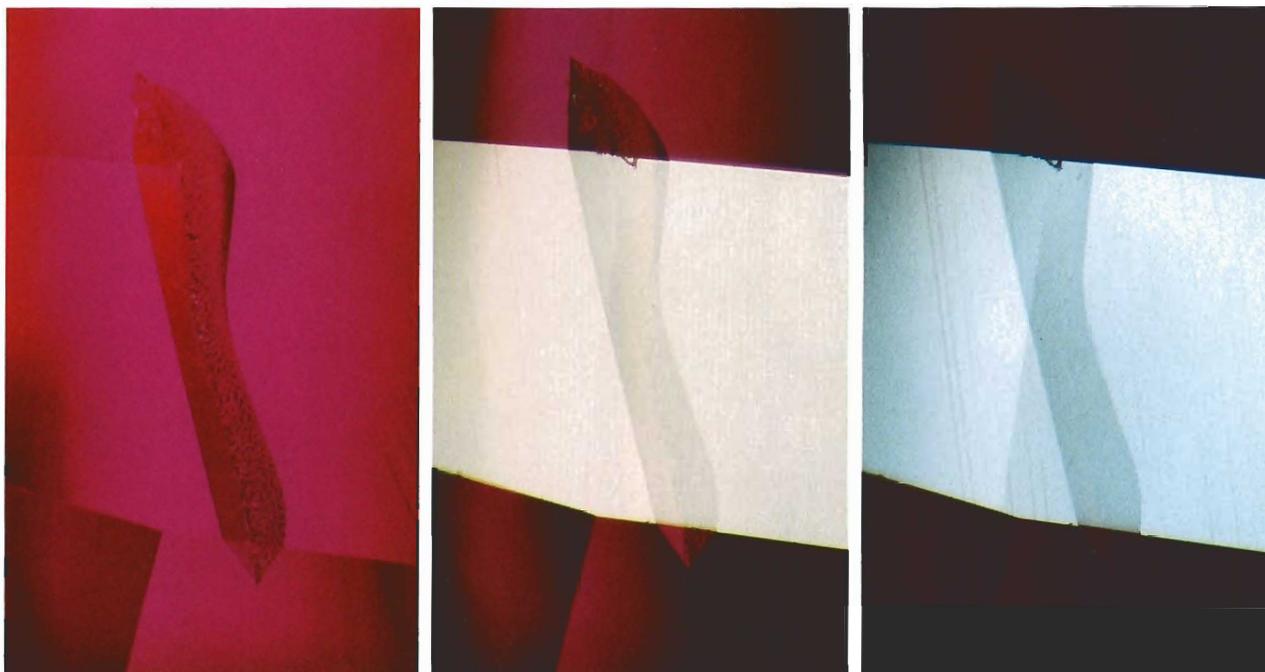


Figure 3. These three photomicrographs of a 2.8×0.4 glass-filled cavity in a 7.01-ct Burmese ruby illustrate how the appearance of the glass filling can change and be readily detected with different illumination techniques. On the left the difference in transparency of the glass and the ruby is evident in dark-field illumination, but there is no apparent difference in luster. In the center, a slight difference in luster is seen with dark-field and fiber-optic illumination. On the right the great contrast in surface luster is seen when reflected illumination only is created with a fiber-optic light source. Magnified $60\times$.

laboratory a matched set of 36 Thai rubies ranging in weight from 1.48 ct to 13.97 ct (total weight, 141.44 ct) that were being compiled to make a ruby-and-diamond necklace, bracelet, and earring suite. When each of the stones was examined individually, nine were found to possess cavities filled with notable quantities of glass.

Subsequently, the author examined two other glass-filled rubies, both of Thai origin, that had been submitted to GIA's Los Angeles laboratory by different clients. The 15 faceted natural rubies—all with surface cavities and pits filled with a foreign glass-like substance—received in the Los Angeles laboratory were examined by the author for this study. All of the stones showed evidence of heat treatment. The 15 rubies were submitted to the laboratory by six different clients who had their offices in different areas of the United States. The two who owned the large Burmese rubies reported purchasing their stones from the same source in Bangkok, and nearly all of the other stones were also reportedly purchased in Bangkok initially. Quite interestingly, though, the author was told by two different and very reliable sources that the service of having a ruby with surface cavities treated so as to fill them with a transparent,

colorless (presumably glass) substance was being offered in New York City! One of the sources felt that some of the natural rubies treated in this manner in New York were being subsequently sent to Bangkok to be offered for purchase. At the time of writing this article, the author has sent a ruby to New York via one of the above-mentioned sources in an attempt to confirm the availability of the "service." All of this would indicate that this treatment is more widespread than was perhaps initially believed. The knowledge and detection of this new treatment is of great importance to the ruby trade worldwide and is essential for gemologists.

DETECTION OF FILLED CAVITIES

In the course of the study, several characteristics were observed to play a key role in establishing the presence of glass-filled cavities in rubies. Surface luster, appearance with immersion, gas bubbles, glass-ruby contact zone, and transparency were found to be particularly important. When present, these features could be seen with low magnification or, in a few stones, with the unaided eye. Tests for refractive index, luminescence, and hardness were also conducted.

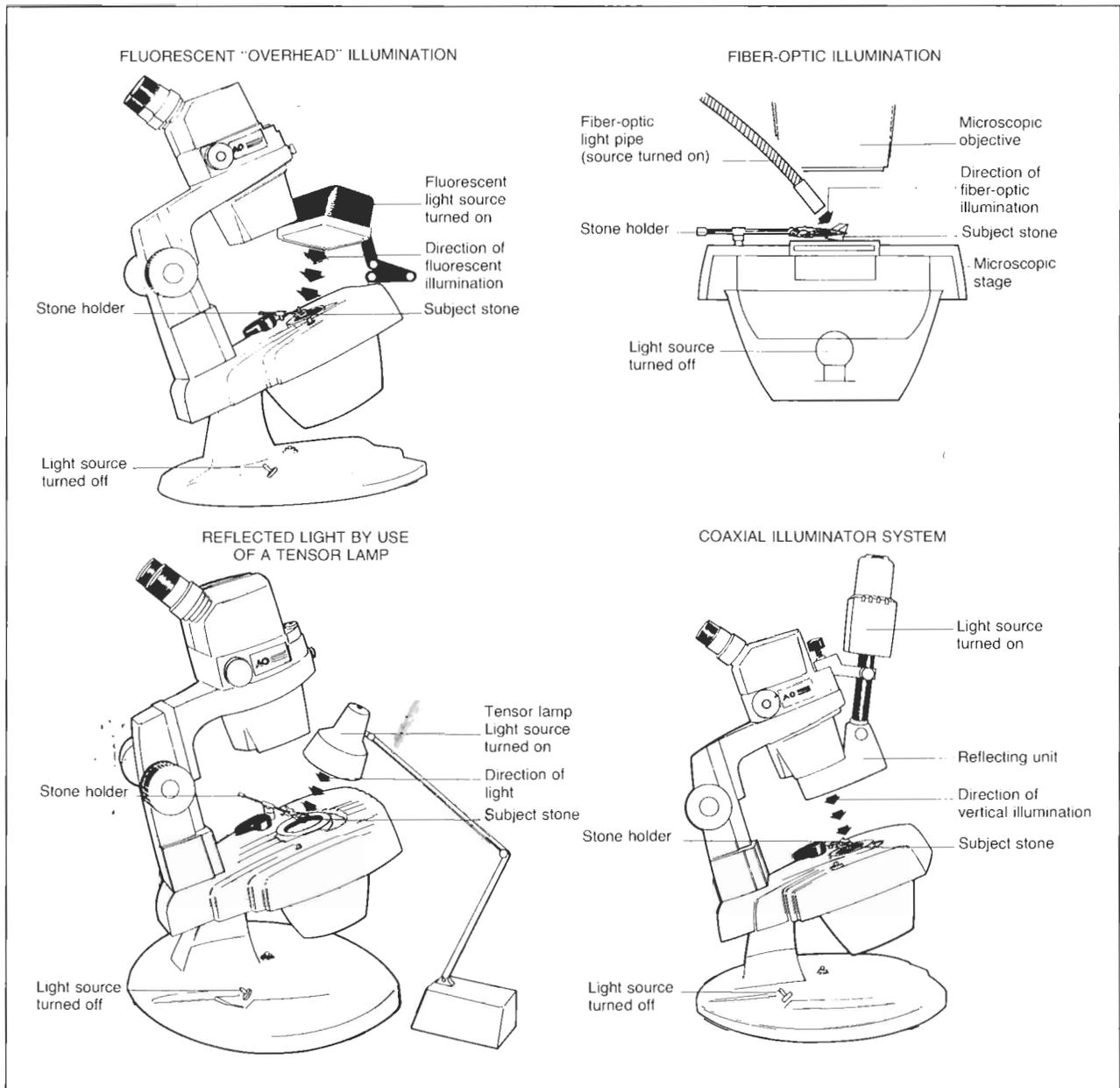


Figure 4. Reflected illumination is produced by positioning a light source near a 90° angle over the surface of the gemstone, so that only the surface is viewed; several methods can be used. For examining surface characteristics, the technique that is generally the easiest, fastest, and least harsh to the eyes is fluorescent "overhead" illumination. Greater surface detail is provided when the reflected illumination is produced with the more intense incandescent light source provided by fiber-optic illumination, a Tensor lamp, or a coaxial illuminator system.

Surface Luster. Because of the different optical properties of the glass and the ruby, there is a great difference in luster between the two materials. This difference is most evident when the surfaces are viewed under magnification using only reflected illumination, that is, with the light source positioned directly (near a 90° angle) over the surface of the material (figure 3). This type of illumination can be achieved with several different

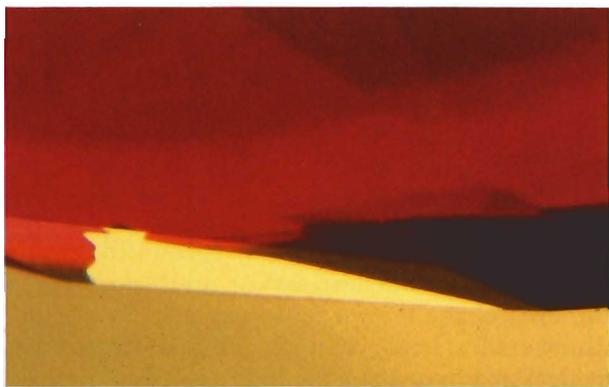
techniques; the most common are (1) fluorescent "overhead" illumination, (2) fiber-optic illumination, (3) a Tensor lamp, and (4) the coaxial illuminator system (figure 4). To detect glass fillings, the technique that is easiest, fastest, and least harsh to the eyes of the viewer is fluorescent "overhead" illumination. In some stones the glass fillings can be detected by using a penlight to create total reflection when the stone is viewed with the unaided

eye or with a loupe. Once the filling is located, however, a more intense light source, such as the incandescent light provided by the other three methods listed above, should be used to reveal greater surface detail. All four methods of illumination provide essentially the same desired result; that is, they achieve "total reflection" so that only the surface of the two materials is being viewed and the great difference in surface luster between the two materials is readily apparent. This difference in luster provides positive proof that the two areas are not both ruby, although it does not prove or even indicate that the nonruby substance is glass.

Appearance with Immersion. Several important observations can be made while examining a suspect ruby that is immersed in methylene iodide. Both examination with the microscope (with the immersion cell placed over transmitted or dark-field illumination) and observation with the unaided eye over a diffused light source (such as the fluorescent light available on many microscopes) are suggested.

In specific viewing positions, the filling material is observed to be colorless (figure 5). The refractive index of the methylene iodide (1.745 at 18°C as reported in Webster, 1983) provides a readily apparent and vivid contrast in relief between the higher R.I. of the ruby (1.762–1.770) and the much lower R.I. of the glass (1.516), as is well illustrated in figure 6. Note also in this figure how the spherical gas bubbles within the glass contrast

Figure 5. At specific viewing positions, the glass-filled cavity in this ruby from Thailand is observed to be colorless when immersed in methylene iodide. Diffused illumination, magnified 25x.

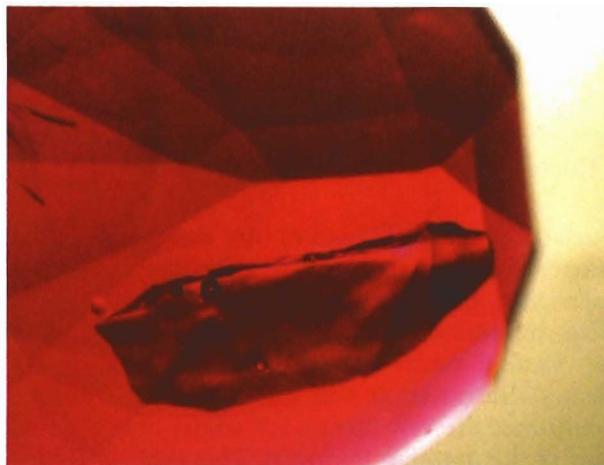


strongly with the glass because of the differing refractive indices of the trapped gas and the glass filling.

Gas Bubbles. Gas bubbles in various sizes and shapes are observed in many of the glass-filled cavities. Those in the glass-filled cavity in the 6.71-ct ruby (again, see figure 6) were large enough to be seen with the unaided eye when illuminated with a penlight. Some of the large filled cavities, however, appeared quite homogeneous, with no visible gas bubbles. It is important to note at this time, though, that many rubies from Thailand have as naturally occurring inclusions angular negative crystals filled with a glassy substance that commonly contains spherical gas bubbles (Koivula, 1984).

Glass-Ruby Contact Zone. In many of the stones examined, the filling material was so perfectly fused to the ruby that no visible irregularities, such as a separation plane of gas bubbles or other optically detectable uneven fusing of the two materials, was observed with the microscope. Even in rubies with very irregularly shaped cavities (figure 7), the junction between the glass and the ruby was so sharp that the filling fit into the tightest corners. In some of the other stones examined, however, uneven voids of trapped gas (figure 8) or a heat-

Figure 6. Immersion in methylene iodide over diffused illumination provides a vivid contrast between this very large glass-filled cavity (7.40 mm × 3.20 mm) and its 6.71-ct Thai ruby "host." Magnified 15x. Photomicrograph by Ricardo Cardenas.



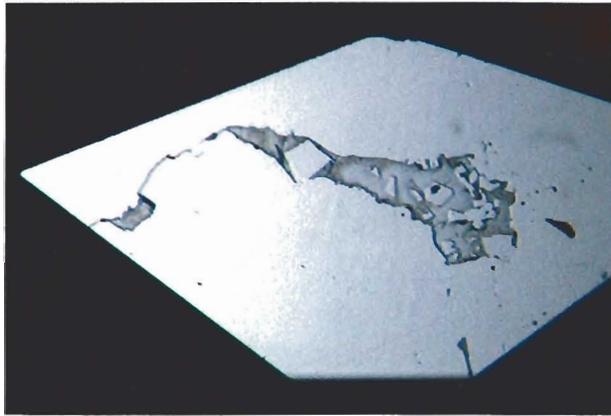


Figure 7. On the bezel facet of a Thai ruby, fiber-optic illumination is used to produce reflected light to accentuate very irregularly shaped glass-filled cavities that extend nearly half-way around the crown and deep into the interior. Magnified 50 \times .

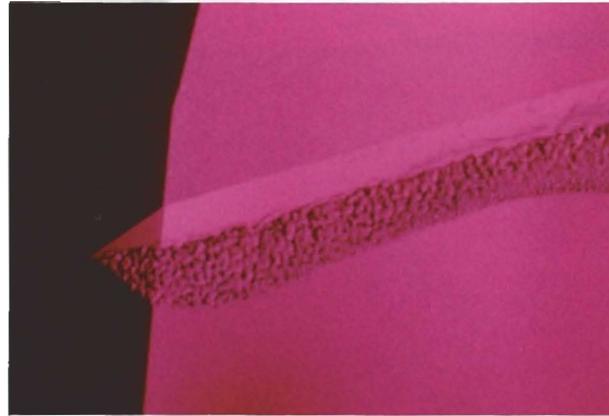


Figure 8. Uneven voids of trapped gas form one side of the junction between a large glass filling and the surrounding Burmese ruby. Dark-field and oblique illumination, magnified 100 \times .

wave appearance (figure 9), were observed at the junction of the two materials.

Transparency. Because the refractive index of the singly refractive glass is much lower than that of the surrounding doubly refractive ruby, and the material itself is far more transparent, the filled areas were readily apparent in some stones. In many cases, however, when the stone in question was examined with the microscope—in dark-field illumination, with the glass-filled areas at an angle perpendicular to the viewing direction—these areas appeared to be depressions in the surface rather than filled areas flush with the surface. Only when the stone was tilted so that the filled area was at an angle to the viewing direction did it become apparent that the cavity was actually filled with a foreign substance.

Refractive Index. One of the very large filled areas (7.40 mm \times 3.20 mm) was tested using a GEM Duplex refractometer in conjunction with a monochromatic light source equivalent to light from a sodium vapor lamp. A singly refractive index measurement of 1.516 was obtained by the author. The refractive index of 1.52 reported by Hughes (1984) was obtained by testing several stones examined in Bangkok; the slight difference in refractive index measurements could be due to the slight error inherent from one refractometer to the next or from slight variations in chemical composition.

Luminescence. When exposed to long-wave ultraviolet radiation (366 nm) and short-wave ultra-

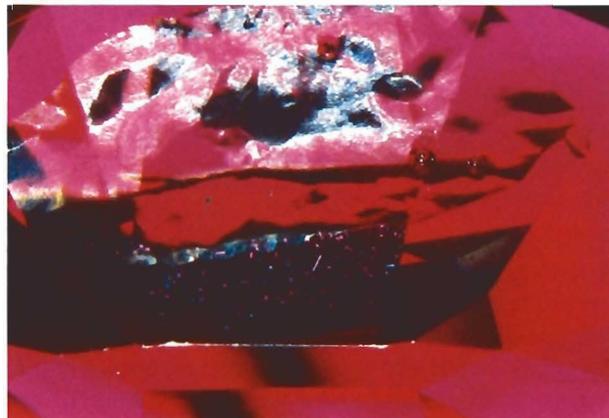


Figure 9. The uneven junction between this large glass-filled cavity and the surrounding Thai ruby is exemplified by a "heat-wave" appearance. Dark-field and oblique illumination, magnified 30 \times .

violet radiation (254 nm), the glass filler did not exhibit any visible fluorescent reaction. No luminescent reaction was observed in the glass fillings in the few stones that were exposed to X-radiation.

Hardness. With the permission of the stones' owners, the most inconspicuous areas of the filled cavities were carefully tested with hardness points. The areas tested were easily scratched by the quartz hardness point (7 on the Mohs scale) and were not scratched by the feldspar hardness point (6 on the Mohs scale). On the basis of these results, the hardness of the glass-filled areas was estimated to be around 6½ on the Mohs scale, which is much lower than the hardness of the surrounding ruby (9 on the Mohs scale).

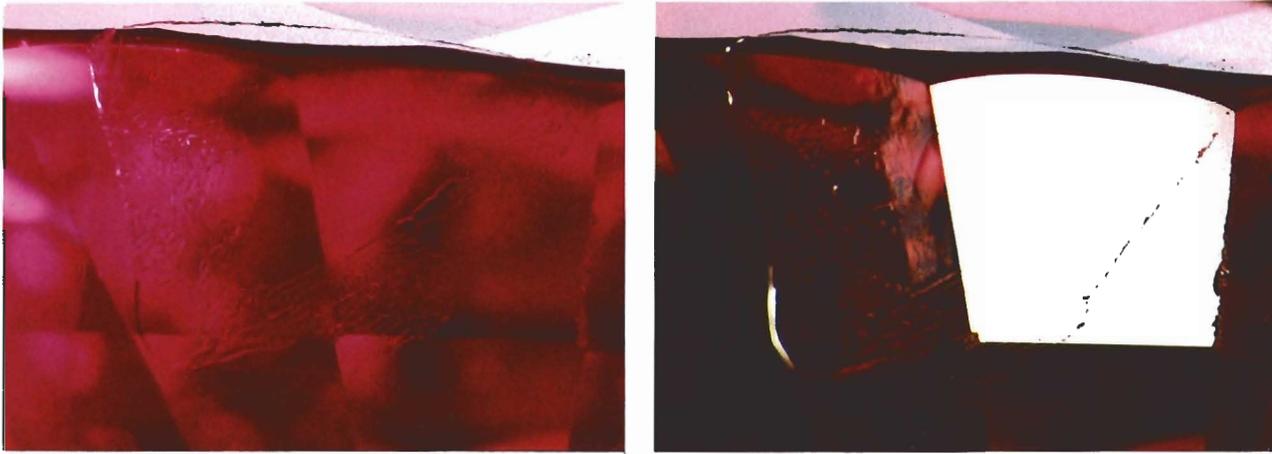


Figure 10. The ruby inclusion in ruby in these two photomicrographs could be mistaken for a glass-filled cavity. On the left, a large area of the ruby inclusion is seen in dark-field illumination with oblique illumination concentrated on the crown to accentuate an area of partial separation. The view on the right, taken with additional reflected illumination, reveals that the surface luster on both sides of the partially healed ruby is identical, thus ruling out the presence of a foreign material. Magnified 45 \times .

IDENTIFICATION OF THE FILLING MATERIAL: NATURAL, ALTERED OR INDUCED

Once a filled cavity is suspected, the jeweler-gemologist must next attempt to determine the nature and identity of the material. A number of feasible possibilities exist: (1) ruby included in ruby, (2) a naturally occurring (that is, not incorporating a foreign material) glass inclusion, and (3) an artificially induced glass.

Ruby Included in Ruby. Natural rubies occasionally contain inclusions of ruby that at one time were either fractured or grew in a different crystallographic orientation from the host ruby crystal. Frequently, these ruby inclusions exhibit evidence of having undergone a healing process which is displayed in the form of a fingerprint pattern (figure 10, left). If a ruby containing this type of inclusion were hastily examined with the microscope in dark-field illumination, the inclusion could possibly be incorrectly identified as a glass-filled cavity. However, when the stone is examined in reflected light using one of the previously discussed illumination techniques, it is readily apparent that the surface luster of the area in question and the surrounding ruby are identical (see figure 10, right). If the area is a foreign included material, such as a glass or even a naturally occurring mineral inclusion breaking the surface of the ruby, the difference in surface luster of the two materials should be obvious in reflected light.

Naturally Occurring (?) Glass Inclusions. Rubies from Thailand frequently have as inclusions small negative crystals filled with a glassy substance of unknown origin that commonly contains one or more gas bubbles (Koivula, 1984). These inclusions are usually observed to be completely contained in the faceted ruby, rather than exposed at the surface. Although the author has observed many inclusions of this type in Thai rubies over the past several years, it is interesting to note that they have not been described in detail previously in the gemological literature. It is possible that these glass inclusions may be the result of the environment in which the gem mineral forms. Or they may have resulted from the heat treatment of rubies (to eliminate silk and reduce secondary colors) that has been widely practiced, particularly in Thailand, for the past five to ten years (Abraham, 1982).

Specifically, heat treatment requires placing the stones in temperatures up to 1600 $^{\circ}$ C for four to eight hours (Abraham, 1982). Because some of the inclusions that commonly occur in natural rubies have melting points below 1600 $^{\circ}$ C, at high temperatures they may melt or begin to alter and expand, sometimes generating stress fractures in the host ruby around the inclusion (Nassau, 1981, fig. 1). These alterations in appearance, structure, and even composition could give these inclusions the appearance of a glass (Koivula, 1984). Unfortunately, very little research into the effects of high-temperature treatment on the inclusions in ruby

has been reported in the gemological literature, although it is well known that as a result of heat treatment solid mineral inclusions in sapphires often alter to white, rounded, melted-appearing forms (illustrated in Hänni, 1982, and Gübelin, 1983).

Regardless of their origin, these "natural" inclusions commonly exhibit an equidimensional angular outline encasing one large spherical gas bubble. Also observed are tabular, glass-filled negative crystals that frequently contain one or several spherical gas bubbles (see figure 11). A third type of natural glass inclusion that is somewhat commonly observed in Thai rubies is less well defined in shape than the two described above (figure 12). One of these inclusions, which contained several small spherical gas bubbles, broke the surface of a faceted Thai ruby. In the center of this solid glass inclusion was a hemispherical cavity where a gas bubble had been before polishing. In an attempt to determine the chemical composition of these naturally occurring glass inclusions, an electron microprobe analysis of a portion of this inclusion was obtained (see discussion below). To confirm that this inclusion was in fact natural and not artificially added to the stone, a similar inclusion in the same general area of this faceted ruby

was exposed to the surface by grinding. The chemical data obtained on this second inclusion were the same as those obtained on the original.

Out of dozens of faceted rubies with "natural" glass inclusions that were examined for this study, only the stone described above contained a glass inclusion that broke the surface. The most diagnostic visual characteristic of the natural glass inclusions in comparison to the artificially induced glass inclusions was size: none of the natural glass inclusions examined exceeded 1 mm, while the author observed artificially induced inclusions as large as 7.4 mm long. In addition to size, the shape of the filled area can reveal much about the possible origin of the glass. Several tests were conducted to determine if there were other routine gemological means of distinguishing between the natural and artificially induced glass inclusions, as discussed below.

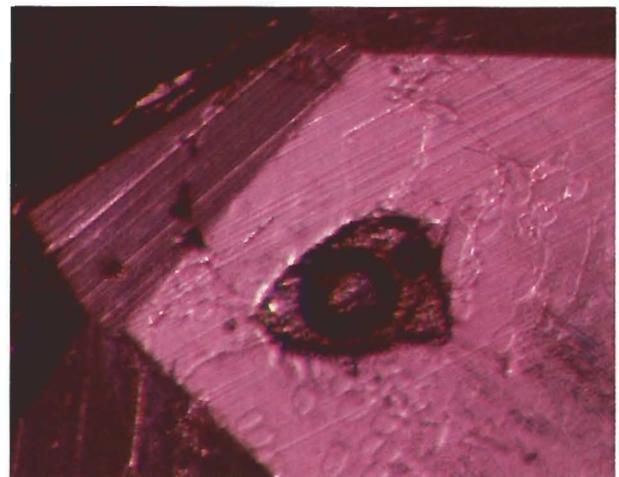
When examined in reflected light, these natural glass inclusions exhibit an obvious difference in surface luster from that of the surrounding ruby host. Since the difference is essentially the same as that observed for artificially induced glass inclusions when examined in reflected light, however, the two cannot be distinguished by their luster.

Examination of the natural glass inclusion that broke the surface revealed no visually detectable diagnostic differences from the artificially in-

Figure 11. Naturally occurring glass inclusions in a Thai ruby (the largest measures 0.10 mm in diameter). The fact that the three gas bubbles in the largest inclusion are stationary proves that this is a solid-and-gas rather than liquid-and-gas inclusion. Dark-field illumination, magnified 50×. Photomicrograph by John Koivula.



Figure 12. This naturally occurring glass inclusion (0.05 mm) is less well defined than the type shown in figure 11. It also shows a crackled appearance; again, note the two gas bubbles. Diffused transmitted illumination, magnified 160×. Photomicrograph by John Koivula.



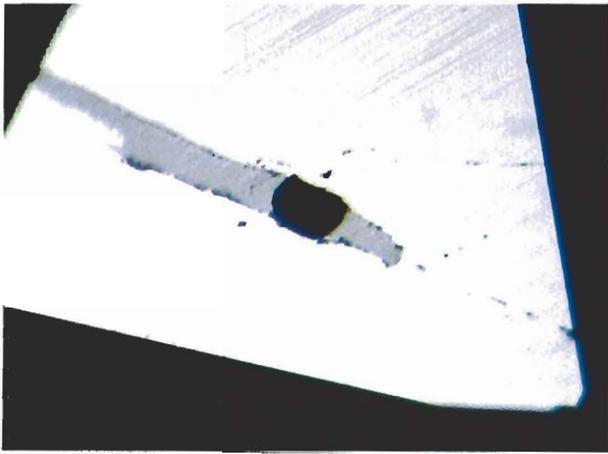


Figure 13. Reflected illumination accentuates one of the more than two dozen irregularly shaped glass-filled cavities in this Thai ruby that extend deep within the stone. The black area is a portion of the cavity that was not filled with glass. Dark-field and fiber-optic illumination. Magnified 75 \times .

duced glass in refractive index, transparency, or appearance while immersed in methylene iodide. However, examination of the numerous fully enclosed natural glass inclusions revealed several notable differences from their artificially induced counterparts. In the natural glass inclusions, the junctions where the inclusion and the ruby meet were so perfect that no visible irregularities were observed with the microscope. As discussed above, in some, but not all, of the artificially induced glass-filled cavities, the contact zone is irregular and exhibits several forms of uneven cohesion. Such a contact zone is, therefore, a good indication that the cavity in question has been artificially filled. Another important indication is the regular shape of the artificially induced glass (figures 13–14) as compared to that of the natural glass inclusion, which often assumes the irregular shape of a negative crystal.

The presence or absence of gas bubbles generally does not provide a means of distinguishing between an induced glass-filled cavity and a natural glass inclusion. However, an excessive number of gas bubbles at the junction of the glass inclusion with the host ruby also is a very good indication of an artificially induced glass-filled cavity (again, see figure 8).

Artificially Induced Glass. Once the possibilities of a ruby inclusion in ruby and a “naturally” occurring glass inclusion have been considered and ruled out or brought into question, the third alter-



Figure 14. A large glass-filled cavity in a 5.01-ct Burmese ruby. The dark area on the left shows a partial filling of the glass, which was observed in many of the “filled” cavities examined for this study. The area directly adjacent was filled with enough glass to allow repolishing flush with the surface of the ruby, as is evident in dark-field and reflected illumination. Magnified 45 \times .

native must be that the material has been added to the stone, whether intentionally or accidentally. Accordingly, tests were next conducted to determine whether (1) the material was indeed a glass and (2) it had been added to the stone artificially. Since it had been determined early in the study that all of the stones examined had been heat treated, special attention was paid to the possible role of heat treatment in this procedure.

To confirm that the filling material was amorphous, as expected of a glass, X-ray diffraction analyses were performed by C. W. Fryer. Minute amounts of powder were carefully scraped from the large fillings in each of four stones: at least one major area containing cavities filled with a glassy substance in three natural rubies (two Burmese and one Thai), and the naturally occurring glass inclusion in one Thai ruby. The X-ray diffraction

films obtained revealed no patterns, thus supporting the amorphous nature of the material.

To further understand the nature of the glass-filled cavities, the same four samples were analyzed with an electron microprobe by Carol Stockton (see table 1). These chemical data provide several interesting observations regarding the nature of these inclusions:

1. The glasses designated A and B have a very similar composition; however, that of glass C is somewhat distinct. In each case, they all differ from the composition of the naturally occurring glass inclusion D.
2. The compositions of glasses A, B, and C do not seem to resemble the likely composition of a melt formed by heating any single mineral that one might expect to find as a naturally occurring single mineral inclusion in a natural ruby.
3. The similarity in composition between glasses A and B, which occur in stones that came from a single supplier and are believed to have been treated at the same time, is difficult to explain other than by the addition, accidental or by design, of a foreign mixture at the time of heating.
4. The distinctive differences in composition between glasses A and B as compared with glass C, which occurred in a ruby obtained from a different supplier, suggest that the

composition of the glass is dependent on substances present in the environment at the time of heat treatment.

At the present time, the significance of these observations cannot be fully assessed, but the data do imply a distinct difference in composition between the artificially induced and the natural glass inclusions. Further study of more material is needed, however.

Glass coatings can apparently be formed accidentally during the heat treatment of corundums under certain circumstances. Examples of this are shown on heat-treated yellow and blue sapphires that were obtained from heat treaters in Chanthaburi, Thailand, by Dr. Peter Keller in 1982 (figure 15). Before they were treated, both stones were reportedly coated with a borax-based solution (Keller, pers. comm., 1982).

Although the specific procedures used in the heat treatment of corundum in Thailand are often proprietary and most probably vary from one treater to another, it is commonly believed that many heat treaters use coating solutions to prepare the corundum for treating. The author's investigations in Thailand indicate, however, that boron-based solutions are not typically used on rubies but possibly only for the heat treating of sapphires. A more likely explanation for the occurrence of the glass fillings in the surface cavities of rubies (and possibly for the coatings observed on the two sapphires) is provided by referring to the many U.S.

TABLE 1. Chemical analyses of the glass areas in four natural rubies.^a

Sample designation	Size of glass inclusion (mm)	Carat weight of stone	Origin of inclusion	Oxide component (wt. %) ^b											
				Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	K ₂ O	CaO	FeO ^c	TiO ₂	Cr ₂ O ₃	MnO	V ₂ O ₃	Total ^d
A	2.8×0.4	7.01	Artificially induced	Bdl ^e	9.9	30.7	44.7	Bdl	7.5	2.4	Bdl	Bdl	0.1	Bdl	95.3
B	3.5×1.5	5.01	Artificially induced	Bdl	10.6	33.3	42.8	Bdl	7.3	1.7	0.1	Bdl	0.1	Bdl	95.9
C	7.4×3.21	6.71	Artificially induced	1.7	0.1	31.9	56.9	3.5	0.1	0.3	0.1	Bdl	Bdl	Bdl	94.6
D	0.1×0.09	1.31	Naturally occurring	0.4	1.9	26.4	56.8	0.6	6.5	1.5	0.4	Bdl	Bdl	Bdl	94.5

^aThese samples were analyzed by Carol Stockton with a MAC microprobe at an operating voltage of 15kV and beam current of 0.05 μA. Data refinement carried out by using the Ultimate correction program (Chodos et al., 1973).

^bValues represent the average of three analyses for each inclusion which were in close agreement with one another.

^cTotal iron reported as FeO.

^dThe low totals may indicate the presence of either water or one or more elements of low atomic number (below 9), which cannot be detected by a microprobe.

^ebelow the detection limits of the instrumentation used (approximately 0.1 weight % oxide).

patents discussed in L. Yaverbaum (1980). In one U.S. (Linde) patent in particular (#2448511), Barnes and McCandless (1948) describe a process "for rapidly and inexpensively treating crystalline precious and semiprecious stones, such as corundum and spinel, to give them glossy and scratch-free surfaces by using both heat and additions agents." The patent also states:

The process is carried out by first applying to the surface of the stone a thin film of an addition agent, advantageously adding just enough to fill the pits and crevices in the surface. It is advantageous to use at least one oxide or oxide-forming compound fulfilling at least one of the following requirements: having a lower melting point than the stone, forming a solid solution with the stone, or forming a low melting peritectic with the stone. Then the film is bonded to the original surface by fusion with heat, as in a gas flame, an electric arc, or a furnace. Either a fully glossed, even surface or a partially glossed, wavy surface can be obtained by properly controlling the heating. Oxides suitable for glossing stones, such as spinel and corundum, include calcium oxide, magnesia, sodium oxide, and silica (silicon dioxide). The oxides of calcium, magnesium, and sodium form eutectics with corundum and spinel. Silica and sodium oxide have lower melting points than corundum and spinel. Magnesia forms a solid solution with corundum prepared from beta alumina. Silica also forms a low melting peritectic with corundum and spinel.

One way to apply the oxide is to paint on the surface of the stone a slurry of solution in water or other liquid of the oxide, or a compound decomposable to form the oxide.

Yaverbaum includes other patents concerning gemstone materials, although not all are in commercial use today. Nassau (1984) provides an excellent review of treatment practices that have been used in the past and are currently employed.

On the basis of the above information, it appears that many if not all of the *induced* glass fillings observed in rubies examined to date by the author are a by-product of heat treatment, the intentional or accidental introduction of a foreign material into surface cavities. Additional observations in support of this conclusion include:

1. All of the rubies with glass-filled cavities examined exhibited strong evidence, in the form of altered inclusions, of having undergone heat treatment.
2. Some of the rubies examined contained one or two glass-filled cavities adjacent to nu-

merous unfilled surface cavities. This suggests that during heating the filled areas may have lain against the crucible wall where a molten foreign residue entered the surface cavities and subsequently formed a glass upon cooling.

3. Several rubies examined contained cavities with very small areas at the edges filled with a glassy substance that were too insignificant to influence the appearance or weight of the stone.
4. Other rubies examined had in excess of two dozen areas (minute to large) on nearly all surfaces of the faceted stone that were filled with glass; this suggests that the stone was coated with or embedded in a foreign substance.
5. Some of the glass fillings were observed in conchoidal chips or small nondescript depressions such as those that would occur during or after the cutting and polishing of the faceted ruby, thereby supporting the conclusion that these stones had been treated after they were cut, which is the common practice when heat treating rubies.

The theory that many if not all of these glass fillings may be a by-product of heat treatment is supported by a photomicrograph published by Kenneth Scarratt (1982). This photomicrograph depicts a blue sapphire with what appears to be a very large cavity that is filled with a transparent substance that contains many spherical gas bubbles of various sizes. This 16.63-ct dark blue heat-treated sapphire was submitted to the London Gem Testing Laboratory by M. Poirot in 1976, at the beginning of the great influx of heat-treated blue sapphires in world gem markets. Although this stone was not examined by the author, the "filling" in the photomicrograph is identical in appearance to some of the glass-filled cavities in the heat-treated rubies examined in this study, and very similar to the filled area shown in figure 6.

CONCLUSION

Recently, natural rubies with glass-filled surface cavities that influence both the weight and appearance of the faceted stone have been seen in gem markets worldwide. Although it is not known at this time how widespread this practice is, the consequences of this treatment for the ruby trade



Figure 15. The irregular glass coatings on the surfaces of these treated sapphires (4.91 ct and 0.98 ct) formed as a by-product of heat treatment, specifically, by the melting of a coating solution that was used to prepare the sapphires for heating. Photo ©1984 Tino Hammid.

could be severe. Consequently, awareness of this treatment and knowledge of its detection are of great importance. Likewise, failure to disclose this treatment when it does affect the weight and appearance of the faceted gemstone should be considered fraudulent.

To date, with the exception of the 16.63-ct blue sapphire reported by Scarratt (1982), all of the glass-filled gemstones reported in the literature and examined by the author have been rubies. Perhaps this is in part due to the large number of blue sapphires from Sri Lanka that are commonly heat treated. Sri Lankan sapphire rough generally exhibits fewer surface cavities and depressions than does ruby rough from Burma and Thailand. In addition, the frequently lower value of sapphires as compared to rubies should influence whether or not weight is saved in cutting and, therefore,

whether surface cavities are left on the faceted sapphire.

The simplest means of identification of glass-filled cavities in ruby is provided by the use of reflected illumination to detect differences in surface luster between the filled area and that of the surrounding stone. Immersion in methylene iodide often reveals readily apparent differences in appearance between the two materials.

If a filled area is very small and nondescript, the gemologist may not be able to distinguish between a naturally occurring inclusion and an artificially induced glass-filled cavity. It is the author's opinion, however, that determination of the nature of the filling in such an instance is of minor importance since the filling will not have a significant impact on either the weight or the vulnerability of the faceted ruby.

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PYROPE-SPESSARTINE GARNETS WITH UNUSUAL COLOR BEHAVIOR

By D. Vincent Manson and Carol M. Stockton

The study of garnets by GIA's Department of Research continues with a collection of 32 garnets that display a variety of hues and yet share a common tendency to show different colors under different sources of light. Even when very slight, the change of color is invariably greater than that encountered in other types of garnets. These unusual garnets proved to be composed principally of a variable mixture of pyrope (25–60 wt.%) and spessartine (20–56 wt.%), with considerable almandine (2–17 wt.%) and grossular (3–23 wt.%) also present. Their primary chemical distinction lies in their $V_2O_3 + Cr_2O_3$ content, which is always in excess of 0.2 wt.%. In conjunction with their distinctive color behavior, these garnets may also be characterized on the basis of specific gravity and absorption spectrum.

ABOUT THE AUTHORS

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During our study of transparent gem garnets over the last four years, we have examined garnets of almost every color: purple, red, orange, yellow, green, and colorless (Manson and Stockton, 1981, and 1982; Stockton and Manson, 1982 and 1983; Stockton, 1982). A final collection remains of garnets that do not neatly fit into any of the previously examined categories because of their distinctive color behavior. The hues represented are yellow, orange, red, and purple, plus a single greenish yellow stone (figure 1), but all of these stones show some degree of color change between different sources of light.

Change-of-color garnets are perhaps the most intriguing members of the garnet group. Much interest has developed over these garnets ever since one such stone was described by Robert Crowningshield in 1970, although the focus has been principally on the causes of the phenomenon (Jobbins et al., 1975; Schmetzer et al., 1980). Our present interest is primarily in the nature of these unusual garnets, how they relate to other types of garnets, and how they can be identified with respect to the needs and practical capabilities of the jeweler-gemologist. Our proposal for the classification of gem garnets will be presented in the next article in this series and will include the present group of stones as well as all the other garnets that we have examined.

PREVIOUS STUDIES

The only types of garnets reported in the past that resemble any of the specimens in this study have been those that display a *distinct* change of color. Among these, two types have been observed: pyropes with high Cr^{3+} content (Hysingjord, 1971; Carstens, 1973; Amthauer, 1976) and stones composed principally of pyrope and spessartine with Cr^{3+} and V^{3+} present (Crowningshield, 1970; Jobbins et al., 1975; Schmetzer and Ottemann, 1979). Since the former have not, as yet, been



Figure 1. This selection of stones from the 32 garnets studied show the wide range of colors of this collection in both fluorescent (top) and incandescent (bottom) illumination. The GIA catalog numbers, from left to right, are 13433, 1009, 1055, 1023, 1043, 665, and 96A. The stones range in weight from 1.12 ct to 3.74 ct. Photos by Mike Havstad.

observed in sizes sufficiently large for cutting into gems (most specimens measure less than 5 mm in diameter), they will not be included in this discussion. It is the latter types, which do occur in gem sizes and qualities, that interest us here.

The color-change gem garnet reported by Crowningshield (1970) was described as blue-green in daylight and purple-red in incandescent light, with a refractive index of 1.765 and a specific gravity of 3.88. The semiquantitative spectrographic analysis reported gave a chemical composition that we calculate to be mostly pyrope and spessartine (see table 1). Cr_2O_3 and V_2O_3 were detected in small amounts. In 1975, Jobbins et al. reported a small piece of rough color-change garnet that appeared greenish blue in daylight and magenta by tungsten illumination. This stone gave somewhat lower refractive index and specific gravity results than Crowningshield's, but it also proved to be primarily a blend of pyrope and spessartine. V_2O_3 , but not Cr_2O_3 , was detected. However, new figures for both V_2O_3 and Cr_2O_3 in the same garnet were obtained later by Schmetzer and Ottemann (1979) in

a study of vanadium-bearing garnets (again, see table 1). In this same study, Schmetzer and Ottemann also reported six other change-of-color garnets that were all primarily mixtures of pyrope and spessartine (again, see table 1), and that all contained both V_2O_3 and Cr_2O_3 .

Absorption spectra in the visible-light range were obtained on the first-reported specimens by use of the hand spectroscope. Crowningshield (1970) found total absorption from 400 to 438 nm, three narrow bands around 465, 485, and 505 nm, and a broad region of absorption between approximately 555 and 595 nm. Jobbins et al. (1975) reported similar findings: complete absorption to about 436 nm, narrow bands at 460, 486, and 506 nm, and a broad absorption between 550 and 590 nm. Using a spectrophotometer, Schmetzer and Ottemann (1979) found the broad region of absorption to be centered around 568 to 576 nm in all the color-change garnets in their study. They correlated this broad band with the presence of Cr^{3+} and/or V^{3+} . The spectra of three of the stones they examined also indicate the presence of narrow bands at approximately 407–412, 417–426,

431–435, 461–463, 505–507, and 527 nm, with a faint band at 694 nm. The first three bands are present within a larger region of strong general absorption. These results correlate with the spectral data reported earlier by Crowningshield and Jobbins et al., adding only those bands that are too weak to be visible with a hand spectroscope and those that are masked (e.g., the shorter wavelengths) by an overlapping strong absorption region.

DATA COLLECTION

The stones selected for this study are those that exhibit color change between incandescent and daylight-equivalent illumination. The result is a collection of 32 garnets of various hues, including purple, red, orange, and yellow.

Refractive index, specific gravity, visible-wavelength optical absorption spectrum, color coordinates, and chemical composition were determined for each stone. The methods and instruments used to collect these data are the same

as those described in the first article on the GIA garnet project (Manson and Stockton, 1981) with two exceptions. The first was in response to the potential significance of minor elements (such as chromium and vanadium) in the compositions of these garnets, as well as to the difficulty of accurately measuring small quantities of these elements by means of the microprobe. This led us to perform five separate analyses on each stone; we felt that the averages of these analyses would provide reasonably accurate figures for the minor elements despite relatively large individual margins for error.

The second departure from our original methods of data collection involved the measurement of color with the GEM ColorMaster. In addition to the key color normally used to characterize the color of a gemstone, these garnets may display two additional colors in any single type of illumination. One is seen in the light that is reflected from the stone's interior (the "reflected" color), while another is visible when light is

TABLE 1. Chemical data (in wt. %), refractive indices, and specific gravities from prior research on color-change garnets, with ranges of values for the 32 garnets in this study.

Data	Garnets studied								
	1 ^a	2 ^b	3	4	5	6	7	8	9 ^c
Oxide composition									
SiO ₂	38.35	39.02	40.3	38.23	40.91	40.7	37.17	40.4	38.99 – 41.15
TiO ₂	0.14	n.d. ^d	0.05	0.04	0.03	0.19	0.07	0.08	0.02 – 0.23
Al ₂ O ₃	26.45	21.05	21.8	21.56	23.81	22.9	25.51	22.9	21.56 – 23.33
V ₂ O ₃	0.32	0.24	0.71	0.29	0.10	0.35	0.24	0.50	0.09 – 0.68
Cr ₂ O ₃	0.54	0.54	0.17	0.51	0.16	0.13	0.11	0.27	0.04 – 0.63
MgO	13.1	7.05	12.9	10.84	12.85	14.1	15.27	14.4	7.58 – 17.92
CaO	2.38	3.46	5.3	4.62	4.93	5.5	1.9	1.9	1.70 – 8.94
MnO	16.73	25.31	18.2	22.24	15.57	15.5	14.8	14.8	9.82 – 24.63
FeO	1.45	1.77	1.2	1.79	2.30	1.50	4.6	4.6	1.37 – 7.43
Total	99.46	98.44	100.63	100.12	100.66	100.87	99.67	99.85	99.39 – 100.39
End-member components									
Schorlomite	0.50	0	0.18	0.14	0.11	0.67	0.25	0.28	0.06 – 0.80
Andradite	0	0	2.46	1.53	0	0	0	0	0 – 1.12
Mn ₃ V ₂ Si ₃ O ₁₂	1.16	0.87	2.57	1.05	0.36	1.27	0.87	1.81	0.33 – 2.45
Uvarovite	1.78	1.78	0.56	1.68	0.53	0.43	0.36	0.89	0.12 – 1.96
Pyrope	43.68	23.50	43.01	36.14	42.84	47.01	50.91	48.01	25.27 – 59.76
Spessartine	37.86	58.08	39.99	50.78	35.89	34.90	33.63	32.78	21.56 – 55.93
Grossular	4.38	7.66	11.37	6.36	12.64	13.81	4.56	4.06	3.57 – 23.28
Almandine	2.91	4.09	0.24	0	5.22	2.74	7.44	10.37	2.64 – 16.48
R.I.	1.765	n.r. ^d	1.757	n.r.	n.r.	n.r.	n.r.	n.r.	1.740 – 1.773
S.G.	3.88	n.r.	3.816	n.r.	n.r.	n.r.	n.r.	n.r.	3.75 – 3.99

^aStone 1, as described by Crowningshield (1970).

^bStones 2–8, as described by Schmetzer and Ottemann (1979), including stones from Jobbins (no. 3) and Gabelin (nos. 6 and 8).

^cThe ranges found for the 32 stones examined in this study.

^dn.d. = not detected; n.r. = not reported.

transmitted through the stone (the "body" color). Since the ColorMaster provides both daylight-approximation and incandescent lighting for the specimen, color-change stones can be described under each condition. We therefore determined coordinates for each observable color (a maximum of three for daylight-equivalent and three for incandescent illumination). The coordinates of the two key colors and the two reflected colors were determined with the stones in the normal face-up position, and those of the two transmitted-light body colors were determined by immersing the stones in glycerine to reduce reflections.

DISCUSSION OF DATA

Physical and Optical Properties. The refractive indices and specific gravities of our collection of unusual garnets cover quite broad ranges: 1.740–1.773 and 3.75–3.99, respectively. For what would at first appear to be a heterogeneous group of specimens, this variability is not surprising. However, these ranges lie within the parameters that we found previously for "pyrope-spessartine" garnets, most of which are more-or-less orange in color (Stockton and Manson, 1982). A comparison of our results with the others provided in table 1 shows agreement with the properties observed by previous researchers.

Chemical Composition. The compositions of the 32 stones that we analyzed are consistent with those reported in previous studies (see table 1). Moreover, with the exception of V_2O_3 and Cr_2O_3 content, the compositions of these 32 specimens are comparable to those of the pyrope-spessartines discussed in a prior article in our series on garnets. However, the present collection is in certain ways different from those pyrope-spessartines described earlier.

The most readily apparent chemical characteristic of these garnets is their high $V_2O_3+Cr_2O_3$ content. Although either of these components can be less than 0.1 wt.%, together they always exceed 0.2 wt.%. By comparison, other pyrope-spessartine garnets never exceed 0.2 wt.% and usually contain considerably less (commonly 0 to 0.1 wt.%). When $V_2O_3+Cr_2O_3$ content is expressed in relation to FeO content—a third chemical component that affects garnet color—this distinction becomes obvious (figure 2).

As a whole, these unusual garnets can be de-

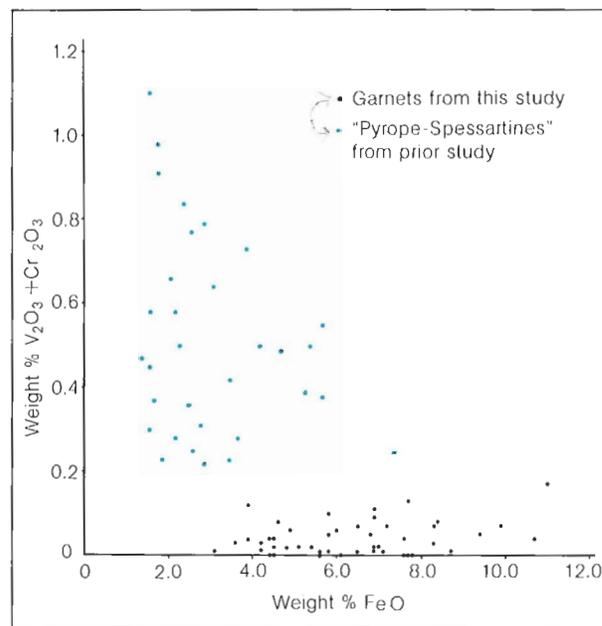


Figure 2. This plot illustrates how minor chemical components that contribute to garnet coloration distinguish the 32 garnets in this study from the orange "pyrope-spessartines" examined in an earlier paper.

scribed by the ranges of their major end-member components as follows: pyrope, 25–60 wt.%; spessartine, 20–56 wt.%; grossular, 3–23 wt.%; and almandine, 2–17 wt.% (figure 3). Specimen GIA-96A, which is notable for its greenish yellow color, also has the highest grossular content of any of the stones examined.

Absorption Spectra. The spectrophotometer indicates the presence of nine to 11 absorption bands in the visible range of these 32 garnets. Eight of these bands lie between 400 and 600 nm at the following approximate locations: 407, 421, 429, 461, 485, 503, 523, and 569 nm. All eight are present in all 32 of the stones (figure 4), although one of the bands is notably displaced in one specimen: The single greenish yellow stone cited above (GIA-96A) revealed a band at 455 nm instead of about 461 nm.

Between 600 and 700 nm, one or more of three absorption features may be resolved with the spectrophotometer. A pair of narrow bands sometimes occurs at about 672 and 688 nm, with the former being considerably weaker than the latter so that at times the 688 nm band appears alone. A third band is centered around 685 nm

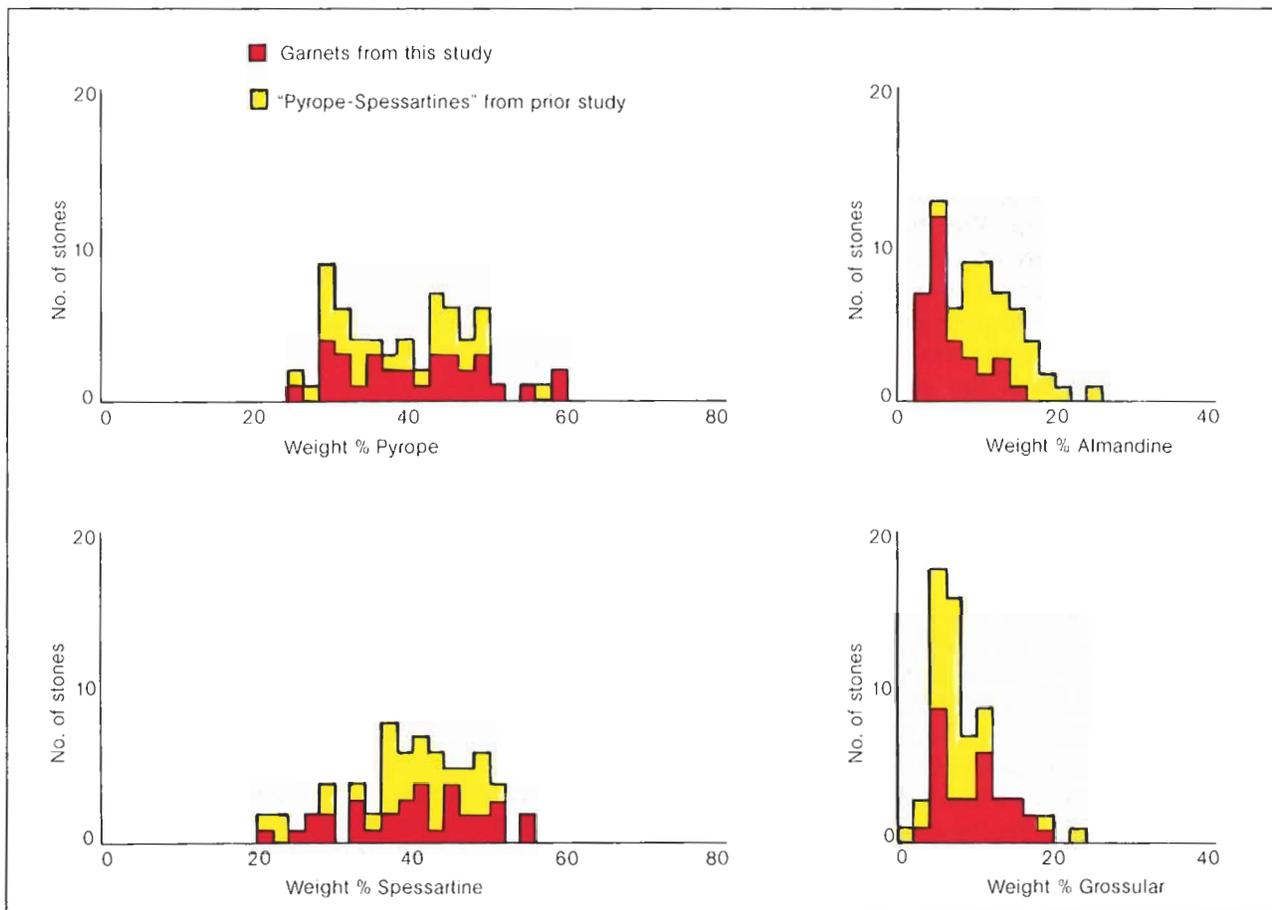


Figure 3. The distribution of major chemical components in our collection of unusual garnets can be seen in the number of stones that contain various amounts of the four principal garnet end members. For comparison, the distribution of the orange "pyrope-spessartines" has been included. Note that our present assortment generally contains more grossular and less almandine than the overall distribution contains.

and is considerably broader than the other two in the same region. When all three occur together, the narrower bands can be discerned as distinct features inside the broad absorption of the third band (figure 4).

Some of these absorption features can be observed with the hand spectroscope (figure 5). There is generally an absorption edge around 430 nm, below which all features are obscured by the strong absorption. The 461 and 569 nm bands are invariably visible. The 485 and 523 nm bands are usually observable, but the 503 nm band is less readily apparent. The 672 and 688 nm bands, especially the former, are usually too weak to be visible or are obscured by the absorption of the broad 685 nm band. Generally, there appears to be increasing absorption beyond 670 nm toward 700 nm.

Various sources have attributed absorption features in pyropes, almandines, spessartines, and

garnets of intermediate compositions to certain elements and cations (see, for example, Amthauer, 1976; Manning, 1967 and 1972; Moore and White, 1972; Schmetzer and Ottemann, 1979). A compendium of these sources and our data suggests that the following assignments can be made: The 407, 421, 429, and 485 nm bands are due to Mn^{2+} ; the 461, 503, 523, and broad 685 nm bands to Fe^{2+} ; and the 672 and 688 nm pair to Cr^{3+} . Some absorption features appear to represent indistinguishably close, overlapping bands that are related to more than one cation: The 421 nm band may also include a contribution from Cr^{3+} ; the broad, strong 569 nm band is undoubtedly a combined effect of Cr^{3+} , V^{3+} , and Fe^{2+} .

Of the features that can be resolved with a hand spectroscope, only one absorption band appears to distinguish the spectra of these garnets from those of the pyrope-almandine series (see Manson and Stockton, 1981, and the sources cited

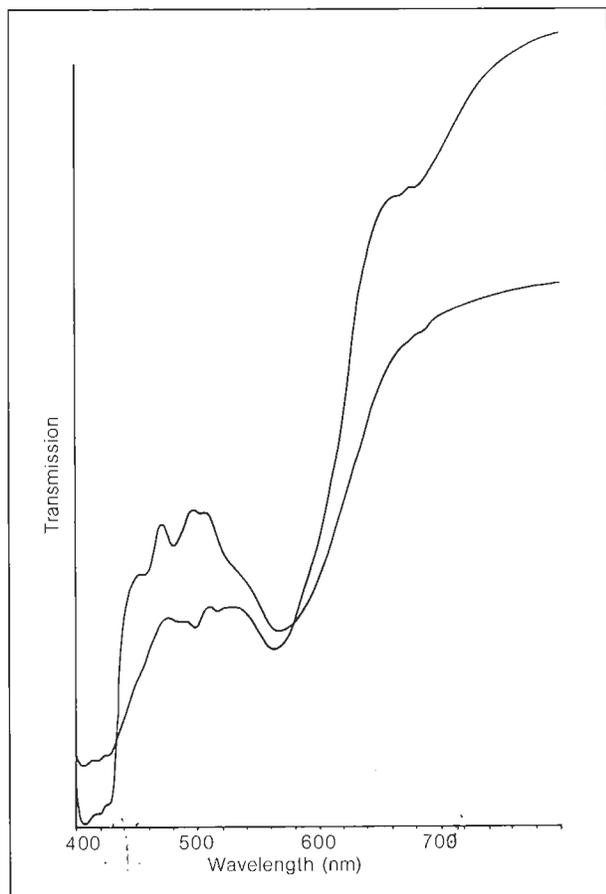


Figure 4. These two representative spectra illustrate the variability of absorption features in our collection of 32 garnets. Both have major transmission regions between 430 and 550 nm and above 580 nm. Both also display all eight absorption bands below 600 nm, although in differing strengths. Above 600 nm, both spectra show two weak bands, at about 672 and 688 nm, while one has an additional broad region of absorption beyond 700 nm.

in the paragraph above). The band at about 485 nm, which can usually be observed in our present collection of specimens as well as in orange pyrope-spessartines and spessartines (unpublished data), is absent in stones of the pyrope-almandine series (usually red-orange to red-purple in color), which instead display a band around 473 nm.

Color and Color Phenomena. The most notable feature of this collection of garnets is their unusual color appearance. None of the stones appears to display a single, easily definable color. Careful examination revealed that these stones show two distinct color phenomena. While all the stones show some change in color between incandescent and daylight or fluorescent illumination, most

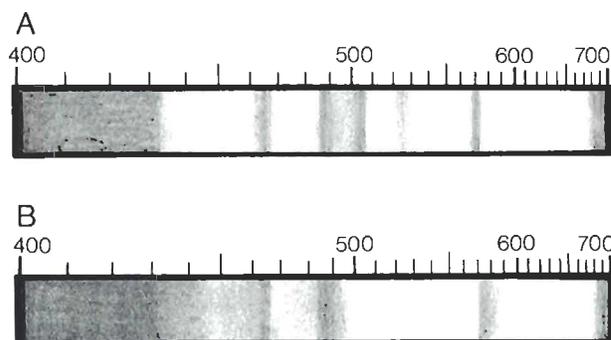


Figure 5. These spectra demonstrate the range of absorption features that can be observed with a hand spectroscope for unusual garnets such as the stones discussed in this article. Spectrum A is that of a high-pyrope-content specimen with weak color change, while spectrum B is from a high-spessartine and very high-vanadium-and-chromium stone with a strong change of color.

also display a different color when light is passed through the stone, as compared to internally reflected light from the same source. We refer to this latter phenomenon as "color shift." Both of these phenomena contribute to the overall color appearance of our specimens.

Although change of color has been well studied (e.g., White et al., 1967; Schmetzer et al., 1980) and is generally well understood, we would like to briefly summarize the concept of color change. This phenomenon occurs when a material has an absorption spectrum in which two regions of the visible spectrum are transmitted while the rest is absorbed (see figure 4). Moreover, the wavelengths and intensities transmitted must be in proportion such that the spectral differences between day (or fluorescent) light and incandescent light cause one hue to be perceived in the former case and the other hue in the latter. Let us say, for a very simplified example, that fluorescent light contains more intensity in the green wavelengths than in the red, while incandescent light has exactly the reverse relationship. If a stone that transmits only green and red is exposed to fluorescent light, the greater intensity of green in this light source in conjunction with the stone's own absorption characteristics results in a green color appearance. Conversely, the greater measure of red in incandescent light provides for perception of a red coloration.

Color shift, however, does not occur with a change in illumination but rather with the relative amounts of light (from a single source of illumination) that a viewer observes either (1) passed through or (2) internally reflected by a

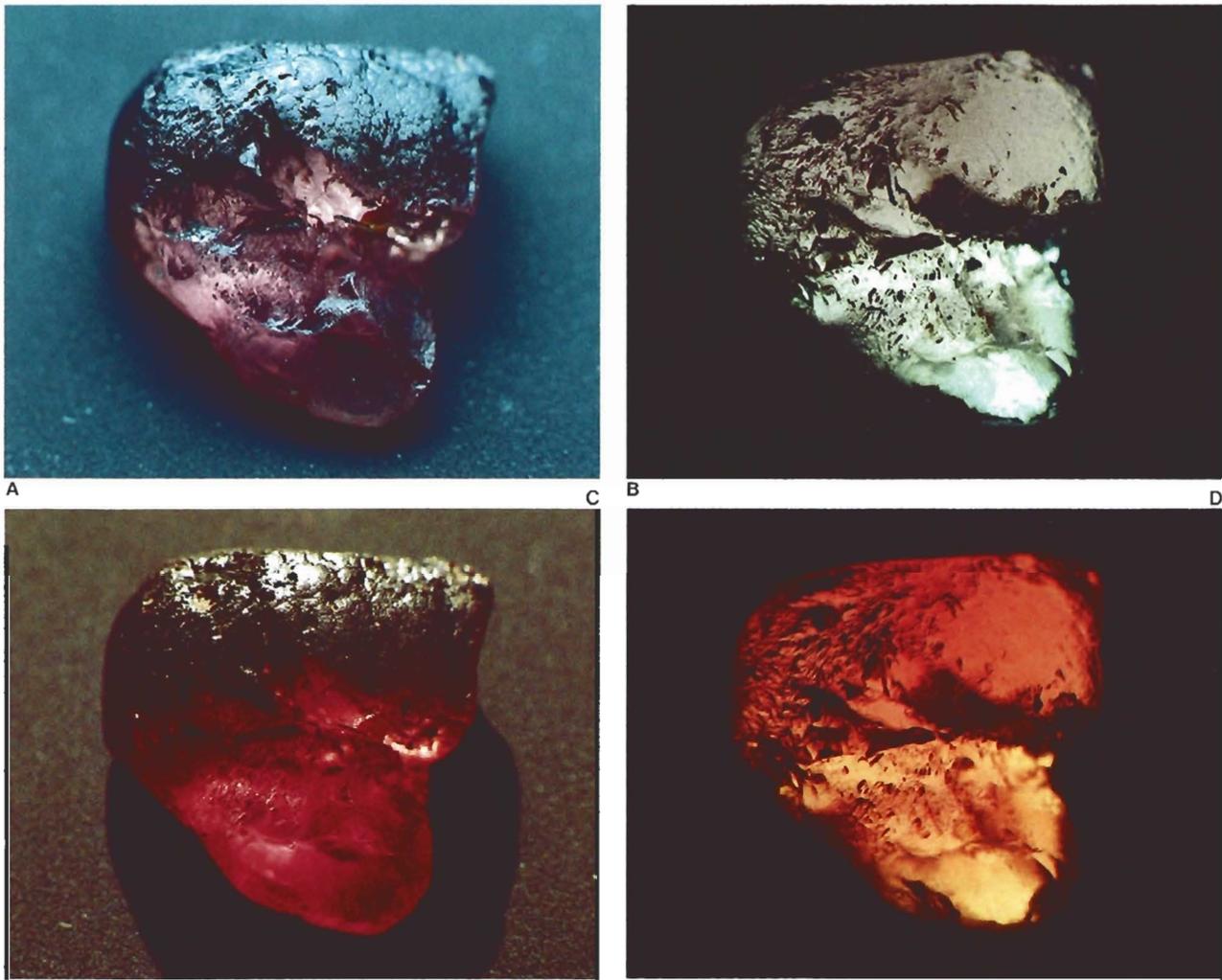


Figure 6. A garnet pebble that exhibits four different colors, one each in (A) reflected fluorescent, (B) transmitted fluorescent, (C) reflected incandescent, and (D) transmitted incandescent light. Photos by Tino Hammid.

gemstone. The former condition reveals the stone's body color; the latter requires the viewer and illuminant to be on the same side of the gem so that the internal reflections (which represent the reflected color) may be observed. As yet, we have not been able to determine the optical or physical mechanism whereby this phenomenon occurs, but it apparently requires an absorption spectrum similar, although not necessarily identical, to that which produces a change of color.

The key color for these stones, as defined by the GIA colored-stone grading system, is the representative or characteristic color that can be seen through the crown facets. For any single light source, it is influenced by the reflected color, the body color, and the cut of the stone. If a stone changes color, then it has two such key colors (one each for incandescent and day or fluorescent

light), two body colors, and one or more reflected colors. The magnitude of color change is usually greatest for body color, less for key color, and least for reflected color. In fact, a strong change in body color combined with a weak or nonexistent change in reflected color will result in only moderate change in the key color. Thus, the change-of-color phenomenon in garnets is not exactly the same as the "alexandrite effect," which has been described as the "color change of a solid from green or bluish green in daylight to red or reddish violet in artificial (incandescent) light" (Schmetzer et al., 1980). In the case of alexandrite itself, this involves a change of color due to selective absorption enhanced by pleochroism alone (White et al., 1967). For the unusual garnets in this study, however, it is due to selective absorption modified by color shift. Nonetheless, the

phenomenon in garnets fits the traditional definition for change of color, that is, "any stone that shows a difference in color from daylight to artificial (incandescent) light, caused by selective absorption" (Shipley, 1974).

The color description of our present collection was therefore more difficult than usual. Figure 6 illustrates the foregoing phenomena with an uncut stone that exhibits different reflected colors and body colors in incandescent and daylight-equivalent illumination. It should be noted that different sets of illuminants may either enhance or reduce the degrees to which these phenomena are observed in various stones. Color shift, for instance, is strongest in fluorescent light as compared to daylight and incandescent light.

CONCLUSIONS

In a previous paper (Stockton and Manson, 1982), we used the term *pyrope-spessartine* to describe orange-colored garnets that were principally made up of those two components. In every characteristic except color behavior and vanadium-plus-chromium content, the unusual garnets described in this article fit that description. Thus, they share a great number of properties with those garnets that have passed under the trade term "malaya." Aside from chemical composition, which is not a readily available or even reasonable test for the gemologist generally, the properties that best distinguish these garnets from grossulars or pyrope-almandines of similar appearance are specific gravity, color behavior, and absorption spectra. The specific gravities of the present collection of 32 garnets range from 3.75 to 3.99, while those of grossulars of any type do not extend over 3.66.

Those stones that exhibit a distinct color change can be distinguished readily from any other kind of garnet on the basis of this color behavior. The remaining stones that we examined still exhibit more change in color appearance between different illuminants than one can see in pyrope-almandines or any other gem garnets.

Absorption spectra will also separate these pyrope-spessartines from grossulars, which have no features visible in a hand spectroscope. A visible 485 nm band will separate these pyrope-spessartines from pyropes and almandines as well, since the latter two types have no band in this position. Otherwise, the spectra observed with the hand spectroscope are essentially the

same for pyrope-spessartines and pyrope-almandines.

The major chemical constituents of the unusual garnets described in this article dictate that these stones should be grouped with pyrope-spessartines (Stockton and Manson, 1982). Those that exhibit sufficiently strong color change perhaps deserve a terminology that identifies a distinct variety. Our recommendations for the gemological terminology and classification of these and all other transparent gem garnets will be presented in the next article in this series.

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GEM-QUALITY RED BERYL FROM THE WAH WAH MOUNTAINS, UTAH

By James E. Shigley and Eugene E. Foord

A detailed investigation of the gem-quality red beryl from the southern Wah Wah Mountains, Utah, has confirmed the unique mineralogical and gemological character of this material. At the Violet Claims, red beryl is found associated with minor bixbyite in a volcanic rhyolite host rock. Analytical data gathered on the red beryl indicate relatively high contents of the minor or trace elements Mn, Ti, Zn, Sn, Li, Nb, Sc, Zr, Ga, Cs, Rb, B, and Pb, which are generally low or absent in other gem beryls. Measured refractive indices (1.564–1.574), specific gravity (2.66–2.70), and unit-cell parameters ($a = 9.222 \text{ \AA}$, $c = 9.186 \text{ \AA}$) of the red beryl are distinct from most other beryls. The red beryl is thought to have crystallized along fractures, in cavities, or within the host rhyolite from a high-temperature gas or vapor phase released during the latter stages of cooling and crystallization of the rhyolite magma.

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Acknowledgments: The present owners of the Violet Claims, Rex and Ed Harris, provided specimens and information on the deposit; additional material was loaned to us by John Barlow and Allen James. John Koivula, Robert Kane, Bill Kerr, and Chuck Fryer assisted in various aspects of the project. The geological content of the manuscript was greatly improved by reviews from W. Griffiths, K. Dutweiler, and P. Modreski of the U.S. Geological Survey.

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Among the varieties of beryl used for gemstone purposes, the rarest by far is the deep-red variety from western Utah (figure 1). Red beryl was first noted in Utah early in this century (Hillebrand, 1905). However, the first crystals suitable for faceting were found only a few years ago in a single area in the Wah Wah Mountains. Except for several short articles (Barlow, 1979; Ream, 1979; Miley, 1980; Flamini et al., 1983), a detailed examination of this gem locality and the red beryl found there has not been made. In addition to its spectacular color, red beryl is unique among gem beryls in its geological occurrence and mineralogical characteristics. The present article summarizes both the geology of the best known red beryl deposit in the Wah Wah Mountains (the Violet Claims), and also the more important chemical, physical, and gemological properties of this material. Although red beryl was initially called "bixbite" by Eppler (1912), because of the confusion of this name with that of another valid mineral species (bixbyite), it has never come into general usage.

Hillebrand (1905) first described red beryl from an occurrence in the Thomas Range in Juab County (figure 2), where it is found as small, translucent (but rarely gemmy) crystals in a rhyolite host rock (see Palache, 1934). It has also been reported from several other places in Utah, one locality in the Black Range of New Mexico (Kimble and Haynes, 1980), and a little known occurrence in the state of San Luis Potosí, Mexico (R. V. Gaines, pers. comm., 1984). In the late 1950s, gemmy, transparent crystals were discovered at a new locality in the southern Wah Wah Mountains in Beaver County (again, see figure 2). These larger and better quality crystals are far superior for cutting purposes to the original, smaller material from the Thomas Range. Thus far, red beryl has not been found anywhere else in the world, and appears to be unique to western North America.



Figure 1. This faceted stone (1.15 ct) and crystal (16 mm high and 9 mm in diameter) represent the finest-quality red beryl currently being mined at the Violet Claims in the Wah Wah Mountains, Utah. Photo ©Harold and Erica Van Pelt.

While gem beryls are common in pegmatites (aquamarine, morganite) and in certain metamorphic rocks (emerald), beryls of any sort are very uncommon in rhyolites. Rhyolites are light-colored, fine-grained igneous rocks that represent the solidified products of rhyolitic magmas or ash flows. They are found in many parts of the world, including numerous areas within western North America, where they are indicative of earlier volcanic activity. Rhyolites ordinarily lack gem minerals, but sometimes contain gem topaz and garnet. The presence of gem red beryl in such rocks in western Utah suggests some unusual conditions for gemstone formation.

The Wah Wah Mountains are accessible by good paved and dirt roads from the nearby towns of Delta, Milford, and Cedar City (figure 2). Local elevations vary from 1500 to 2200 m. This high

altitude combined with the limited rainfall and semi-arid climate give the region a high-desert vegetation. Temperatures range from 80° to 100°F (25° to 40°C) in the summer to 10° to 20°F (-12° to -5°C) or lower in the winter. Access to the area is limited during the winter months. The recent article by Ream (1979) provides the best description of gem mineral collecting in the Wah Wah, Thomas, and other nearby mountain ranges in this part of the state.

GEOLOGY

Southwestern Utah lies along the eastern margin of a large geologic region known as the "Basin and Range" physiographic province, which covers Nevada and parts of the surrounding states and takes its name from the alternating mountain ranges and parallel alluvial valleys that dominate the topog-

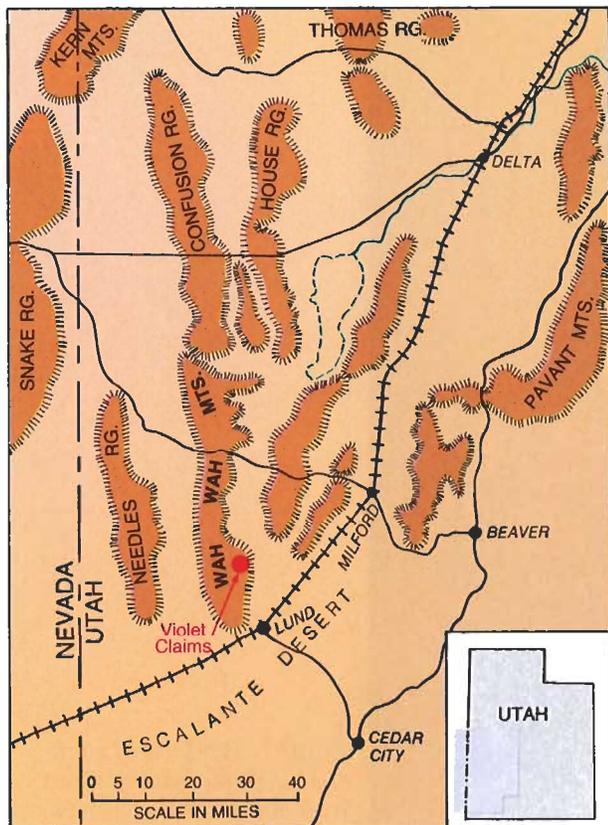


Figure 2. Index map of southwestern Utah (adapted from Miller, 1966), with the general location of the red beryl deposit at the Violet Claims indicated. The Thomas Range, site of the original red beryl discovery, lies at the top center portion of the map, while the Wah Wah Mountains are located near the left center.

raphy. On the basis of the work of various investigators (Miller, 1966; Rowley et al., 1978; Lemmon and Morris, 1979; Weaver, 1980; Christiansen, 1980; Abbott et al., 1981; Steven and Morris, 1983), the geologic history of the southern Wah Wah Mountains can be briefly summarized as follows.

In this area of southwestern Utah, shallow marine carbonate and continental sediments were deposited on crystalline basement rocks during the Paleozoic and Mesozoic eras. Subsequent mountain-building events during the Upper Cretaceous and Lower Tertiary periods produced large, low-angle thrust faults that placed carbonate-dominated sediments over Mesozoic continental rocks.

Approximately 30 million years ago, in the Middle Tertiary, explosive volcanic activity took

place over a broad area in this region. The resulting calc-alkaline volcanic rocks (andesites, dacites), which formed large calderas, lie unconformably over the remnants of the thrust-faulted sedimentary units.

In the Wah Wah Mountains, the nature of this continuing volcanic activity then changed abruptly about 23 million years ago. During this period, potassium- and silica-rich trachyandesites and rhyolites were emplaced in the form of numerous subvolcanic intrusions, small volcanic domes, or short lava flows. These rocks are locally rich in fluorine, and small deposits of uranium, beryllium, and fluorine minerals (including gem topaz and red beryl) are associated with them. Although rhyolitic volcanic activity has continued into the Quaternary, basaltic volcanism has been volumetrically more important in this area since about 15 million years ago.

The southern Wah Wah Mountains lie just within the northern edge of the Blue Ribbon lineament (Rowley et al., 1978), a prominent east-west structural zone in southern Utah and Nevada that cuts across the north-south trending mountain ranges and valleys of the Basin and Range province. This lineament is believed to be a deep crustal fault zone along which mineralizing magmas and fluids, including those that formed the beryllium-containing rhyolites that host the red beryl, were able to migrate toward the upper levels of the crust.

The red beryl occurrence is located just north of Blue Mountain, a peak that itself is situated near the intersection of the Blue Ribbon lineament and an area of extensive faulting. In this immediate area, recent geologic mapping has revealed a large subsurface elliptical dome structure of volcanic origin (Weaver, 1980), which apparently resulted from the emplacement of a body of silica-rich magma. The gem red beryl deposit occurs in rhyolite that may have vented to the surface as a lava from this magma chamber along a ring fracture system at the northern edge of the buried dome.

DESCRIPTION OF THE DEPOSIT

The red beryl deposit is collectively referred to as the Violet Claims and is located approximately 40 km (25 mi.) WSW of Milford in Beaver County. It is situated along a mountain ridge that is composed of rhyolite and other light-colored volcanic rocks and is capped by a layer of dark basalt. Along the



Figure 3. View (looking south) of the Violet Claims and the lower rhyolite occurrence that has become more exposed as a result of recent mining activity for red beryl. Blue Mountain is in the distance. Photo by Ed Harris.

ridge, the rhyolite forms a number of small, rounded hills, some of which have produced red beryl (figure 3).

The rhyolite consists of a small number (usually less than 10%, but sometimes up to 20%) of phenocrysts (2–3 mm) of sanidine, plagioclase, quartz, and minor biotite set in a fine-grained, granophyric groundmass of these minerals. The rock is massive, grossly uniform in texture and mineralogy, and varies in color from light gray to light reddish gray. Small, open (miarolitic) cavities are widespread but not abundant. Locally the rock is cut by small fractures that may be stained by oxide alteration minerals. In some portions of the rhyolite, thin, parallel flow bands or ash layers of lighter and darker pyroclastic material of differing texture occur. Some areas of the rhyolite are quite fresh, but those portions that contain the red beryl are often partly altered to clay minerals (chiefly smectites). All of these features are typical of the type of rhyolites known as “topaz-bearing” rhyolites which are found scattered in several areas of the western United States (see Burt et al., 1982; Christiansen et al., 1983). Age dating of the

rhyolites at the Violet Claims area indicates that they are 20–22 million years old or younger (Christiansen, 1980; Burt et al., 1982). The rocks are thought to have crystallized at 650°– 800°C (Christiansen, 1980). Table 1 presents chemical data for an unaltered rhyolite sample from the Violet Claims.

So far, only two prominent outcrops of rhyolite within the claims area have produced red beryl. Each outcrop differs slightly in the mode of occurrence and the nature of the red beryl. In the upper outcrop, the red beryl crystals occur along or within a few centimeters of several narrow, steeply dipping fractures or veins filled with later-formed oxide and clay minerals. In contrast, the crystals from the lower outcrop are found in small, scattered cavities, within the solid rhyolite, or in areas of fractured and altered rhyolite (figure 4). For additional details, see Ream (1979).

In contrast to the occurrence in the Thomas Range (Palache, 1934; Ream, 1979), the red beryl from the Violet Claims is not found with gem topaz, although small amounts of topaz have been collected locally. The most obvious associated

mineral is bixbyite $(\text{Mn,Fe})_2^3\text{O}_3$ in the form of rounded, irregular grains. The lack of topaz at the Violet Claims may be due to a lower fluorine content in the rhyolites of this area in comparison to those of the Thomas Range (see data in Christiansen et al., 1983), or to the conditions of mineral crystallization.

CHARACTERIZATION OF RED BERYL

With the exception of the recent study by Flamini et al. (1983), there have been no detailed descriptions of red beryl from the Violet Claims. The



Figure 4. Red beryl matrix specimen from the lower rhyolite outcrop. The crystal, approximately 1 cm in diameter, occurs in a small cavity in the rhyolite. Photo by Ed Harris.

TABLE 1. Chemical composition of a rhyolite sample from the Violet Claims, Wah Wah Mountains, Beaver County, Utah.

Major/minor elements ^a (weight percent)		Major/minor/trace elements ^b (parts per million)	
SiO ₂	70.6	Al	70,000
Al ₂ O ₃	17.2	Fe	7,000
Fe ₂ O ₃	1.01	Mg	300
MgO	< 0.10	Ca	700
CaO	0.08	Na	15,000
Na ₂ O	1.61	K	30,000
K ₂ O	4.15	Ti	150
TiO ₂	0.03	Mn	700
P ₂ O ₅	< 0.05	B	20
MnO	0.07	Ba	7
F	0.26	Be	30
Cl	< 0.01	Cu	3
Loss (900°C)	4.36	Nb	150
		Pb	70
		Sn	15
-O = F, Cl	0.11	Sr	7
Total	99.42	Y	15
		Zr	150
		Ga	70
		Li	150
		Yb	3

Looked for but not detected:
Ag, As, Au, Bi, Cd, Co, Cr, La,
Mo, Ni, Pd, Pt, Sb, Sc, Te, W, Zn, P,
Ce, Ge, Hf, In, U, V, Re, Ta,
Th, Tl

^aValues determined using X-ray fluorescence spectrophotometry by Joseph Taggart. Fluorine and chlorine were determined separately by E. Brandt and Harriet G. Neiman, all of the U.S. Geological Survey. These results are consistent with rhyolite data in Christiansen (1980), Burt et al. (1982), and Christiansen et al. (1983). According to the classification method of De la Roche et al. (1980), rocks of this composition are correctly termed rhyolites or alkali rhyolites. Loss (900°C) on ignition.

^bValues determined using semiquantitative six-step spectrographic analysis by Nancy M. Conklin of the U.S. Geological Survey. The following trace elements are unusual in rhyolites: Mn, Be, Nb, Pb, Zr, and Li.

following section summarizes the results of our investigation (see box).

Morphology. Red beryl occurs as euhedral crystals that display typical beryl morphology. Some of the crystals are well formed, transparent, and gemmy (figure 5), but most are less well formed and are translucent to opaque as a result of numerous fractures and inclusions. An elongate, prismatic crystal habit is more common than a shortened, tabular shape. Some crystals have an unequal development of prism faces. Pinacoid terminations may be slightly concave in shape, show a slight growth spiral, be capped by a second crystal in parallel arrangement, or exhibit other interesting growth-related surface characteristics (see Flamini et al., 1983). In contrast, prism faces typically lack these features and display no striations, but may exhibit a slight outward bulge to give the crystal a somewhat barrel-shaped appearance. No distinctive etch figures or other corrosion features frequently seen on other types of beryl crystals are apparent, although some red beryls have partially frosted surfaces. Twinned crystals have not been found, but multiple crystal groups are sometimes encountered. Individual crystals may be as much as 2.5 cm long and 1 cm wide, but they average about 1 cm × 0.5 cm. Doubly terminated crystals are relatively common, but most crystals show an

**SUMMARY OF MINERALOGICAL
DATA ON RED BERYL
FROM THE VIOLET CLAIMS**

Morphology: euhedral, prismatic crystals to several centimeters in maximum size (average about 1 cm); crystal forms—{0001} basal pinacoid and {10 $\bar{1}$ 0} 1st order prism (common), {11 $\bar{2}$ 1} and {11 $\bar{2}$ 2} 2nd order dipyramids (moderately common), {11 $\bar{2}$ 0} 2nd order prism (rare), {10 $\bar{1}$ 1} 1st order dipyramid (very rare); some crystals doubly terminated; some multiple crystal groups

Chemistry: distinct from other beryls in terms of relatively high contents of Mn, Ti, Zn, Sn, Cs, Li, Rb, B, Pb, Nb, Sc, Zr, and Ga

Physical properties: transparent to translucent or opaque, conchoidal fracture, vitreous luster, S.G. 2.66–2.70 (heavy liquid and hydrostatic methods), indistinct 0001 cleavage, brittle, some color zoning

Unit-cell parameters: measured for core and rim portions of a color-zoned crystal from Debye-Scherrer powder diffraction films with a silicon metal internal standard

core— $a = 9.229(1)$ Å, $c = 9.212(1)$ Å
rim— $a = 9.234(1)$ Å, $c = 9.204(3)$ Å

Optical properties:

Refractive indices— $\epsilon = 1.564$ – 1.569 , $\omega = 1.568$ – 1.572 (Duplex II refractometer)
 $\epsilon = 1.567$ – 1.568 , $\omega = 1.574$ (grains in R.I. liquids)

Color—light to medium dark in tone; very slightly grayish to strong in saturation; orange-red to purplish red in hue (GIA colored stone grading system)

Birefringence—usually 0.006 to 0.008; sometimes as low as 0.004

Pleochroism— $\epsilon =$ purplish red, $\omega =$ orange-red to red

Optical sign—uniaxial negative

U.V. fluorescence: inert to LW and SW

Color filter: inert reaction

Spectrum: absorption bands at 425, 480, 530, 560, and 810 nm depending on crystal orientation (see figure 9); with a hand spectroscope, bands at 430 (weak) and 490–510, 560–580 (strong) are usually visible

Microscope observations: numerous healed and unhealed fractures; some color zoning and banding; symmetric growth banding and other growth features; several types of inclusions—two-phase, colorless quartz, black bixbyite, minute unidentified inclusions; some iron oxide staining (see figures 10–13)

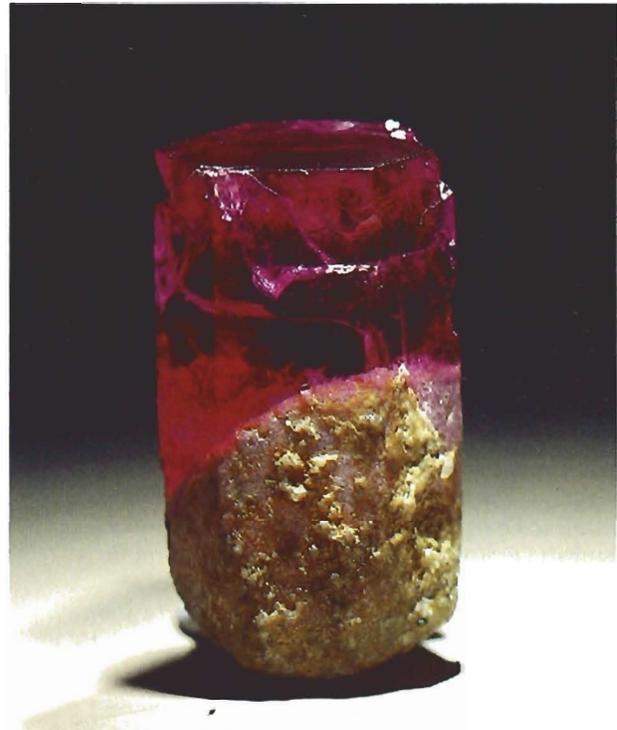


Figure 5. The finest gem-quality red beryl crystal (12 × 22 mm, about 30 ct) yet recovered from the Violet Claims. Photo by Michael Havstad.

apparent point of attachment to the rhyolite. Crystals are commonly fractured both perpendicular and parallel to their c-axis; however fractures parallel to the c-axis are often confined to the central core of the crystal, leaving a cleaner, gemmy exterior.

Bixbyite is not only the major associated miarolitic-cavity mineral in the deposit, but it also forms prominent inclusions in some red beryl crystals. A single grain of bixbyite sometimes occurs at the center or central edge of a doubly terminated crystal or, in the case of a crystal with a single termination, near the center of the point of attachment of the crystal to its host rock (figure 6). This positioning suggests to us that the bixbyite may have acted as a "seed" on which subsequent crystallization of the red beryl took place.

Physical and Optical Properties. The beryl crystals range in color from orange-red to purplish red (most commonly the latter) with medium tones and moderate saturation levels. Although most of the purplish red crystals appear to be uniform in color, a number exhibit a distinct color zonation.



Figure 6. The broken point of attachment of a small red beryl crystal showing three included bixbyite grains symmetrically arranged around the central axis of the crystal. In most crystals with bixbyite inclusions, only one bixbyite grain is present near the center or edge of the crystal. In such instances, the included grain(s) of bixbyite may have acted as the sites from which crystallization of the red beryl was initiated. Photo by Ed Harris.

This zoning is evident as a brownish orange-red core surrounded by a purplish red rim; in some instances, a crystal will exhibit a more complex, concentric color zoning (figure 7). If such a crystal

is sliced parallel to the c-axis, however, the width of this orange-red inner zone is seen to taper from one end of the crystal to the other, creating a light-colored central area shaped like an inverted triangle (figure 8). In a few instances, however, we observed doubly terminated crystals in which the color zoning was more fully developed, creating an "hourglass" appearance with the light-colored central zones decreasing in width from both ends toward the middle (see also Flamini et al., 1983). The light-colored triangular areas generally do not meet at the center of the crystal, but rather are separated by a narrow horizontal zone of dark red color. In addition, a bixbyite inclusion, if present, is often located close to the corners of these two triangular areas near the center of the crystal. No other type of internal color zonation was noted. These marked color differences reflect important changes in chemical composition during crystal growth. They can be correlated with variations in other physical properties such as refractive index. They also affect the faceting of red beryl to give the best color appearance.

Depending on the inclusions and fractures in the individual crystals, the degree of transparency varies. Red beryl has a vitreous luster that is uniform over all crystal faces and broken surfaces. No chatoyancy or asterism was noted. There is no obvious cleavage, but, as mentioned earlier, frac-

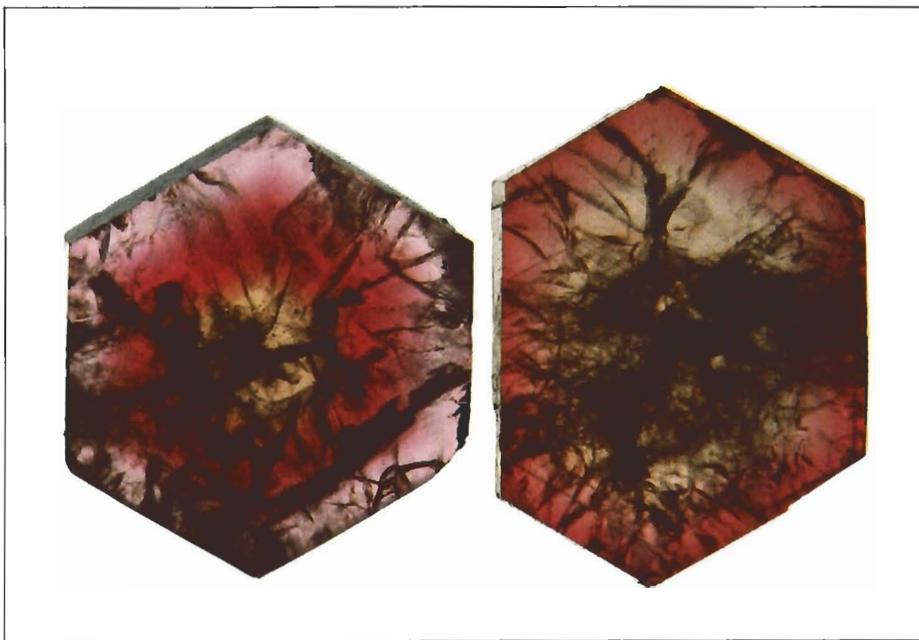


Figure 7. Sections cut perpendicular to the c-axis through two red beryl crystals that show concentric color zoning. The crystal on the left has an orange-red core and a purplish red rim. The one on the right has several zones. Both crystals are about 0.5 cm in diameter. Transmitted light, magnified 10x. Photo by John Koivula.



Figure 8. A section cut parallel to the *c*-axis through a red beryl crystal. Here the width of the light-colored, triangular, central zone decreases from the upper end of the crystal to the bottom (where an included bixbyite grain would most likely be located if it were present). The crystal is about 0.5 cm long. Transmitted light, partial shadowing, magnified 15 \times . Photo by John Koivula.

tures are common. In many instances, the fractures have a pattern that appears to be related to the color zoning described earlier; that is, the fractures are often located along the boundaries between color zones, or are restricted to the light-colored inner portions of crystals (see figures 7 and 8). When broken, the material exhibits conchoidal or uneven fracture.

The measured specific gravity of 2.66–2.70 for red beryl is within the lower range of values reported for beryl (Deer et al., 1962, cite 2.66–2.83; while Sinkankas, 1981, gives 2.63–2.91). Our measurements are consistent with the data given by Nassau and Wood (1968), Miley (1980), and Flamini et al. (1983). The crystals display no fluorescence when exposed to long-wave (366.0 nm) or short-wave (253.7 nm) ultraviolet radiation.

Red beryl is optically uniaxial negative with

refractive indices that are among the lowest values known for beryls. Deer et al. (1962) list indices of $\epsilon = 1.565\text{--}1.590$ and $\omega = 1.569\text{--}1.598$, with a birefringence range of 0.004–0.008, for the beryl group as a whole (also see Arem, 1977; Sinkankas, 1981). Our refractometer measurements on crystals and cut stones of uniform coloration were $\epsilon = 1.564\text{--}1.569$, $\omega = 1.568\text{--}1.572$ and a birefringence of about 0.007. For color-zoned crystals, the following values were obtained by the "Becke line" method: for the light-colored material in the central core of the crystal, $\epsilon = 1.567$, $\omega = 1.574$, and for the dark-colored material from a crystal rim, $\epsilon = 1.568$, $\omega = 1.574$. These indices agree with those for red beryl reported by Nassau and Wood (1968), Schmetzer et al. (1974 a and b), Miley (1980), Bank and Bank (1982), and Flamini et al. (1983). The crystals we examined have a pronounced pleochroism, with $\epsilon =$ purplish red and $\omega =$ orange-red to red.

Figure 9 illustrates absorption spectra for one of our crystals. The ϵ spectrum has absorption bands at 560 and 425 nm, while the ω spectrum has bands at 810, 530, 480, and 425 nm. Nassau and Wood (1968) and Schmetzer et al. (1974b) published similar spectral curves.

Chemical and X-Ray Data. Table 2 presents chemical analyses of a representative red beryl sample from the Violet Claims that are consistent with the results obtained by Flamini et al. (1983). The composition of these crystals is unique among beryls. In terms of minor elements, red beryl is relatively rich in Mn, Ti, Zn, Sn, and Li, and low in Na and Mg, as compared to other beryls (Sinkankas, 1981). Whereas most beryls contain some water—Sinkankas (1981) reported beryl analyses with water contents up to 4 wt.%—the red beryls are noted for their virtual absence of water (Nassau and Wood, 1968). Our analysis of one red beryl sample gave a value of only 0.36 wt.% water.

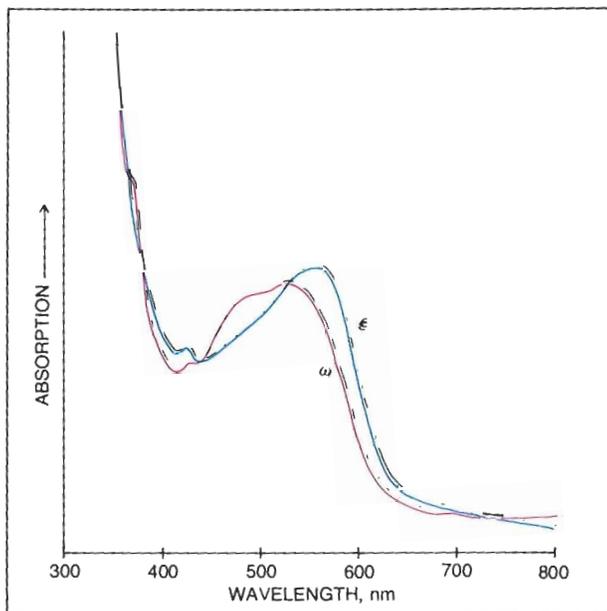
As noted by Staatz et al. (1965), the trace-element content of these crystals is also very distinctive among beryls. In addition to the minor elements mentioned above, the Wah Wah red beryl contains significant amounts of B, Nb, Pb, Sc, Cs, Zr, Ga, and Rb—most of which (excluding Cs and Rb) are generally absent in beryls from other geological environments. The similar suite of trace elements in both the red beryl and the host rhyolite (compare tables 1 and 2) illustrates how

the composition of the red beryl reflects that of the volcanic rhyolite.

Another interesting feature is the marked difference in chemistry within the color-zoned crystals described earlier. Proceeding from the rim to the core of such a crystal, we found that there is an increase in Al, K, Zn, and Na, but a decrease in Ti, Si, Fe, Mn, Sn, and Cs. These changes are most pronounced at the core-rim boundary where the marked change in color occurs; they reflect compositional variations as the beryl crystal grew, and can be related to differences in physical properties noted earlier.

There is an additional distinctive aspect of red beryl chemistry. As noted by Nassau and Wood (1968), the content of the common alkali elements (K, Na, Li) in red beryl is very low in comparison to other beryls. This is consistent with its low specific gravity and refractive indices (Palache, 1934; Sinkankas, 1981). Thus, graphical relationships

Figure 9. Polarized visible-light absorption spectra for red beryl. Absorption bands occur at 425 and 560 nm in the ϵ spectrum, and at 425, 480, 530, and 810 nm in the ω spectrum. Transmission of light by the crystal takes place in the red portion of the spectrum and to a lesser extent in the violet, but in the yellow-blue-green region there is general absorption. Spectra were obtained with a Pye-Unicam PU8800 UV-VIS spectrophotometer using a 10-nm bandwidth. Path lengths through the samples were approximately 2 mm.



which allow one to estimate the alkali content of a beryl from its refractive indices (see Černý and Hawthorne, 1976) do not apply to red beryl.

X-ray powder diffraction films (114 mm Debye-Scherrer camera) were prepared for both core and rim samples of a color-zoned crystal as well as for a crystal of uniform color. Least-squares computer refinement of the resulting data yielded the following unit-cell dimensions: for the core material— $a = 9.229(1)$ Å, $c = 9.212(1)$ Å; for the rim material— $a = 9.234(1)$ Å, $c = 9.204(3)$ Å. Additional data for an unzoned crystal gave $a = 9.222(2)$ Å, $c = 9.186(4)$ Å. Similar findings were reported by Nassau and Wood (1968) for a Thomas Range red beryl. These values are slightly larger than the unit-cell dimensions of many other beryls

TABLE 2. Chemical composition of a color-zoned red beryl crystal from the Violet Claims, Wah Wah Mountains, Beaver County, Utah.

Major/minor elements ^a (weight percent)		Major/minor/trace elements ^b (parts per million)		
	Rim	Core		
SiO ₂	66.8	66.1	Ti	150
Al ₂ O ₃	17.6	18.3	Fe	15,000
TiO ₂	0.4	0.0	Mn	2,000
K ₂ O	0.1	0.2	Zn	700
FeO	1.8	1.5	Sn	150
MnO	0.3	0.1	Cs	2,000
ZnO	0.08	0.2	Na	300
SnO ₂	0.02	0.0	Mg	700
Cs ₂ O	0.25	0.12	Ca	50
Na ₂ O	0.03	0.1	B	70
MgO	0.1	0.1	Ba	7
H ₂ O	0.36	0.36	Cr	1.5
			Cu	7
			Nb	30
	87.84	87.08	Pb	100
BeO	12.16	12.92	Sc	70
			Zr	70
Total	100.00	100.00	Ga	70
			Rb	500
			Li	150

Looked for but not detected:
Ag, As, Au, Bi, Cd, Co, Mo, Ni,
Sb, Sr, Te, U, V, W, Ge, Hf, In, Re,
Ta, Th, Tl, La, Ce, Y, P, Pd, Pt

^aMicroprobe analyses by E. Foord. ARL EMX-SM instrument, operating voltage 15kV; natural beryl used as a standard for Na and Cs, pure elements or synthetic oxides used as standards for remaining constituents. Water determined using a microcoulometric technique by E. Brandt and Harriet G. Neiman of the U.S. Geological Survey. BeO content calculated by difference. Data refinement carried out using the MAGIC-IV computer program of Colby (1968). Microprobe results substantiated by analyses of other crystals by Carol Stockton. Red beryl crystals that are uniform in color have compositions similar to the one for the rim of the crystal listed here.

^bValues determined using semiquantitative six-step emission spectrographic analysis by Nancy M. Conklin of the U.S. Geological Survey.



Figure 10. Various types of "fingerprint" inclusions and partly healed fractures originating from a central portion of a red beryl crystal. Dark-field and oblique illumination, magnified 20 \times . Photo by Robert Kane.

(Sinkankas, 1981). Available data are insufficient to establish a correlation between the differences in minor- and trace-element chemistry and unit-cell parameters of the core and rim areas of a crystal, although such a relationship probably exists.

Inclusions. Several types of inclusions are present in red beryl. Some are typical of inclusions in gem beryls, while others seem unique to red beryl and its particular environment of formation. Healed fractures—in the form of "fingerprints"—as well as unhealed fractures are quite common, especially along the central portions of the crystals or along color-zone boundaries (figure 10). Two-phase inclusions of unknown identity are frequently observed along flat planes (figure 11), and groups of the smaller two-phase inclusions often form flat or curved "fingerprint" patterns. Also observed in several red beryl crystals were well-formed "comet-tail" inclusions that trail behind the edges of the fingerprint-like patterns (figure 12). These are probably a result of directional growth disturbances caused by the inclusions that they trail behind. Distinct color zoning and growth features are also frequently seen in red beryl (figure 13). Finally, various solid inclusions are present—in particular quartz and bixbyite.

The identification of red beryl should present little difficulty for the jeweler. Other common red gem materials (ruby, spinel, garnet, tourmaline, zircon) have basic gemological properties that differ sufficiently from those of red beryl. The R.I.,

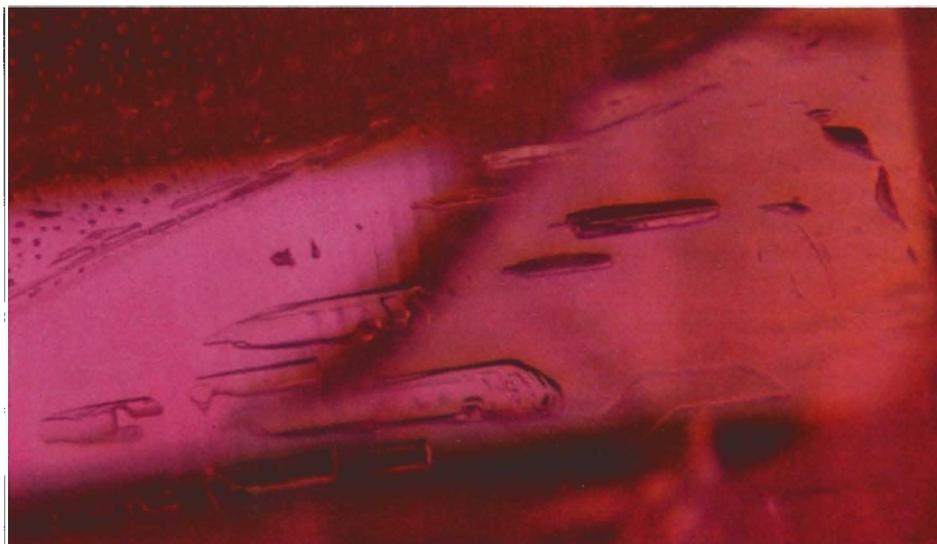


Figure 11. Distinctly formed two-phase inclusions oriented in several different planes in red beryl. Dark-field and oblique illumination, magnified 35 \times . Photo by Robert Kane.

Figure 12. This faceted stone is host to dense concentrations of minute, white particles forming "comet tail" inclusions which are seen trailing behind "fingerprint" inclusions. Dark-field and oblique illumination, magnified 25 \times . Photo by Robert Kane.



S.G., color, and absorption spectrum of red beryl are quite diagnostic.

FACETING RED BERYL

As with the faceting of other gem beryls, the orientation of the cut stone relative to the c-axis of the crystal has a great influence on both the color and durability of red beryl. Stones cut with their table parallel to this axis are more purplish red in hue, but they may show some color gradation across the table as a result of the "hourglass" color zoning. This orientation is used for crystals that have a highly fractured inner zone but are more transparent around the outer rim. In contrast, stones cut with the table perpendicular to the c-axis display a more uniform orange-red hue. This is the preferred orientation for the best overall color. In either case, the color of the stone is improved if it is cut with the culet located near the center portion of the crystal. During faceting, stones may fracture in either cutting orientation because of the growth characteristics of the original crystals. It is also important to note that the red color of these crystals does not seem to be affected by heating to temperatures of several hundred degrees centigrade for an extended period.

PRODUCTION

While only a limited number of red beryl crystals recovered from the Violet Claims have been suitable for cutting, those that have been faceted exhibit a spectacular color (figure 14). From the initial discovery of the deposit in the late 1950s until the property was acquired by the present owners in

the mid 1970s, mining activity (mainly for mineral specimens) was sporadic. Recent mining for gem material has been carried out entirely on the surface by several individuals using earth-moving equipment and some blasting. For the most part, gem crystal recovery involves breaking up promising pieces of rhyolite one at a time in the search for red beryl. The current mining operation generates a sufficient number of crystals to produce 80–100 faceted stones per year, a level that is likely to continue for the foreseeable future. Cut stones are generally less than 0.5 ct, with an average of 0.15 ct. However, stones weighing several carats have occasionally been cut. Most of the red beryl crys-

Figure 13. Well-formed angular growth features reflect the original growth and hexagonal crystal symmetry of the red beryl. Dark-field and oblique illumination, magnified 30 \times . Photo by Robert Kane.

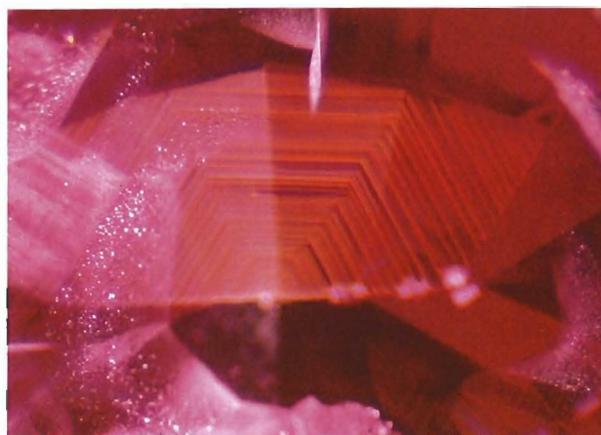




Figure 14. Faceted red beryl has appeared in a variety of jewelry forms, such as this necklace set with a 0.52-ct red beryl and the ring, with a 0.54-ct red beryl as the center stone. Jewelry courtesy of Rex and Ed Harris. Photo © 1984 Harold & Erica Van Pelt.

tals produced at the Violet Claims find a ready market as mineral specimens.

DISCUSSION

Red beryl possesses the same desirable gemological characteristics of beauty, hardness, and durability as do the more common gem beryls emerald and aquamarine. Its most conspicuous feature is the intense red color. The absorption spectra of beryls have been investigated in some detail (Wood and Nassau, 1968; Schmetzer et al., 1974 a and b; Sinkankas, 1981). As with certain other gem minerals, the coloration of red beryl is primarily due to trace elements incorporated within the beryl crystal structure. In the case of red beryl from the Thomas Range, Nassau and Wood (1968) concluded that manganese is the principal coloring

agent. Iron and titanium do not seem to play a significant role. They related the spectrum of red beryl to that of pink morganite, whose paler color is also attributed to this same element (Wood and Nassau, 1968). Differences in the intensity of color between red beryl and morganite could be due to a higher level of manganese in the former (by two or three orders of magnitude), or to differences in the valence state of this element. However, slight variations among the spectra of these and other pink or reddish manganese-colored compounds prevented Nassau and Wood from fully explaining the observed spectral features of red beryl. On the basis of the similar spectra and chemistry, it appears that the same cause of color exists for red beryl from the Wah Wah Mountains. According to G. Rossman (pers. comm., 1983), more recent studies

of absorption spectra of red beryl have substantiated the general conclusions of Nassau and Wood (1968), although specific details still require further investigation. These studies suggest that manganese in the 3+ valence state is the cause of the deep red color.

Many of the characteristic features of the red beryl result from its formation within a rhyolite host rock under conditions of low pressure and high temperature in a volcanic environment. The similar trace-element chemistry of both the rhyolite and red beryl substantiate their common origin (see tables 1 and 2). Red beryl occurs in "topaz-bearing" rhyolites, a class of silica-rich volcanic rocks that are geochemically distinct in terms of the presence of topaz and the high content of fluorine and certain other elements. At present the petrogenesis of this type of volcanic igneous rock, and the crystallization of the gemstones found therein, seems reasonably well understood (see Bikun et al., 1980; Burt et al., 1982; Christiansen et al., 1983) and can be summarized as follows.

Topaz rhyolites are derived from magmas that originate in the lower portions of the earth's crust. Certain areas of the crust, such as in the Basin and Range province, have been involved in large-scale regional crustal extension and thinning, and are marked by high heat flow, seismic activity, extensive faulting, and volcanism. Under these conditions, some lower crustal rocks undergo partial melting, which produces rhyolitic magmas preferentially enriched in silica and other constituents relative to the original rock. One of the most important of these is fluorine, which experimental studies have shown to have a pronounced effect on the properties and crystallization of magmas (Bailey, 1977). With time, these rhyolitic magmas rise to the upper levels of the crust, where they are emplaced as shallow, subsurface domes, or they erupt at the surface to form lavas or pyroclastic ash flows. On the surface, the magma crystallizes under conditions of low pressure, high temperature (about 800°C or less), low water content, but relatively high fluorine content. Such conditions favor the release of a gas or vapor phase from the rhyolite magma during its cooling and crystallization. If the appropriate elements are present, minerals such as gem topaz, garnet, and red beryl can crystallize from this gas phase in miarolitic cavities, along fractures, or within the rhyolite itself.

The composition of this gas phase is likely to

differ somewhat from that of the rhyolite magma as a consequence of the preferential enrichment of each element in either the magma or the gas. This segregation of elements would have an important influence on the composition of the red beryl. In particular, the marked difference in beryllium content between the red beryl and the host rhyolite suggests that this element was concentrated in the gas. The same can presumably be said for certain other elements in the red beryl, such as cesium, rubidium, scandium, and tin. In contrast, the low content of the alkali elements sodium and potassium in the red beryl as compared to the rhyolite may suggest that these were retained in the magma.

CONCLUSIONS

Red beryl is now—and is likely to remain—the rarest of all gem beryls. Its occurrence in rhyolite in the Wah Wah, Thomas, and possibly other mountain ranges in western Utah represents a geologic setting that differs from that of all other gem beryls, and so far appears to be unique in the world. Material from the Violet Claims provides both spectacular gemstones and mineral specimens. The red beryl crystallized from a gas or vapor phase given off by a rhyolitic magma as it was cooling after having been erupted from volcanic centers. Crystallization under these conditions and from this type of host rock resulted in the unusual chemistry of red beryl, which in turn provided for the distinctive color as well as other physical and optical properties. Red beryl is currently being mined at the Violet Claims in the Wah Wah Mountains, and the likelihood of continued limited production is good.

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4TH ANNUAL GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

The Winter issue marks the end of the 1984 *Gems & Gemology* volume year. Once again, we are asking you, our subscribers, to participate in the 4th Annual Most Valuable Article Award. We count on you to give our authors the recognition they deserve for the time and effort invested in their articles. We also need to hear your feelings about *Gems & Gemology*—we value your opinion and want the journal to continue to reflect your needs and interests.

Your ballot is located on the insert card inside this issue. Please choose three articles from 1984 and mark them in order of numerical preference: (1) first, (2)

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After voting, detach the postcard ballot and drop it in the mail (postage is prepaid if mailed in the U.S.). Ballots must be received by March 15, 1985 to be included in the final tally.

The winning articles will be announced in the Spring 1985 issue of *Gems & Gemology*. Cash awards of \$500, \$300, and \$100, respectively, will be given to the authors of the articles that place first, second, and third in the balloting.

NOTES · AND · NEW TECHNIQUES

AN EXTRAORDINARY CALCITE GEMSTONE

By C. S. Hurlbut, Jr. and Carl A. Francis

A 1,156-ct calcite gemstone cut from a twin crystal presents an unusual phenomenon when the interior is viewed through the table. One observes a multitude of colored images of the lower pavilion facets that change position and color with change in the viewing angle. This kaleidoscopic effect results in part from dispersion and the high birefringence of calcite, but the large number of facet images is caused by the twinning. As a single light ray enters the table, it is broken into two rays, O and E. On crossing the twin plane, each of these rays is divided into O and E rays, resulting in four rays that are reflected across the pavilion to be reflected toward the table. On this upward path, the rays again cross the twin plane and once more are divided into new O and E rays. Thus a single entering light ray emerges as four O and four E rays.

Several varieties of calcite are used for ornamental purposes but, because of its low hardness and easy cleavage (it has three perfect cleavage directions), calcite is rarely cut into faceted stones. The gemstone described here is an exception. Not only is it an unusually large faceted calcite (1,156 ct, 75 mm long × 44 mm wide × 48 mm high), but a most remarkable feature is seen when the interior of the stone is viewed through the table (figure 1). Considering the strong birefringence of calcite (0.172), one would expect a pronounced doubling of the back facets. In this stone, however, a multitude of colored images of the back facets also appear, changing color and position in a kaleidoscopic manner as the viewing angle is shifted slightly.

CRYSTALLOGRAPHIC POSITIONING OF THE FACETS

This gem was loaned by Professor Sidney Ross of Troy, New York, to the Harvard Mineralogical Museum for exhibition and study. It was faceted by Mr. Arthur Grant of Hannibal, New York, from flawless, optical-quality calcite from the Faraday Mine, Faraday Township, Hastings Co., Ontario, Canada. Specifically, the gemstone was cut from a twin crystal composed of two individuals twinned on the negative rhombohedron {01 $\bar{1}$ 2}. In the following discussion, these individuals will be designated as crystal 1 and crystal 2. In this type of twinning, two of the three cleavages are common to both individuals; the third cleavage directions of crystals 1 and 2 make an angle 143° with each other (figure 2). This stone has been cut so that its length is parallel to the direction of intersection of these third cleavages. Since this direction is parallel to the twin plane, the twin plane is also parallel to the length. Although the twin plane divides the stone into two roughly equal parts, the table lies in only one individual and makes an angle with the twin plane of approximately 67° (see figure 3). This

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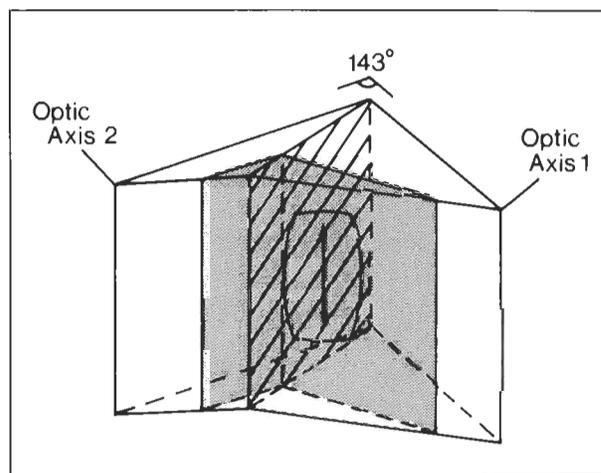
Figure 1. The Ross calcite displaying the kaleidoscopic effect. The gem is 75 mm × 44 mm × 48 mm and weighs 1,156 cts. Photo © 1984 Tino Hammid.

orientation of the table with respect to the twin plane is responsible for the intriguing kaleidoscopic appearance of the faceted stone.

The pavilion facets are arranged in six courses parallel to the girdle. The facets of the top row make angles of about 75° with the table, those of the bottom row about 37°. Light entering through the table is reflected from the upper three rows of pavilion facets to the opposite side of the pavilion, striking facets there at angles less than the critical angle, and then passes out of the stone. However, light striking the lower three rows is reflected across the stone to strike opposing facets at angles greater than the critical angle and is totally reflected upward through the crown facets.

This movement of light is essentially the same as in any properly proportioned gemstone but only partially explains the unusual feature of this particular stone. To understand the observed phenomenon, a review of some of the principles of crystal optics that apply to calcite may be helpful.

Figure 2. Drawing of calcite twinned on $\{01\bar{1}2\}$ and bounded by cleavage surfaces. The ruled area is the twin plane. The stippled area shows the position of the plane of the table with the outline of the table superimposed. The double arrow indicates the direction of the length of the stone.



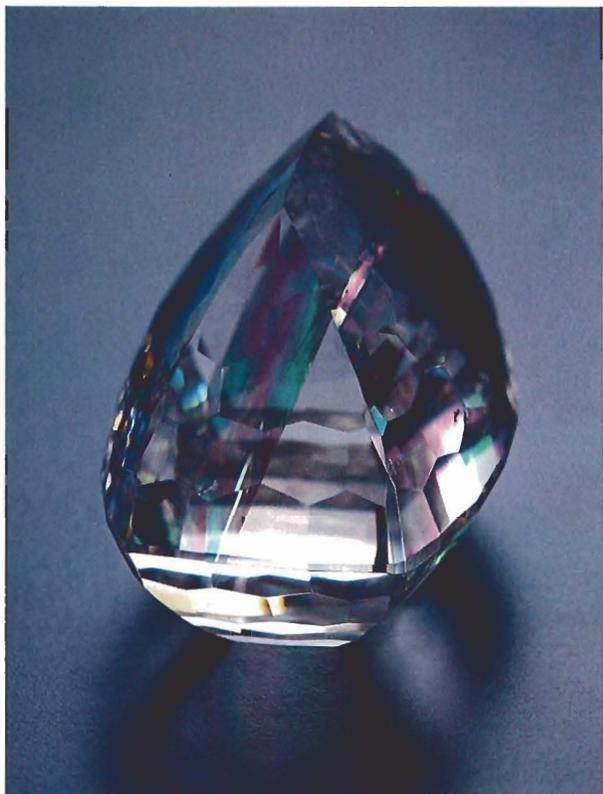


Figure 3. The twin plane that almost bisects the Ross calcite is clearly evident in this photo. Note how the table lies entirely in one individual. Photo © 1984 Tino Hammid.

CRYSTAL OPTICS OF CALCITE

A beam of light entering calcite (or any uniaxial crystal) is broken into two polarized rays, the ordinary (O) ray and the extraordinary (E) ray, which vibrate at right angles to both the direction of movement and to each other. The O ray vibrates at right angles to the optic axis and the E ray in the principal section, that is, in a plane that includes the optic axis. Except when light moves parallel to the optic axis, the two rays, traveling at different velocities, follow different paths. The familiar illustration of the double image of a dot viewed through a calcite cleavage piece shows the divergence of the two rays (Hurlbut and Switzer, 1979). The doubling of back facets also illustrates the divergence: one image is produced by the O ray, the other by the E ray. (See Bloss, 1961, p. 73, or Wahlstrom, 1969, p. 220, for a more complete discussion of the crystal optics of calcite.)

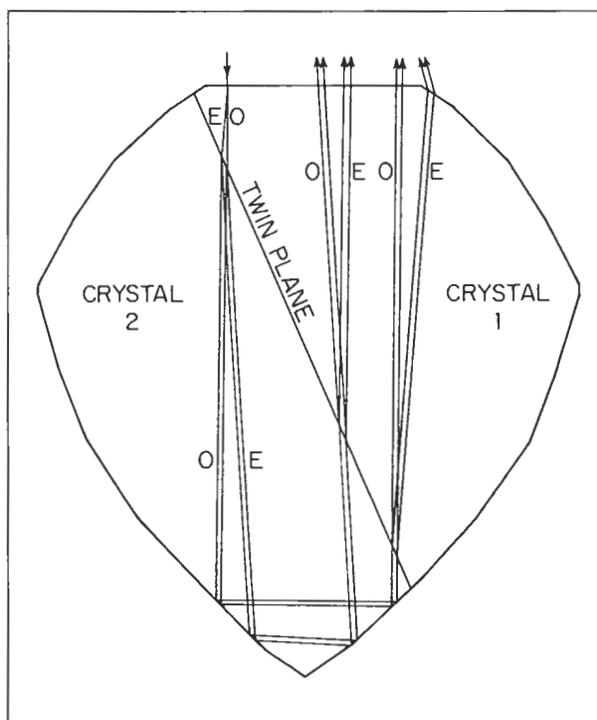
The plane in which the optic axes of the two

twin individuals lie is at right angles to the twin plane and in this gemstone makes a low angle with the table. The optic axis of crystal 1 (the individual containing the table) makes an angle of 20° with the table. Knowing this angle, the divergence of the two rays resulting from light entering perpendicular to the table was calculated to be 4° .

THE EFFECT OF TWINNING

Figure 4, a cross section of the Ross calcite at right angles to its length, shows schematically the manner in which light entering as a single ray at right angles to the table passes through the stone. The resulting diverging rays move into the stone only a short distance before they encounter the twin plane. As they pass through the twin plane, the rays are constrained to vibrate in conformity with the optical orientation of crystal 2; that is, as O rays vibrating perpendicular to its optic axis and as E rays vibrating at right angles to the O rays in

Figure 4. Cross section of the Ross calcite gemstone at right angles to the twin plane and the table. The lines crossing the figure show the manner in which a single light ray, entering perpendicular to the table, is divided and subdivided into O and E rays as it passes through the stone.



the principal section. Thus the O ray and E ray of crystal 1 each breaks into an O and E ray of crystal 2 (again, see figure 4). This results in four separate rays that pass to the lower pavilion facets to be reflected across the stone. On striking the opposing facets, at angles greater than the critical angle, the rays are totally reflected upward toward the table. But before they reach the table, the reflected light rays must again pass through the twin plane. As in the first crossing of the twin plane, each separate O and E ray is broken into O and E rays with vibration directions conforming to the optical orientation of crystal 1. Thus the light that entered the table as a single ray emerges from the stone as four O rays and four E rays.

In order to trace the passage of light, we have considered a single entering ray. But of course, when the table is bathed in light, beams of parallel rays enter the stone from all directions. Each set of parallel rays is divided in the same manner as the single ray described above, and each subdivision carries with it the images of the first facets from which it is reflected. The result is a multiplicity of overlapping facet images—and the distinctive kaleidoscopic appearance.

DISPERSION

Yet an additional factor contributes much to the charm of this stone: dispersion. In calcite, the dispersion of the refractive index of the O ray is 0.024 and of the R.I. of the E ray, 0.012. Although these values are low compared to the dispersion of diamond (0.444), they are significant, particularly in a large gemstone. Not only is a beam of white light entering the stone broken into O and E rays, but each of these rays is also composed of all wavelengths of the visible spectrum and every wavelength (color) takes a slightly different path through the stone. Because of this, the images of the facets are colored. With a slight change in the line of sight or a degree or two rotation of the stone, a facet image changes color.

Because facet images overlap and overlies one another, only rarely does an entire facet present a pure spectral color. In most instances, the color that reaches the eye is a combination of colors coming from two or more superimposed images. Some of these colored images leave the stone with vibration directions of the O ray, others as the E ray. By viewing the interior of the stone through a polarizing filter and then rotating the filter (less

than 90°), one will find a position that eliminates completely some of the facet images; a 90° rotation of the filter from this position will eliminate others. In one position all the overlying images emerge as the O ray, in the other they emerge as the E ray. However, some facets, or portions of facets, are visible in all positions of the filter, which demonstrates that the image and its color are a combination of O and E rays. When one ray is eliminated by the filter, the color resulting from the other is seen. Each of these colors is purer and deeper than the composite color.

CONCLUDING THOUGHTS

The phenomenon observed in this gemstone is probably unique to calcite, because no other mineral found in large gem-quality crystals has the same high birefringence, clarity, and twinning. Calcite is almost commonly twinned on $\{01\bar{1}2\}$, as in the gemstone described. Although such instances are rare, calcite may be twinned on another negative rhombohedron, $\{02\bar{2}1\}$, and on the positive rhombohedron $\{10\bar{1}1\}$ (the cleavage rhombohedron). A gemstone cut from either of these twins, with proper regard to positioning the table with respect to the twin planes, would also show the same effect. Calcite is also commonly twinned on the base, $\{0001\}$, but because in this case the two individuals have parallel optic axes, the vibration direction of a light ray would not be changed on passing from one individual to the other. Thus, gemstones cut from this twin would not display the optical effect described here.

We congratulate Mr. Grant for his skillful and imaginative cutting of this gem. The Ross calcite is no longer unique. Several smaller gems displaying the kaleidoscopic effect have since been cut by Mr. Grant and by Mr. Michael Gray of Midpines, California, including a 70-ct stone on exhibit at the Los Angeles County Museum of Natural History, Los Angeles, California.

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GREEN OPAL FROM EAST AFRICA

By John I. Koivula and C. W. Fryer

Bright green, nickeliferous, gem-quality opal from Tanzania, East Africa, is described and its gemological properties are given. Chemical analyses and structural data are provided as well.

Chrysoprase, the nickel-bearing green variety of chalcedony, has been used as a gem material for centuries. However, nickel-colored green opal (called prase opal), from Poland and Tanzania (Webster, 1975; Schmetzer et al., 1976) and from Australia and Peru (R. Crowningshield, pers. comm., 1984), has been only briefly mentioned in the literature. Therefore, we were pleased to receive several pieces of nickeliferous opal for gemological study and experimentation. This Tanzanian opal is virtually the same color as chrysoprase. Like chrysoprase, the opal samples tested by the authors have a diaphaneity ranging from very translucent (figure 1) to semitranslucent. In addition, both gem materials are commonly associated with an earthy brown limonite matrix in the rough (figure 2). In light of this strong potential for mistaken identity, we conducted a thorough examination of this unusual opal. The standard gemological properties of this material, as well as the results of chemical and X-ray analysis, are described below.

GEMOLOGICAL PROPERTIES

Several gemological tests were conducted to determine the properties of this material, especially as they compare to chrysoprase (table 1).

Refractive Index. A small piece was sliced from the main mass and an optical flat was polished on one side. Using the GIA utility lamp with monochromatic light and a Rayner DIALDEX refractometer, we determined the refractive index to be 1.452.

Specific Gravity. The same 3.06-ct piece used to determine the refractive index was used to measure the specific gravity. Using a Voland doublepan balance equipped for hydrostatic testing, we determined the specific gravity to be 2.125.

Ultraviolet Radiation. When exposed to ultraviolet radiation, the whitish areas in and on the opal

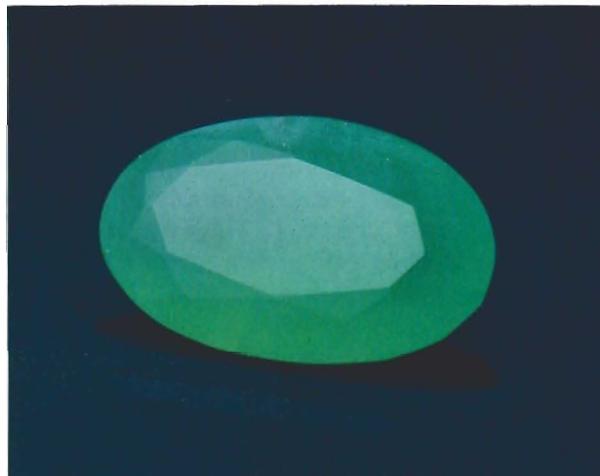


Figure 1. A faceted green opal from Tanzania (1.78 ct). Photo by Tino Hammid. Stone courtesy of Andreas Becker of Friedrich August Becker, Idar-Oberstein, Federal Republic of Germany.

all glowed bluish white, while the main mass of green opal and the brown limonite matrix were inert. With short-wave ultraviolet radiation, the reaction was strong to moderate; with long-wave U.V., a moderate to weak fluorescence was noted.

Spectroscopic Analysis. Using a Beck prism spectroscope, we observed a general absorption in the red from 660.0 nm upward, and a cut-off in the blue from 470.0 nm downward. Depending on the thickness of the material, the absorption areas increase as the thickness increases. Chrysoprase has essentially the same spectrum, which also depends on the thickness of the material tested.

ABOUT THE AUTHORS

Mr. Fryer is chief gemologist, and Mr. Koivula is senior gemologist, in the Applied Gemology Department at the Gemological Institute of America, Santa Monica, California.

Acknowledgments: The authors would like to thank Julius Petsch and Dr. Peter C. Keller for supplying the opals used in this study. Dr. George Rossman, of the California Institute of Technology, performed the chemical analysis. William Kerr prepared the opal section for optical testing.

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Figure 2. A close-up of the opal and limonite matrix interface. Oblique illumination, magnified 25 \times .

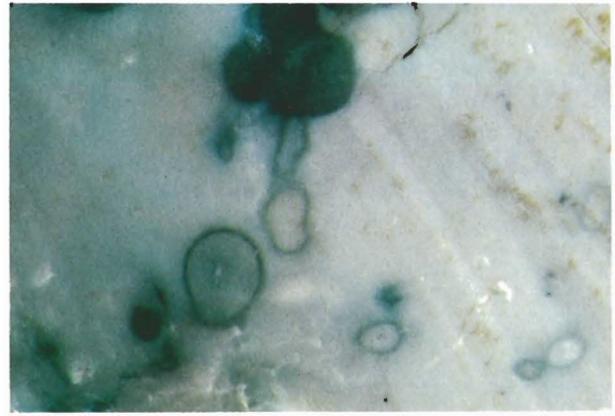


Figure 3. Thin chalky white coating, also of opal CT, on the surface of one of the rough opals. The green spots are areas where tiny cavities in the opal break or almost break the surface. Oblique illumination, magnified 30 \times .

Microscopic Observation. With magnification, numerous white irregularly shaped spots were visible in the opal. Where these spots occurred on the surface, as in figure 3, it became evident that they were in fact tiny cavities or vugs, lined with small spheroids of botryoidal opal (figure 4).

CHEMICAL AND X-RAY ANALYSIS

A rough sample of the opal was sent to Dr. George Rossman for chemical analysis. Aside from silicon, the only significant element present in the analysis was nickel, the same element responsible for the coloring of chrysoprase.

An X-ray powder diffraction pattern was made at room temperature in a Debye-Scherrer camera using a copper target tube at 48 kV and 18 mA for 4.8 hours. The test revealed a cristobalite structure with stacking disorders attributed to tridymite. This agrees with an opal CT (cristobalite-tridymite) classification as proposed by Jones and Segnit (1971).

CONCLUSION

This interesting green opal bears a very strong resemblance to top-quality chrysoprase and can easily be confused with it on sight. However, a refractive index reading will easily separate the two. The



Figure 4. The interior of one of the numerous cavities in the opal decorated with a botryoidal lining. Transmitted and oblique illumination, magnified 50 \times .

general availability of this material is not known, but several carvings up to five or six inches (12–15 cm) in height have been seen at recent gem shows. The classification of this opal derived by the authors agrees with earlier results published on similar opals (Schmetzer et al., 1976).

TABLE 1. A comparison of the gemological properties of chrysoprase chalcedony and Tanzanian green opal.

	Refractive index	Specific gravity	U.V. reaction
Green opal	1.452	2.125	inert
Chrysoprase chalcedony	1.535	2.620	inert

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DIAMOND, Unusual Inclusion

A gemologist from Victoria, British Columbia, brought to our attention a very unusual loose diamond crystal inclusion in a 0.02-ct single-cut diamond. As figure 1 indicates, the crystal sometimes may be seen to project from the face of the stone, with the stone oriented differently, however, the crystal falls below the surface. The inclusion is quite irregular in shape. It apparently was attached at one time in its cavity, since one end is polished, indicating that it once lay in the same plane as the crown facet.

C.F.

EMERALDS, Natural and Imitation

Submitted to the Los Angeles laboratory for identification was a segmented, reversible necklace typical of the style commonly manufactured

Figure 1. Profile of a 0.02-ct single-cut diamond, with a diamond crystal protruding from one of the crown facets. Magnified 9×.

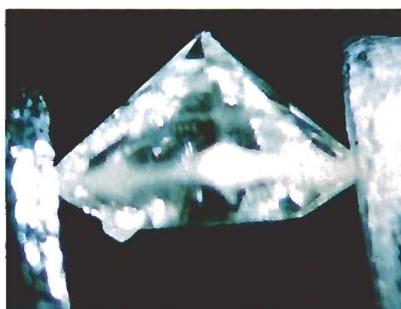


Figure 2. Enamel floral motif on one side of an emerald-and-simulated emerald necklace.

in India. One side of the necklace was enameled with a floral motif (figure 2). The other side (figure 3) was bezel set with 17 transparent green carved heart-shaped cabochons (the largest measuring approximately 20.6 × 21.8 mm) and numerous small, transparent, near-colorless, rose-cut stones. Suspended from the main necklace were 36 transparent green drilled oval beads. Subsequent testing revealed that the beads were natural emeralds. However, the carved heart-shaped cabochons showed a refractive index spot reading of 1.54, slight doubling, and a number of large two-phase hexagonal negative crystals. When viewed with dark-field and fiber-optic illumination, the heart-shaped cabochons were determined to actually be colorless, but

with a green backing. The heart-shaped cabochons were thus identified as rock crystal quartz, with the color due to a green backing. Because of the closed-back mounting, the nature of the backing could not be determined. The large center stone, in particular, in figure 3 shows a partial separation between the colorless quartz and the green backing; note especially the deeper color toward the bottom of this stone where the backing is still attached. This type of emerald substitute was commonly used many years ago.

R.K.

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

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Figure 3. Carved, simulated emeralds on the other side of the necklace shown in figure 2. The large stone at the bottom illustrates well how light the carved rock crystal is in those areas of the stone where it has separated from the backing material, compared to the deep green area at the bottom of the stone where the backing is still attached.

OPAL, Oolitic vs. Sugar-Treated

We recently examined a polished opaque slab of opal exhibiting a patchy play of color. Because the entire surface was peppered with tiny black spots, sugar-treated opal was immediately suspected. Examination with the microscope, however, revealed the structure of oolitic opal (figure 4), a rare form of natural opal that shows an unusual dark, circular, spotted appearance under magnification. When oolitic opal is observed without magnification, it closely resembles and can be easily mistaken for the much more common sugar-treated opal. For comparison purposes, a sugar-treated opal is shown in figure 5. This is the first oolitic opal encountered since 1982 [*Gems & Gemology*, Summer 1982, p. 104].

John Koivula

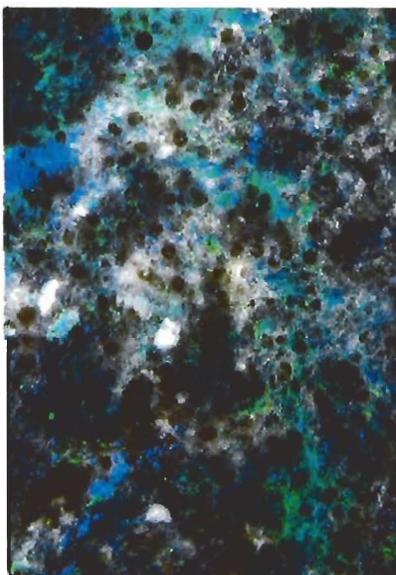
PEARLS

Dyed Cultured Pearls

The Los Angeles laboratory received for identification a strand of 7.4-mm

bluish black pearls that had been represented to be Tahitian black pearls. The X-radiograph revealed the internal structure that identified them as

Figure 4. Circular black spots identify oolitic structure in opal. Magnified 20x.



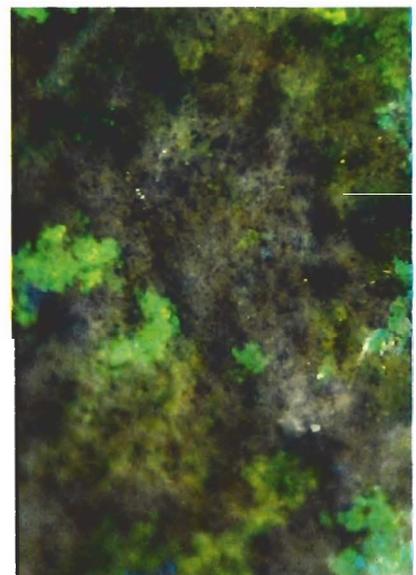
cultured pearls. When we exposed the beads to ultraviolet radiation, we noticed a chalky white fluorescence that was stronger to short-wave than to long-wave. Natural-color black pearls fluoresce reddish to long-wave ultraviolet radiation. Most of the pearls appeared to be fairly even in color, but in a few the color was concentrated around the drill hole, with distinct colored veins originating from this area spreading around the pearls in a peculiar fashion (figure 6). A cotton swab that had been dipped in a 2% nitric acid solution picked up some bluish color from areas inside the drill hole, proving that these pearls had been dyed to simulate the appearance of black pearls. Apparently, dye had been introduced to these drill holes and spread inside the pearls, creating the web-like pattern.

K.H.

First American Freshwater Cultured Pearls from Tennessee

Both the New York and Los Angeles laboratories had the opportunity to

Figure 5. While to the naked eye this sugar-treated opal closely resembles its natural oolitic counterpart, with 45x magnification as shown here the separation is easily made.



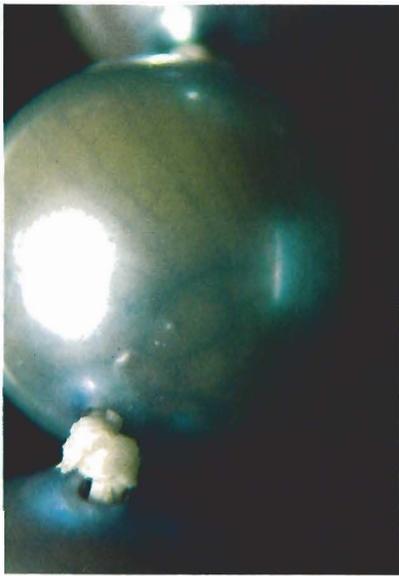


Figure 6. Dye is evident around the drill holes of these 7.4-mm cultured pearls. Note also the web-like veins emanating from the dye area in the center pearl.

examine a lot of 11 pearls sent by an American firm in Camden, Tennessee. According to the owner, this lot represented samples of the first freshwater pearls that had been successfully cultivated in Tennessee over a period of some years (see the article on freshwater pearl cultivation in the Fall 1984 issue of *Gems & Gemology*). These pearls have been produced in a variety of shapes, sizes, and colors (figure 10, p. 138, Fall 1984 issue of *Gems & Gemology*). The group included five small (approximately 4.5 mm in diameter) almost round pearls and five larger pearls that were more oval in shape; all of these pearls were primarily white, although some showed a very slight rosé overtone. The largest pearl in this group (measuring approximately 12 × 9 × 4 mm), although oval in shape, was quite flat on one side. A similar, smaller pearl had the extremely high luster that is sometimes seen in natural freshwater pearls. This same pearl also showed a very unusual purple fluorescence to X-rays that we noticed, though less pronounced, in the smaller (4.8 mm)

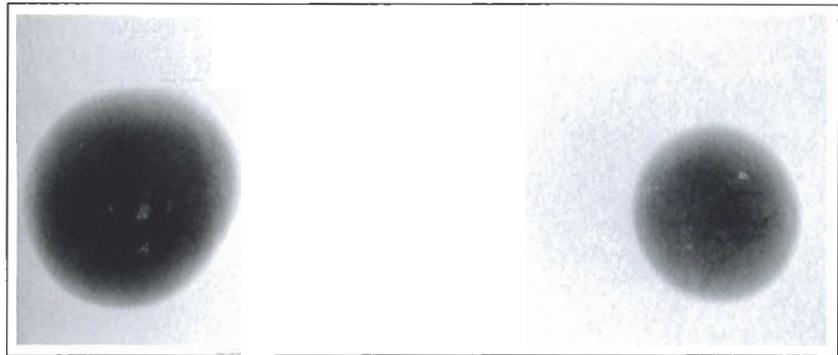


Figure 7. This X-radiograph shows two of the American freshwater cultured pearls examined in the New York and Los Angeles laboratories. The irregular nucleus characteristic of mantle-tissue nucleation is prominent in the pearl on the left and less obvious, though clearly visible on film, in the one on the right.

pronounced, in the smaller (4.8 mm) round brownish pink pearl as well. All the other pearls fluoresced very strong yellowish white to X-rays, indicating freshwater origin. The X-radiographs of all the pearls showed the typical irregular voids that prove mantle tissue nucleation (see figure 7).

Pseudo Star QUARTZ

Most gemstones that exhibit asterism owe the star effect to tubular or needle-like inclusions that are oriented in the correct crystallographic directions so that when the stone is cut *en cabochon*, reflected or transmitted light will reveal a star

C.F.

Figure 8. The star-like pattern in this 27-ct "strawberry" quartz cabochon is caused by modified goethite needles.



pattern. However, the Los Angeles laboratory recently identified a 27-ct reddish brown oval quartz cabochon that displayed a star effect that was not due to true asterism, but to a dark growth formation (figure 8). Microscopic examination of the cabochon showed that the quartz was densely crowded with long reddish brown needles of goethite that caused not only the color, but also the star. These prismatic needles were oriented along the directions of the three horizontal crystallographic axes and met at the junctions between the major and minor rhombohedral faces of the host quartz. Some, but not all, of the needles displayed a morphological change from acicular goethite to the flat, plate-like form known as lepidocrocite (figure 9). This denser accumulation of inclusions causes the rhombohedral junctions to appear dark reddish brown in color, and, when the material is properly cut and viewed parallel to the c-axis, gives the appearance of the six dark intersecting rays of a star. A similar effect is seen in some trapiche emeralds where carbona-

Figure 9. Goethite needles partially altered to lepidocrocite in the "strawberry" quartz cabochon shown in figure 8. Magnified 45x.

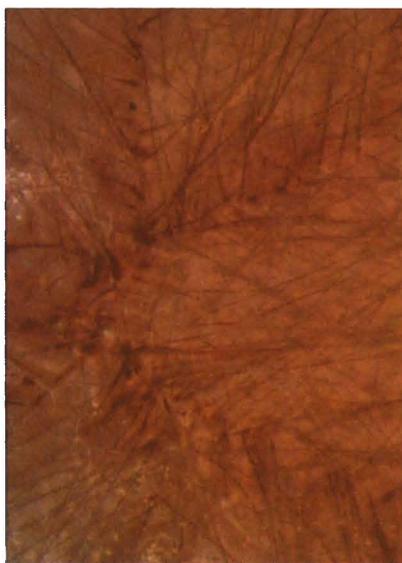


Figure 10. Unidentified red coating in the drill hole of a 4-mm corundum bead. Magnified 15x.

ceous inclusions collect along the horizontal axes. In the trade, this type of material has been referred to as "strawberry" quartz. It was first discovered in Sonora, Mexico, about 15 years ago. *K.H.*

RUBY SIMULANTS

Color-Enhanced Corundum Bead

A small (4 mm in diameter) natural corundum bead recently examined in the GIA Applied Gemology Department probably owes most of its purplish pink body color to the red substance that was found to be lining the drill hole (figure 10). In the past, we have frequently seen near-colorless corundum beads take on a pinkish cast when they were strung on a red cord, but this is one of the few times we have encountered a color-coated drill hole. Of course, it is impossible to judge the true colors of such items without removing the coating in the drill hole.

John Koivula

Spinel and Synthetic Ruby Doublet

Figure 11 illustrates an attractive cluster ring that came into the New

York lab for identification. The ring was set with an impressive number of diamonds and what appeared to be a large (approximately 20 ct) ruby. Unfortunately, the "ruby" turned out to be an assembled stone consisting of a colorless synthetic spinel top cemented to a Verneuil synthetic ruby back. Figure 12 shows the bubbles in the rather poor cement plane as well as the curved striae in the synthetic ruby pavilion. This is the first time we have seen such a combination of materials in an assembled stone, and we cannot understand the reasoning behind it. *R.C.*

SAPPHIRE, More Colors of Heat-Treated Stones

Heat treatment is commonly known to produce blue and shades of yellow to orange-brown sapphires from milky lighter colored sapphires and to enhance rubies by minimizing their blue component. Recently, however, the New York lab encountered heat-treated stones in colors they have not seen previously. The strain discs evident in the beautiful 4-ct red-purple sapphire shown in figure 13 suggest



Figure 11. Ring set with diamonds and an approximately 20-ct synthetic spinel and synthetic ruby doublet.

that the stone owes its color, at least in part, to heat treatment. But the zones of chalky fluorescence that appeared when the stone was exposed to short-wave ultraviolet radiation are proof positive that the stone has been heat treated.

Figure 14 shows a 9-ct oval pinkish orange sapphire that the owner believed to be the best padparadscha he had ever seen. When exposed to short-wave ultraviolet radiation, however, it too revealed the zones of chalky fluorescence characteristic of heat treatment. We subsequently learned that heat treatment can cause some sapphires to turn a pinkish orange, presumably if the stone contains enough chromium in addition to iron to give the necessary balance. It is possible that the refinement of heating techniques with sophisticated ovens will begin to produce an abundance of sapphires of this color, which heretofore have been so rare as to be virtually unavailable. If this comes to pass, it will be interesting to see if these stones get the same reception from the trade as the bulk of blue heat-treated sapphires have received. R.C.

SPINEL, Color Change

Among a selection of gemstones reportedly from Burma that were recently submitted to the Los Angeles laboratory for identification was a very attractive pinkish purple oval



Figure 12. Bubbles in the cement plane, and curved striae in the synthetic ruby pavilion, of the doublet shown in figure 11. Magnified 15x.

mixed-cut stone that weighed 7.23 ct. Subsequent testing revealed that the stone was a natural spinel exhibiting a color change from pinkish

Figure 14. Pinkish orange color of a heat-treated 9-ct sapphire. Magnified 10x.

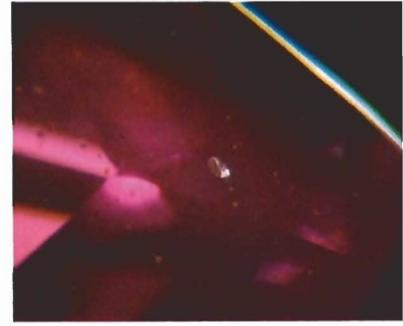


Figure 13. Strain discs strongly suggest that this sapphire has been heat treated. Magnified 63x.

purple when viewed with fluorescent illumination (figure 15) to purplish pink under incandescent lighting (see figure 16).

A single refractive index reading of 1.716 was obtained with a monochromatic light source equivalent to sodium vapor. When viewed with the microscope, this stone provided an interesting display of inclusions: short, thin intersecting needles; relatively large euhedral crystals of various habits; fingerprints; and healed fractures. Figure 17 shows the absorption curve as recorded with a Pye



Figure 15. This 7.23-ct spinel shows pinkish purple in day or fluorescent light.



Figure 16. Under incandescent light, the color-change spinel shown in figure 15 turns purplish pink.

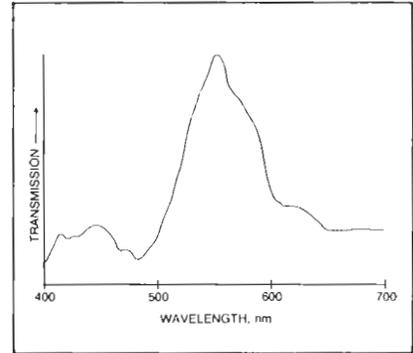


Figure 17. Absorption curve of the color-change spinel.

Unicam PU 8800 UV-VIS spectrophotometer. When exposed to long-wave ultraviolet radiation, this attractive color-change spinel exhibited a moderate chalky yellowish green fluorescence, an unusual and

unexpected reaction. It was inert to short-wave ultraviolet radiation.

R.K.

Treated TOURMALINE

Routine microscopic examination of

a brownish gray oval cat's-eye tourmaline showed that the larger growth tubes running parallel to the c-axis had been filled and sealed by a foreign substance. Some of these filled tubes, as shown in figure 18, were easily spotted because they contained two or more gas bubbles in the same channel. The odor from a carefully applied hot point indicated that the filling material was probably a plastic. Such voids are usually filled to prevent the detritus caused by the cutting process from entering them. Shellac is normally used for this purpose, because it can be easily removed with alcohol after the cutting and polishing process is finished. Because of the relatively large size of the tubes, plastic may have been used in this instance to achieve a more permanent seal.

John Koivula

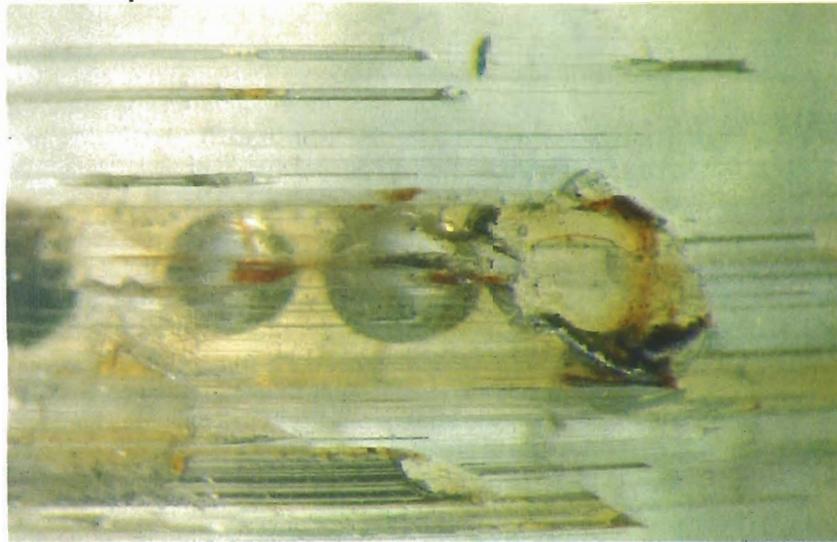


Figure 18. Gas bubbles indicate that the large growth tubes in this tourmaline had been filled. Magnified 25x.

PHOTO CREDITS

Ricardo Cardenas took figures 11, 12, 13, and 14. John Koivula photographed figures 4, 5, 9, 10, and 18. A. de Goutière furnished figure 1. Shane McClure provided figures 2, 3, 6, 8, and 15. Tino Hamid supplied figure 16. Karin Hurwit contributed figure 7, and Jim Shigley provided figure 17.

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COLORED STONES AND ORGANIC MATERIALS

Aquamarine and beryls of other colours from Nigeria. H. Bank, *Goldschmiede Zeitung*, Vol. 82, No. 6, 1984, p. 103.

Large quantities of various colored beryls are emerging from a deposit in Nigeria. Many kilos of beryl have come from this source for some time; however, the precise location is unknown. The material is reportedly near-colorless, pale to dark blue, yellow, or green, is poor in quality, and is more suited for cabbing than for faceting. All of the colors seem to turn a rich dark blue when

heated. The refractive indices (approximately 1.574–6 to 1.568–9) and birefringence (.006–.007) of the material are somewhat low. The reason for this is unknown and will require further investigation. Despite the generally low quality of the material, Nigeria appears to be becoming an important producer of beryl.

Mary Hanns

The gem collection of the National Museums of Canada.

W. Wright, *Canadian Gemmologist*, Vol. 5, No. 1, 1984, pp. 2–14.

This short article reviews the history of the acquisition of Canada's National Gem Collection, which is maintained by the Mineral Sciences Division of the National Museum of Natural Sciences in Ottawa. The collection numbers 1,500 specimens, "many of which are fine, rare gemstones." The majority of the article consists of a partial catalogue of these stones, including name and locality, cut, carat weight, color, and the date the stone was acquired. SAT

Korite®—a unique organic gem. G. Brown, *Australian Gemmologist*, Vol. 15, No. 6, 1984, pp. 206–208.

Korite® is the registered name for an organic gem material derived from the iridescent nacre of an extinct, fossilized marine mollusk, the ammonite. This material, which is found in southern Alberta, Canada, was

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discovered in 1908. However, it did not have real commercial potential until 1970, when a deposit of apparently stable shell was discovered.

Prospecting is complicated, requiring surface topography, stratigraphy, experience—and luck. Mining is costly, and only about 1% of the total fossil recovery is gem-quality material. Approximately 95% of this material is used in assembled stones, with the remaining 5% used as solid cabochons.

The spectral colors displayed are produced by diffraction at thin, regularly spaced layers of aragonite, with red, orange, and green predominating. Most of the material has been cracked and rehealed by coarse-grained, noniridescent, brownish aragonite that gives the material its characteristic stained-glass-window appearance. Korite® has a refractive index of 1.52–1.67 (unlike that of most fossilized shell, which is calcite, 1.486–1.658) and a specific gravity of 2.70–2.85. Four photomicrographs accompany the article. RCK

Kunzite. M. W. Mills, *Lapidary Journal*, Vol. 38, No. 4, 1984, pp. 546–552.

Kunzite, a lithium aluminum silicate, is a transparent gem variety of spodumene. It ranges in color from pale pink to reddish purple to purplish blue.

The most important sources for gem-quality spodumene are the Mawi and Laghman areas of Afghanistan; the Pala District, California; Minas Gerais, Brazil; and Stoney Point, North Carolina. The Afghanistan material is noted for its diversity of colors and its depth of color. Bicolored and tricolored stones are found in this area. Some of the kunzite crystals reach a meter in length and weigh over 6 kg.

The author includes a section on color agents, stability, and irradiation. He concludes with an excellent discussion on the cutting of kunzite; it is based on the author's extensive experience and should be read by anyone who is considering the challenge of cutting spodumene. GSH

Negative inclusions in zircon from Anakie, Queensland.

A. D. Robertson, *Australian Gemmologist*, Vol. 15, No. 5, 1984, pp. 164–166.

Zircon from the Anakie mining field of Queensland, Australia, is generally free of primary inclusions. This article reports on the presence of elongated, rod-like inclusions found in some zircons from this locality which superficially resemble rutile. Close examination of these inclusions revealed them to be two-phase (liquid and gas) negative cavities, sometimes flattened on one end and occasionally on both ends.

Although the inclusions are definitely of primary origin, the author speculates on two modes of formation: (1) that they were generated from defect pits on the growing surface of the crystal, and (2) that they were originally rutile which was subsequently resorbed.

Robertson notes that similar though smaller inclusions found in sapphires from the same locality are thought to be rutile. Chemical analysis of one zircon revealed very little titanium, however, indicating that if the inclusions were originally rutile, it was not absorbed into the zircon lattice. RCK

Turquoise or chrysocolla from the Jervois area, Northern Territory. H. Bracewell and G. Brown, *Australian Gemmologist*, Vol. 15, No. 6, 1984, pp. 189–195.

The Jervois mining area of Northern Territory, Australia, is commercially exploited for its lead-silver ores. Copper mineralization also occurs here, primarily in iron-rich quartz rocks. In one such deposit, a greenish blue copper-containing material originally described as turquoise was discovered in 1981. Chemical analysis indicated the presence of copper in the material, although subsequent X-ray diffraction proved that it was not turquoise.

Gemological testing revealed the following properties of the material: color—variegated greenish blue to green with fine veins of grayish white quartz and reddish brown iron oxides; hardness—4 to 6; fracture—conchoidal, with a finely granular surface; mean S.G.—2.47 (2.3 to 2.5); mean R.I.—1.53; diaphaneity—opaque; luster—vitreous to greasy; fluorescence—dull bluish green surface; no diagnostic absorption spectrum; chemical stability—a yellowish stain is produced upon application of diluted hydrochloric acid. It was concluded that this material is a rock consisting of a chrysocolla-rich quartz, variable amounts of other copper minerals, and some iron oxide, visually similar to "Eilat stone."

An opaque, greenish blue reconstructed material was also examined, with the following properties: hardness—2 to 3; S.G.—1.78 (cerussite was apparently added to increase density); R.I.—1.52; luster—waxy; no fluorescence or diagnostic spectrum; chars when tested with the hot point; no yellow stain produced when tested with hydrochloric acid. RCK

DIAMONDS

Mineral inclusions in diamonds from kimberlites in Colorado and Wyoming. H. O. A. Meyer and M. E. McCallum, *Geological Society of America, Abstracts with Programs*, Vol. 16, No. 6, 1984, p. 595.

While plentiful data exist on inclusions in diamonds from Africa and Siberia, there is little information on inclusions in diamonds from North America. In this study, 80 diamonds were examined from kimberlites in the Colorado-Wyoming state-line area. The majority of these diamonds were small (approximately 1 mm), irregular in shape, and appeared to have suffered resorption and fragmentation in the kimberlite. The inclu-

sions are less than 70 μm and are generally altered. Primary inclusions include olivine, diopside, omphacite, richterite, phlogopite, rutile, and potassium feldspar (sanidine?). Other types of inclusions, such as magnetite, spinel, and calcite, may be alteration products. Diamonds with multiple inclusions are common. Overall, the types of inclusions are similar to those found in African and Siberian diamonds, although potassium feldspar and richterite have not previously been noted. The absence of garnet inclusions in these diamonds may be due to an inadequate sample of diamonds available for examination. *JES*

A note on the geology of some Brazilian kimberlites.

D. P. Svisero, H. O. A. Meyer, N. L. E. Haralyi, and Y. Hasui, *Journal of Geology*, Vol. 92, No. 3, 1984, pp. 331–338.

Although diamonds have been known to occur in Brazil for several centuries, it was only in the late 1960s that kimberlites were first recognized. This initial discovery was due to a systematic exploration for minerals in western Minas Gerais. In view of the widespread occurrence of alluvial diamonds in Brazil, further exploration has since been carried out, resulting in possible kimberlite discoveries in other parts of the country. In addition to the Alto Paranaíba district of Minas Gerais, other possible kimberlite districts now recognized include Lajes (Santa Catarina), Paranatinga and Aripuaña (Matto Grosso), Pimenta Bueno (Rondônia), and Gilbuês (Piauí). A summary is presented on the geology of the most studied and best known kimberlite occurrence at Alto Paranaíba. The kimberlites in this area are similar to those in other parts of the world. Unfortunately, the kimberlites in many areas of Brazil are so extensively altered by weathering that little is currently known about their mineralogical and chemical nature. As further work is carried out, more information will become available that will enable the geology of these kimberlites to be better understood. *JES*

GEM LOCALITIES

Gem travels in Asia. P. Read, *Canadian Jeweller*, Vol. 105, No. 4, 1984, pp. 35–40.

In an engaging travelogue, Read describes the highlights of his recent visit to three gem centers: Sri Lanka, Thailand, and Burma. In Sri Lanka, he visited gem mines and viewed an uncut specimen of taaffeite. In Bangkok, the author attended a colored-stone conference and then participated in a two-day seminar on diamonds for the Asian Institute of Gemmological Sciences. The diamond theme was particularly relevant because of the growing importance of Bangkok as a diamond-polishing center (the city now contains three large polishing operations). Bangkok's Wat Kao Street provided some unexpected excitement, since glass, synthetics, and even the sophisticated Kashan rubies were much in evidence,

together with a wide range of fancy-cut cubic zirconia. In addition, the reported occurrence of chrome diopside on Thailand's border with Burma was believed to be a positive indicator for ruby. Although Read was able to cross into Burma, internal problems in that country prevented his planned visit to the gem areas of the interior.

WEB

Gold fever hits the Amazonian jungle. N. Hollander and R. MacLean, *Smithsonian*, Vol. 15, No. 1, 1984, pp. 88–97.

Photographs by Harold Mertes and Peter Frey of "mud-caked Amazon miners" and their milieu make this piece an attention-grabber despite its gee-whiz tone and everything that it does not say. The "gold fever" mystique is retold once again, with endless anecdotes, but only one sentence refers to the importance of the gold to the nation of Brazil, which hopes to use it to help pay off its national debt. Nothing is said about the effect of the mining, now and in the future, on the lives of the indigenous inhabitants of the area, and but one remark ("Both the mountain and the stream have been consumed by the mine, and in their place is a giant wound . . .") refers to its effect on the jungle.

The authors say "The mine is a melting pot, and anyone can be a garimpeiro [roughly, an independent miner] as long as he gives up what he was for the sake of gold," but give us no hint of some of the heinous hiring practices, such as actual kidnapping, attested to by people who have been on the scene. They do, however, explain in some detail how the economy of the operation works and some of the political changes that have come about as the mining progresses. So while reading between the lines may dissolve some of the romance, the lines themselves are informative and thought-provoking. *FS*

Manganese-rich red tourmaline from the Fowler talc belt, New York. R. A. Ayuso and C. E. Brown, *Canadian Mineralogist*, Vol. 22, No. 2, 1984, pp. 327–331.

A red uvite tourmaline was recently found at the Arnold talc mine near Fowler, St. Lawrence County, New York. It occurs with manganese-bearing tremolite (hexagonite), braunite, talc, and quartz in a sequence of carbonate-rich metasedimentary rocks that are part of the Precambrian Grenville Complex. The tourmaline is found as grains up to 3 mm in diameter that exhibit moderate absorption and rose to red dichroism. The chemistry of this tourmaline is unique in terms of the high manganese content (4.34 wt.% MnO) for a member of the uvite-dravite solid-solution series. Manganese does occur in lithium-rich elbaïtes, but it is not common in lithium-poor tourmalines such as uvites. The authors suggest that manganese-rich tourmaline may form in geologic environments other than pegmatites, provided

the bulk composition and geochemical setting allow for the formation of manganese-rich minerals as was the case at this locality. JES

There's still gold in them thar hills. G. Maranto, *Discover*, Vol. 5, No. 7, 1984, pp. 56–59.

One hundred and thirty-five years after the start of the great California gold rush, modern miners are searching, and destroying, the hills of the 125-mile Mother Lode region near Sacramento. The placer nuggets have long been exhausted; today's treasures are the "infinitesimal flakes" of gold sprinkled throughout the rock in that region. Sonora Mining Co. was scheduled to begin a 25-year strip-mining project this summer; literally whole mountains will be crushed into ore. This company plans to retrieve the precious flakes by grinding the ore and leaching it in pits of water and thiourea, a nitrogen compound in animal urine. It appears that other mining companies might use cyanide in their leaching process, and environmentalists are greatly concerned about possible groundwater contamination. Residents are also protesting the wholesale destruction of the land and its wildlife, as well as the noise from processing plants. It is hoped that stricter mining regulations and close supervision by the Tuolumne County board of supervisors will help keep these threats in check.

This controversial type of mining enables a company to produce about 330 ounces of gold a day at a cost of about \$200 per ounce (at the time this abstract was written, gold was selling for about \$330 per ounce). Mother Lode Gold Mines Corp. has proven reserves of 9 million tons of ore; Sonora Mining has 24.7 million tons estimated to contain 1.7 million ounces of gold. SAT

A visit to New Zealand museums and jade factories. R. Kemp, *Lizzadro Museum*, Summer-Fall, 1984, pp. 8–21.

Mr. Kemp addresses nephrite with regard to both its historical and current importance to the people of New Zealand. The author focuses on the Maori tribe, the first settlers of New Zealand, who eventually established villages in the western regions of the island in order to be near the highly prized nephrite deposits. The nephrite, often called "greenstone," is a very tough material that the Maori shaped into various implements, tools, weapons, and even jewelry. They recognized that the toughness of the stone allowed them to produce very sharp and durable pieces. It was not until the arrival of the European settlers in the late 18th century that metals were introduced into the Maori culture; until that time, the shaping and polishing process was long and arduous.

Nephrite is still being mined in New Zealand today, mostly from mountainous areas. It is fashioned in various New Zealand jade factories, although the Maori are reportedly not involved with the work.

The article lists a number of museums that contain

selections of Maori artifacts, carvings, and history for those interested in exploring New Zealand, its nephrite, and the Maori culture. Mary Hanns

INSTRUMENTS AND TECHNIQUES

Optical anomalies of beryl crystals. E. Scandale, S. Lucchesi, and G. Graziani, *Physics and Chemistry of Minerals*, Vol. 11, No. 2, 1984, pp. 60–65.

X-ray topography is a recently developed technique for studying the growth history of crystals. It involves passing an X-ray beam through the crystal, and then recording on photographic film an image of the crystal which reveals many of the internal structural defects. These defects, such as growth zones and dislocations, reflect the environment and conditions under which the crystal grew, and thus may be used to understand something of the crystal's natural or synthetic origin. While not yet applied to the study of natural and synthetic gemstones, this technique holds some promise in helping to answer this troublesome gemological question.

In this study, basal plates cut from natural Brazilian beryl crystals were examined by a combination of analytical techniques. These beryl crystals displayed an anomalous biaxial character with a small 2V due to the nature of their growth history. It was found that structural defects identified in X-ray topographic photographs could be correlated with variations in both optical properties measured with the microscope and the contents of various impurity elements obtained by microprobe analysis. Such features in turn could be related to the growth stages of the beryl.

While currently there are insufficient data to fully interpret these results, it seems likely that future work may provide the means of distinguishing a natural crystal from one grown by flux, hydrothermal, or other synthetic techniques. The use of X-ray topography might then become important in the study of gemstones whose origin is in question. JES

Testing the authenticity of corundum—methods and limitations. H. A. Hänni, *Swiss Watch and Jewelry Journal*, No. 3, 1984, pp. 461–467.

Dr. Hänni provides an excellent short but concise outline of state-of-the-art procedures currently used for the gemological testing of natural and synthetic corundum. The methods, in the order they are discussed, are: microscopy, ultraviolet spectrophotometry, energy-dispersive X-ray fluorescence spectrometry (EDS-XRF), neutron activation analysis, and X-ray topography. Of these, the light microscope and optical microscopy are the only instrument and technique presented that are generally accessible to the jeweler-gemologist; six color photographs of typical features observed in natural and synthetic corundums highlight this section. The article points out that in order for a microscope to be effective,

gemstones must contain inclusions. If a ruby or sapphire is without inclusions, then other testing procedures are necessary.

Ultraviolet spectrophotometry is then discussed. This method details the effect of those elements present in a gem on the absorption spectrum as individual wavelengths of light in the ultraviolet region are passed through the gem. The method works well on most synthetic and natural rubies. However, when some of the newest synthetics were subjected to this test, the results were identical to those from natural stones.

Energy-dispersive X-ray fluorescence spectrometry employs a primary beam of X-rays that bombard a subject and produce secondary X-rays, whose fluorescence energies correspond to the elements present in the material being tested. With EDS-XFR, elements from sodium (11) through uranium (92) can be detected. The presence of gallium in concentrations greater than 200 parts per million in natural rubies was previously thought to be proof of natural origin. Now, however, some of the newer synthetics are doped with gallium and this testing is no longer valid. More work must be done in this area to develop detailed characteristic trace-element profiles of both natural and synthetic gemstones.

Neutron activation analysis is another method that relies on the presence or absence of trace elements. It employs neutrons from a nuclear reactor that bombard the subject, producing unstable isotopes in the structure. The energies released upon the decay of these unstable isotopes are characteristic for the elements they represent. By reading these decay energies, neutron activation analysis permits quantitative determination of several trace elements simultaneously. The drawback to neutron activation analysis is the creation of radioactive elements within the gemstone. It takes 30 days for the chromium isotopes in a ruby to decay to a point where the ruby is no longer a health hazard. Hänni also mentions that neutron irradiation could cause color alteration in some gems.

The last method discussed by Dr. Hänni is X-ray topography. Such equipment is very expensive, and because of the relative opacity of corundum to X-rays, thin slices must be cut from the test subject; obviously, this cannot be done with gemstones. In view of this, X-ray topography is not particularly useful in separating natural from synthetic corundum.

Hänni concludes that most corundums can be identified by normal gemological testing, microscopy, and spectrophotometry. Only a few extreme "problematic" cases require other testing methods. Dr. Hänni also states that the use of magnetic resonance, fission-track analysis, thermoluminescence and raman-laser probe testing, or a combination of some of these, may prove useful in some of these extreme cases. He closes by stating that "Inclusions are widely regarded as devaluating defects in gemstones. Yet, they are what lend a stone

its unique character. Moreover, we are relieved for every ruby or sapphire whose discrete inclusions prove the authenticity, representing a certificate to the stone itself. Such stones ought to be promoted by the trade for they truly differ from their synthetic rivals."

John I. Koivula

JEWELRY ARTS

Beetle of the gods. T. B. Larsen, *Aramco World Magazine*, Vol. 35, No. 1, 1984, pp. 20-21.

If you ever wondered how the lowly dung-beetle was elevated to sacred status by the ancient Egyptians, this brief, concise article gives the answer. Depicted in such detail by early Egyptian artists that centuries later, entomologists have been able to identify them, the scarab was the sacred "symbol of the sun, of rebirth, of life itself." Apparently, the scarab's daily routine of food gathering, whereby it rolls a ball of dung over considerable distances, suggested the sun's relentless passage across the heavens; the female scarab laying her eggs in the sand encased in balls of dung represented the sun's setting in the western desert; and with the 28-day cycle of gestation completed, the newly hatched scarabs pushing their way up out of the sand implied the sun's collaboration with the moon to miraculously produce new scarabs out of dust. These manifestations signified life and rebirth to the early Egyptians.

The scarab was fashioned in "virtually all the materials used in ancient Egypt," and can be found in nearly every aspect of their civilization. Carved in granite bas-relief and in the plaster walls of tombs, found in the jewelry of Tutankhamen and used as sacred seals by religious officials, utilized as good luck charms and commemorative tokens, the ubiquitous scarab appears and reappears, again and again. *EBM*

Gold in fashion. C. Raats, F. de Lassus, and B. Fornas, *Aurum*, No. 17, 1984, pp. 27-55.

On April 5, 1984, Intergold's world premier "Gold in Fashion" show was unveiled to an international group of 700 people. The objectives of the show were twofold: first, to alert the jewelry trade to the relationship of gold jewelry and fashion, and second, to disseminate the news throughout the world-wide fraternity of fashion journalists.

The background of Intergold's campaign and the strategies used to accomplish it are presented in this abundantly illustrated article. In the jewelry trade, as in most other sectors of the consumer market, a company can prosper only by continually introducing new products that meet market needs. To help identify the needs of the consumer, Intergold established a relationship with Promostyl, a company that detects and defines the underlying currents that bring about changes in fashion. Their research revealed that consumers are fashion- and

price-conscious; they are either young and trendy or established with an eye for investment. The information collected by the specialists identified a major cultural trend—a movement toward refinement and sophistication, a movement toward narcissism and an epicurean search for pleasure. They found a decline in the violence and slovenliness of previous years.

Another important aspect of the contemporary scene is that there is no longer just one fashion in any given season, but several coexisting themes. Four dominant trends—Exotic, Natural, Avant Garde, and Retro—are identified as having a long-term influence on fashion. These trends have inspired four major fashion themes of the 1984–85 season: Arab, Bacchus, Gypsy, and Monastic.

It is on the basis of these themes that fashion designers and jewelry manufacturers collaborated with Intergold in producing jewelry and garments for the "Gold in Fashion" show. Promostyl produced 105 different sketches of garments—about 26 per trend. Sketches were analyzed to make sure the gold jewelry could be worn and displayed to advantage. A total of 45 gold-jewelry manufacturers and designers were given sketches of the outfits, and they designed and produced sets of gold jewelry that served as perfect accessories to the garments.

The gold jewelry carried out the mood and theme of each fashion trend. The Arab theme has oriental origins, giving it a mysterious, sensual flavor. Clothes are vivid and colorful. Gold jewelry is sparkling, open worked, multi-colored, and combined with nonprecious materials. The Bacchus theme is an expression of the natural trend. The style of dress is serene, the jewelry has shapes reminiscent of nature; it is highly polished and has rounded forms. The third theme, Gypsy, was inspired by the Avant-Garde trend. Its connection with movement and fire makes it a flamboyant, seductive style. Jewelry has twirling scrolls of gold lacework inspired by wrought-iron gates and rails. The Monastic theme is an interpretation of the Retro trend. It is austere and sophisticated, with a touch of "neo-retro" chic. The jewelry is geometric and traditional.

Unquestionably, the jewelry trade must link gold jewelry with fashion in order to satisfy the needs of the consumer, and to create excitement and interest in gold jewelry.

Lorraine Gruys

Jewelry from the Siwa Oasis. F. Bliss and M. Weissenberger, *Ornament*, Vol. 6, No. 4, 1983, pp. 6–11, 42–44.

This is a detailed and extensive account of the cultural history of the Berber tribes from the Siwa Oasis as seen through their jewelry. The Siwa Oasis is located in the western deserts of Egypt, not far from the Libyan border. Already an old city when Alexander the Great came to visit, its origin can be traced to the early age of Islam.

The traditional jewelry of the women denotes their status as single, engaged, married, or elderly. The elaborations in terms of designs and traditional ornamentation with coral, shell, and stones have symbolic value as protective talismans. The authors name every article of jewelry, trace the history and symbolism of each, and discuss the possible influences that other cities or tribes may have had on their development.

I found this article to be more anthropological than gemological in nature and a bit difficult to follow. One sad but interesting fact that can be gleaned by the gemologist is that these tribes, out of monetary considerations, are now using base metal instead of silver or gold and are substituting glass and plastic for gems. The authors also note that the cost of the jewelry has increased while the quality of workmanship has gone down. A parallel might be drawn between the decline of their jewelry and the decline of these small Berber tribes.

EBM

Magic in the masks. B. Braun, *Connoisseur*, Vol. 214, No. 863, 1984, pp. 82–85.

One of the rarest forms of pre-Columbian art is the Aztec mosaic. Comprised of minute tiles of turquoise, malachite, shell, and lignite inlaid on carved wood, the mosaics take the shape of masks, pectorals, knife handles, scepters, helmets, and vessels used in ceremonial rites by the Aztecs. Of only 50 mosaics in existence, the finest examples "have come out of princely European collections of great age," and are presumed to have been gifts from Montezuma to Cortez. These were brought to Europe and kept as curios by the nobility.

Three masks depicting gods and a pectoral in the shape of a double-headed serpent are shown in this brief photo-essay. The exquisitely cut tiles form the contours of the faces and the bodies of the snakes. The work was executed by Mixtec craftsmen in the south-central highlands of Mexico using materials from other parts of the region.

Because the Spaniards suppressed what they perceived to be pagan rituals, the original symbolism and use of these superb pieces can only be theorized. The author, an art historian, gives the reader a tantalizing taste of what is conjectured to be the origins of these mosaics. In her words, "these magnificent examples of the stonemason's art epitomize the supreme paradox of Aztec civilization: the strange, even baffling, coexistence of exquisite refinement and harrowing brutality."

EBM

Pre-Columbian necklaces, then and now. R. K. Liu, *Ornament*, Vol. 7, No. 1, 1983, pp. 2–5, 14–15, 44–45.

Liu presents several sources of information on the forms and uses of pre-Columbian necklaces. His research concludes that the most reliable sources are Peruvian mummy bundles, murals and reliefs, statues, and ce-

ramic figures. Forty-two drawings of necklaces modeled on pre-Columbian ceramic figures demonstrate the range of styles found in the Mayan (Yucatan?) and Veracruz regions of Mexico. These pieces range in complexity from single-strand chockers to elaborate, multi-strand arrangements with several pendants. The majority of these necklaces were fashioned from stone or shell beads, although gold and copper were also used occasionally. Five "mystery" pieces from the Veracruz region appear to have been made from cords of rope or a pendant of cloth. Liu also provides photos of modern necklaces that show that contemporary craftsmen can successfully incorporate ancient jewelry components and designs into their own creations. SAT

RETAILING

Catalog showrooms: America's top jewelers? M. Plotnick, *Accent*, Vol. 9, No. 5, 1984, pp. 57-64.

Catalog showrooms now claim 20% of the market share for jewelry and watch sales. Although a variety of products can be purchased in a catalog showroom, jewelry and watch sales are purported to be the "meal tickets." "Eventually we want jewelry and watches to be 50% of our total sales," projects David Grove of W. Bell and Co.

Showroom customers are generally middle or upper-middle class. These customers make purchases with both price and style in mind. Female customers have become important enough to affect showroom policies, and showroom hours have been expanded to accommodate the working woman.

Watches, diamonds, and 14K jewelry are the leading product categories. Of the total 14K jewelry units sold, rings and neckchains are the median leaders, with 30% each. Earrings are 25%, followed by pendants and charms at 13%, and other 14K items at 10%. Some catalog coordinators are dropping gold-filled and sterling jewelry from their upcoming catalogs and adding diamond jewelry.

Catalogs play an important part in the marketing of showroom jewelry. Most coordinators expect the number of pages devoted to jewelry and watches to increase in the 1984-85 issues. Marcia Hucker

The fun beauty treatment. A. Gold, *Accent*, Vol. 9, No. 6, 1984, pp. 39-44.

Wardrobe consultants have found a niche in the fashion industry. Is there one developing for jewelry consultants? If so, what would they need to know? And, a more timely question, what do salespeople need to know until the jewelry consultant niche has been filled?

Beauty experts—celebrity photographers, hair stylists, and make-up artists—offer their answers to these questions. Advice ranges from the basic to the more avant garde: "Women should wear jewelry that's scaled to their size," says Lee MacCallum, senior editor of *Glamour*. "Jewelry can work with a woman's personal

style to accent or compensate for different facial shapes," says another expert. One hair stylist interviewed sees a relationship between hair style and jewelry. The current asymmetrical hair styles, for example, lend themselves to free-form and sculptured shapes in earrings; two earrings in one ear and one in the other is another approach to complement a woman's appearance.

Make-up can be an important feature in selecting jewelry. Photographer Ariel Skelley photographed a model with copper-colored hair wearing copper-colored make-up, complemented by copper-colored jewelry. She views this monochromatic color scheme as an "effective" harmonizing of make-up and jewelry. Make-up artist Joey Mills agrees: "Make-up is one good way of choosing jewelry." He suggests using the color of eye make-up. As an example, whitened or iridescent eye make-up is compatible with pearls, slate gray or grayish blue calls for hematite, amethyst goes with mauve, and emeralds go with celery or slate-gray eye make-up.

Jewelry is used as a fashion statement. The advice here is: concentrate on one area of the body—the neck, the wrist, or the waist—and make one statement at a time.

Several experts agree that "rules" are meant to be broken. While curved earrings soften a square jawline and round earrings add width to a long face, an effective way of using jewelry is to emphasize the shape—to stylize it, dramatize it, accentuate it. Photographer David King agrees with breaking the rules but cautions, "It all depends on the individual woman and what she can carry off."

General guidelines are given to assist in the training of sales personnel. Encourage a woman to try something new, but don't push. If the customer is uncomfortable with something, she will never be at her best. Be tactful. Advice should focus on "how to." Be sincere. Too many have heard and are weary of "everything looks wonderful on you."

Trifari's Quick Reference Chart for the cosmetic approach to fashion jewelry is included as a sidebar. The six basic facial outlines are given, together with recommended jewelry shapes and styles, as well as items to be avoided.

A second sidebar outlines the various functions of a consultant. These tasks range from giving advice on all aspects of appearance to lessons in diction. A breakdown of the financial remuneration for consultants and the financial profits of their clients is given. Lorraine Gruys

SYNTHETICS AND SIMULANTS

Inclusions in synthetic corundum by Chatham. G. Brown, *Australian Gemmologist*, Vol. 15, No. 5, 1984, pp. 149-154.

Brown begins with an overview of the flux synthesis of corundum and a summary of characteristics reported in

previous examinations of Chatham synthetic corundum. He then describes the results of his own microscopic study of Chatham flux-grown ruby and sapphire. Several previously reported inclusions are noted: high- and low-relief two-phase flux, negative crystals, metallic inclusions, angular color zoning, layering resembling lamellar twinning, color inhomogeneities resembling "treacle" in Burma ruby, and planes of gas bubbles at the junction of the crystal cluster with the seed (shown by Kane—*Gems & Gemology*, Fall 1982—to be in a "ceramic" coating on the base of the cluster). Also noted were trigonal growth features on relatively slow-growing crystal faces on crystal clusters; long, thin, two-directional needle-like inclusions of undetermined nature (which were neither mineral needles nor margins of rhombohedral parting planes); and thin, irregularly outlined, doubly refractive flakes of an undetermined mineral with optical properties similar to mica.

The investigator concludes with a warning that several of these inclusion types, if viewed in isolation, could lead the inexperienced observer to identify the material as a natural stone. RCK

Some observations on a Kashan synthetic ruby. C. R. Burch, *Journal of Gemmology*, Vol. 19, No. 1, pp. 54–61.

Burch reports on three kinds of inclusions observed in a single Kashan synthetic ruby. One type consists of opaque, homogeneous bodies with a metallic luster. These are thought to be coarse, crystalline, residual flux. Another type, the "fingerprint" inclusion, is composed of very small, spherical structures, most of which are highly transparent and appear to be two-phased. The author speculates that these may consist of amorphous flux with a shrinkage bubble; the immobility of the gaseous phase is consistent with this view. The final type is described as composite bodies consisting of a homogeneous, transparent material with a thin outer coating of a white, translucent-to-opaque substance with a granular or "crazed" appearance. It is postulated that the center is actually amorphous flux with a coating of solid, residual crystalline flux.

In conclusion, the investigator suggests that the three types of inclusions are related to each other and that a transition exists among them. Variations in aluminum content, original size disparities among the inclusions, and differences in the cooling rates from one area to another in the stone could all contribute to the very different visual characteristics of these three inclusion types. RCK

A scrimshaw imitation. N. A. Clayton, G. Brown, and J. Snow, *Australian Gemmologist*, Vol. 15, No. 6, 1984, pp. 201–205.

This article begins with a brief summary of the history and technique of scrimshanding—the art of decorating bone or ivory with colored, incised designs. It then pro-

ceeds to investigate a realistic imitation of walrus tusk scrimshaw called the "Whaler Ionia."

An exposed cross-section of the imitation revealed some interesting features. Apparently the manufacturer tried to imitate the circumferential growth banding found in the outer layer of natural ivory. A hand lens revealed numerous rounded gas bubbles and plastic melt/burn marks on or just under the surface of the piece in question. The material dissolved easily in acetone, but was insoluble in nitric acid. It melted readily when exposed to a flame, producing an acrid odor and smoke; it had a refractive index of 1.56 and a specific gravity of 1.85, with a pale blue fluorescence when exposed to long-wave ultraviolet radiation. The properties (with the exception of the specific gravity) indicated a molded polystyrene resin plastic.

Examination of the central core revealed that it was inhomogeneous, consisting of a central mass of cured polystyrene containing a mineral filler of irregular, angular particles. This filler was birefringent, displayed rhombohedral cleavage, had no relief when submerged in bromoform, effervesced to hydrochloric acid, and responded negatively to Meigen's test for aragonite.

The authors conclude that the specimen was a molded polystyrene imitation whose central core had been filled with crushed calcite. It is noted that the manufacturer's catalogue did in fact indicate that it was a molded product. RCK

MISCELLANEOUS

Safety and health: a concern for all electroplaters. *American Jewelry Manufacturer*, Vol. 32, No. 5, 1984, pp. 28–42.

"Safety thrills me," reads my favorite bumper sticker—favorite because it is so apparently absurd. But how's this for a thrill: "Wear a supplied-air respirator if cleaning requires working inside the degreaser tank. A second worker, similarly equipped, must be stationed outside the tank. . . . able to communicate by voice or visual signals with the worker inside the confined space. . . . Continue to ventilate the degreaser, even while using an airline respirator. Illness may occur from skin absorption if solvent concentrations are allowed to rise to unsafe levels." Or this: "[in handling acid carboys] proper rinsing is essential. . . . Acids, when in contact with cyanide, can lead to the production of hydrogen cyanide gas, a potentially lethal substance." These nine pages are condensed from the 75-page looseleaf *Manufacturing Jewelers & Silversmiths of America Health & Safety Manual*, and appear to cover every hazard from "nickel itch" to flash steam explosions, with the appropriate preventive measures for each. The advice given is clear, sounds sensible, and is accompanied by sketches, charts, and diagrams. Readers may easily be thrilled enough to decide to look into the manual itself for more of the same. FS

GEM NEWS

John I. Koivula, *Editor*

DIAMONDS

Australia.

Loan for Argyle development. European Banking Co. Ltd. has announced the signing of a 12-year loan of US\$32 million for Northern Mining Corporation's 5% interest in the Argyle Diamond Mine in Western Australia. (*Mining Magazine*, July 1984)

India

The Golconda "D" diamond resurfaces. In the 17th century, the wealth of India was concentrated in the Kingdom of Golconda, now part of the State of Hyderabad. All that remains now is a ruined fort near Hyderabad.

The most famous diamond mines were at Kollur, in the gorge cut by the River Krishna. From this ancient source have come some of the world's finest and most famous diamonds, such as the 108.93-ct Koh-i-noor (now among the Crown Jewels of England) and the 70.20-ct Idol's Eye.

Among the great diamonds to be unearthed from Golconda was a magnificent piece of rough that yielded a polished stone of over 50 ct. At that time, Shah Jehan, who built the famous Taj Mahal, was Mogul Emperor of India, and it is believed that this 50-ct diamond, like the Koh-i-noor, may have been set in his fabulous Peacock Throne. In 1739, Persia's Nadir Shah invaded India, captured Delhi, and seized the Peacock Throne. Nothing further was heard of the 50-ct brilliant-cut diamond until it reappeared in Bombay recently. Laurence Graff in London purchased the stone and had it repolished in New York.

The gem now weighs 47.29 ct and has been named the Golconda "D," honoring both its Indian origin and its body color. (Graff Diamonds Ltd., London, England)

Thailand

Noted gemologist and author John Sinkankas has provided *Gems News* with the following information on diamonds in Thailand:

"I cannot recall seeing previous mention of the occurrence of alluvial diamonds in Thailand and submit this note for the information of readers of *Gems & Gemology*. The basic reference is 'The geology of the tin belt in Peninsular Thailand around Phuket, Phangnga and Takua Pa,' by M. S. Garson, B. Young, A. H. G.

Mitchell, and B. A. R. Tait, London, *Institute of Geological Sciences Overseas Memoir No. 1*, 1975. It is a portfolio with pocket maps and an illustrated text of 112 pages.

"Diamonds, occurring in cassiterite-wolframite concentrates, are described and discussed in chapter 16, pp. 77-85, with maps and a fine photo of typical small crystals of diamond keyed to a table that provides descriptions of 20 crystals, giving weights, form, luster, and special features such as fluorescence, inclusions, etc. The diamonds are very small, the largest stone being only 0.89 ct and the lot of 20 weighing 6.28 ct altogether. The photographic plate shows that the crystals are mainly rounded dodecahedra, some quite ball-like, and only a few display good octahedral form. Sampling and prospecting have failed to uncover kimberlite-related minerals, e.g., pyrope, diopside, etc., and the source of the diamonds is unknown."

U.S.A.

A diamond is melted. A laboratory accident at Cornell University in Ithaca, New York, has resulted in the melting of a diamond and the production of liquid carbon. Using a powerful infrared laser, Jon S. Gold, a graduate student in geology, was heating a mixture of graphite and potassium bromide between two diamond "anvils" in a special press. The pressure at the time of the accident was greater than 120,000 times that of the atmosphere. Although the temperature could not be accurately measured, researchers suspect that it was close to 4000°C. The laser had been accidentally set at a higher power than planned. The graphite was converted to diamond, and the laser melted a furrow about one-tenth of a millimeter long across the face of the diamond anvil. The furrow was bordered by rounded glassy ridges of melted diamond. The researchers now involved in this project say that the next step will be to accurately determine at exactly what temperature the diamond melted. (*Science News*, September 1984)

Punch Jones diamond sold. The Punch Jones diamond, a 34.46-ct greenish-gray octahedron was sold at auction last October by Sotheby's in New York. This stone is the largest alluvial diamond ever found in the United States. It was discovered in 1928 at Rich Creek near Peterstown, West Virginia by Grover C. Jones and his son William P. "Punch" Jones while they were playing horseshoes.

However, it was not until the stone was tested at the Virginia Polytechnic Institute in 1943 that it was identified as a diamond. The Punch Jones has been on display at the Smithsonian since 1944.

World's largest uncut diamond displayed at Smithsonian. The world's largest existing uncut diamond—890 ct—was placed on display at the National Museum of Natural History, Smithsonian Institution, following its unveiling by The Zale Corporation in Frankfurt and New York (figure 1). The date and place of the stone's discovery are not known.

Cutting of the stone was scheduled to begin immediately after the close of the exhibit on January 6, 1985. The undisclosed cutter estimates it will take 18 months to finish the faceted gem. The final shape has not yet been determined, although the modern pear, oval and briolette are among the cuts being considered.

Only three rough diamonds larger than this one have ever been found—the Cullinan (3,106 ct), the Excelsior (995.2 ct), and the Star of Sierra Leone (968.9 ct). The largest individual polished diamonds are the Cullinan I and II, which weigh 530.20 and 317.40 ct, respectively, and currently rest among the British Crown Jewels. Some experts feel that Zale's diamond could yield a cut stone larger than either of these.

The diamond is owned by Christ, the European subsidiary of The Zale Corporation.

USSR

Soviets claim production of large synthetic diamond. Moscow's World Service recently reported that scientists at the USSR Academy of Science have produced a 2-kg (9,988-ct) synthetic diamond crystal for use in that country's laser and optical industries. The report stated that the synthetic diamond was grown in an experimental pressure chamber in temperatures higher than those at the sun's surface. (*Rapaport Diamond Report*, August 1984)

GEM NEWS Editor's note: The proposed use of this material in lasers and optics suggests a crystal with at least some areas of high purity. Yet there have been no other developments in the field to suggest that the level of technology necessary to produce an optically pure synthetic diamond crystal that is over three times the weight of the largest known natural gem-quality diamond crystal (the Cullinan, 3,106 ct) exists.

COLORED STONES

Chrysoberyl found in Queensland. A yellow-green chrysoberyl from Anakie, Queensland, Australia, was found in a parcel of yellow-green sapphires from the same area. The rough chrysoberyl appeared to be so similar to the sapphires that its true identity was not detected until after it had been cut and polished and was subjected to standard gem-testing techniques. The refractive index obtained from the 0.43-ct faceted



Figure 1. The 890-ct Zale diamond, the fourth largest rough diamond ever discovered, with its 1-ct faceted counterpart.

chrysoberyl was: alpha = 1.756, beta = 1.761, and gamma = 1.768. The specific gravity was 3.74, and in the spectroscope a broad absorption band was noted between 425 and 458 nm. Gemologists should be on the lookout for more chrysoberyl from this locality. (*Australian Gemmologist*, August 1984)

Irradiation of yellow sapphires. X-ray equipment at the Sri Lanka Cancer Institute in Maharagama is being used to treat pale yellow sapphires. While the deep orangish color obtained by irradiating the pale yellow stones is very pleasing, it is not permanent; when exposed to sunlight the stones will fade to their original color in a matter of hours. (*Jewellery News Asia*, July–August 1984)

Large Mexican opal found. A nearly flawless, fist-sized fire opal displaying all of the spectral hues in its vivid play of color was reportedly found earlier last year in an opal mine in the state of Querétaro, Mexico. This opal has been described as one of the largest and finest gem-quality opals ever discovered in this mining area. It has been on display in the city of Querétaro since it was unearthed. The Mexican opal mining industry is currently very active, especially in Querétaro and near Magdalena in the state of Jalisco. (*Lapidary Journal*, August 1984)

Notes on danburite, zircon, and andalusite. The following three short notes were translated from the *Boletín de la Asociación Española de Gemología* for Gem News by Elise Misiorowski, of the GIA library.

Golden brown danburite. Golden brown danburite from Madagascar, first discovered in 1920, has reappeared on the market. The crystals and crystal sections are reportedly of "good size and relatively clean." The stated color ranges from an intense pinkish orange topaz to a paler sherry-brown. This contrasts sharply with the usual colorless to near-colorless nature of danburite.

Australian pink zircon. Some samples of gemmy pink zircon from Australia have been seen recently in London, England. It is reported that the pink is fairly dark in tone and closer in appearance to pink diamond than to pink sapphire. The exact place of origin of these zircons is not yet known.

Colorless andalusite. A report from Brazil describes a colorless andalusite cut from a bicolored crystal. This andalusite displays low optical properties (R.I. 1.630–1.634–1.638 and birefringence 0.008), and is believed to have a low iron content.

Treated Moroccan anglesites. Gem collectors are not the only ones who must be wary of treatment practices; treated minerals are now causing major problems for specimen collectors. It was recently discovered that the large, fine, gemmy anglesite (lead sulfate) crystals and crystal groups from Touissit, Morocco, have been treated to give them their amber-red color. The color is produced in the pale yellow and near-colorless crystals by dipping them in a strong bleach solution. The chemical reaction that changes the color takes only a few seconds. A Moroccan dealer discovered this treatment by accident, and other dealers in Morocco decided to treat and sell the material without disclosing that it had been artificially enhanced. The color is present as a thin skin that covers both crystal faces and broken surfaces. The treatment process leaves the beautiful anglesite luster intact, and the treated color coating will not wash off. Dr. George Rossman, of the California Institute of Technology in Pasadena, discovered that immersion of the treated specimens in a saturated bromine-water solution reverses the reaction without damaging the luster. However, bromine is very dangerous and should

only be used by experts. (*Mineralogical Record*, July–August 1984)

The Walker emerald from North Carolina. A large and very fine emerald crystal was recently recovered from what has been described as "very rich ground" at the North Carolina Emerald Mines' Rainbow's End mine. The rich green, hexagonal, transparent to semitransparent crystal weighs 63.70 ct and measures approximately 28.30 × 16.75 × 15.69 mm. It was discovered by Mr. Fred Walker, Vice President of Carolina Emerald Mines, Inc. This area has also yielded an 1,800-ct translucent specimen-quality emerald crystal, a splendid amethyst cluster, and some blue sapphire crystals found in albite feldspar. (Carolina Emerald Mines, Inc., September 1984)

PRECIOUS METALS

Alaskan gold. Anaconda Minerals Co., a subsidiary of Atlantic Richfield, has reported finding significant gold, zinc, lead, and copper deposits on the west side of Cook Inlet, about 96 km southwest of Kenai, Alaska. Exploratory drilling has indicated gold values as high as 41.4 g per ton. (*Mining Magazine*, April 1984)

Refinery opens in Singapore. The first precious metals refinery to be set up in Asia outside of Japan is now open and operational in Singapore. The refinery was a joint project between Handy and Harman Manufacturing, a U.S. metal refiner, and King Fook Investment Company of Hong Kong. Because of their experience in this area, the new refinery will be operated by Handy and Harman Manufacturing. (*Jewellery News Asia*, July–August 1984)

Sri Lankan gold jewelry to be hallmarked. The Sri Lankan government will introduce legislation to make gold hallmarking mandatory. Sri Lanka's state gem corporation wants fineness stamped on all gold jewelry that is sold in or exported from Sri Lanka. Sri Lanka has also applied to join the International Federation of Hallmarking in London, England.

Other Asian countries have already incorporated or are planning required gold-hallmarking programs. India has announced plans to begin its own gold-marking system, and Hong Kong will begin a hallmarking program for all gold jewelry above eight karats beginning January 1, 1985. Singapore has been using a system of voluntary hallmarking since 1980. (*Jewellery News Asia*, September/October 1984)

SYNTHETICS

Gem-quality synthetic jadeite created at G.E. Scientists at the General Electric Research and Development Center in Schenectady, New York, announced last November the creation of the first synthetic jadeite. One of the last gemstones to be synthesized, the man-made jadeite

was formed at high pressures and temperatures in the same laboratory used to create synthetic diamonds.

To synthesize jadeite, the G.E. scientists began with the same materials as in the natural stone—sodium, aluminum, and silicon oxides. The materials (in powder form) are mixed together and heated in a furnace to about 2,700°F, causing them to melt. The molten liquid is then withdrawn from the furnace and allowed to cool into a glassy solid. Next, the glass is crushed and “re-fired” at about the same temperature in a tiny (1" × ½") furnace inside a diamond-making press. There, the material is simultaneously exposed to pressures of up to 440,000 pounds per square inch. The end result of this process is a cylindrical piece of white jadeite.

By adding small amounts of other minerals to the starting powder mix, the G.E. scientists are able to synthesize jadeite pieces of varying colors, such as green (by adding chromium), black (by adding larger amounts of chromium), and lavender (by adding manganese). In addition, the G.E. team has synthesized samples featuring layered combinations of colors, such as green and white, as often occurs in nature.

The cylindrical jadeite samples (½" thick × ½" long) represent the first jadeite to be produced in sufficient size and quantity suitable for gemstone purposes. According to a G.E. spokesperson, the company does not have any plans at this time to produce the synthetic jadeite commercially.

Russian hydrothermal synthetic emeralds. Recently submitted to both the Los Angeles and New York offices of GIA's Gem Trade Laboratory, Inc., were several faceted examples of a sophisticated type of synthetic emerald. The stones resemble in many ways synthetic emeralds of Russian hydrothermal manufacture that were recently obtained by Mr. Thomas Chatham in Hong Kong (see figure 2) and generously provided by Mr. Chatham to the Los Angeles lab for research.

Some of the optical and physical properties of most of the Russian hydrothermal synthetic emeralds exam-



Figure 2. A 0.88-ct hydrothermal synthetic emerald manufactured in Russia. Photo © 1984 Tino Hammid.

ined to date are similar in many respects to those of some of their natural counterparts, in particular, emeralds from Zambia. Because refractive indices, birefringence, specific gravity, and luminescent reactions may overlap with some natural emeralds, it is essential to become more familiar with the unusual growth features and other characteristic inclusions, as well as with the unusual absorption spectrum, observed in these Russian hydrothermal synthetic emeralds. The latter is due in part to an abundance of iron, which also affects the reaction to ultraviolet radiation and the color filter (inert for both).

A detailed article on the unusual properties and identification of synthetic emeralds of known Russian hydrothermal manufacture will appear in an upcoming issue of *Gems & Gemology*.

ANNOUNCEMENTS

Ashberg diamond on display. The 102-ct light yellow Ashberg diamond is currently on display at the Gem and Mineral Hall of the Los Angeles County Museum of Natural History. The Ashberg is the largest faceted diamond currently on public display in the U.S. According to Laurence L. Copeland in *The Book of Diamonds . . . Famous, Notable and Unique*, the Ashberg, as shown at the 1949

Amsterdam Diamond Exposition, “was mounted in a necklace with other diamonds and gemstones. It is said to have been part of the ancient Czarist Russian Crown Jewels that were brought to Sweden after the Bolshevik Revolution in 1917.”

Important jewelry exhibition. The famous Tiffany Iris Corsage, a turn-of-the-century brooch with 120

American sapphires from Yogo Gulch, Montana (figure 3), is one of the highlights on display in the cross-country jewelry exhibition, “Objects of Adornment: Five Thousand Years of Jewelry from the Walters Art Gallery in Baltimore.” According to Walters Gallery documents, the brooch was purchased in 1909 by Henry Walters, an avid jewelry collector who patronized con-



Figure 3. The gold and platinum Tiffany Iris Corsage set with American sapphires as well as diamonds, demantoid garnets, and citrines. Photograph courtesy of Intergem, Aurora, Colorado.

temporary artists. His jewelry collection includes many fine pieces by Tiffany & Company and Rene Lalique.

More than 200 pieces of historical jewelry from this collection will be on display. The traveling exhibition opened last October at the Cooper-Hewitt Museum in New York, and will visit the Chrysler Museum, Norfolk, VA; the Carnegie Institute Museum of Art, Pittsburgh, PA; and the San Antonio Museum of Art, San Antonio, TX. The tour will conclude on February 8, 1987, at the Toledo Museum of Art in Ohio.

The Tucson Gem and Mineral Society's 31st Annual Show will be held February 7–10, 1985, at the Tucson Community Center, 260 South Church Avenue, Tucson, Arizona. Diopside will be the featured mineral. There will be exhibits of gems, jewelry, lapidary, and fossils, as well as related instruments, equipment, and publications. The show will provide the background for the an-

nual meeting of the Mineral Museums Advisory Council. For further information, please contact: TGMS Show Committee, Box 42543, Tucson, AZ 85733.

Association of Women Gemologists plans national meeting. The third annual meeting of the Association of Women Gemologists will be held in Tucson, Arizona, February 3, 1985, from 8 a.m. to 12 noon in the Holiday Inn Holidome on Palo Verde Boulevard. For further information, contact AWG, P.O. Box 1844, Pearland, TX 77588; (713) 485-1606.

ICA to sponsor colored gemstone congress. The International Colored Gemstone Association (ICA) will sponsor a colored gemstone congress to be held in Idar-Oberstein, West Germany, May 20–22, 1985. For further information, please contact Maureen E. Jones, ICA Administrator, 22643, Strathern St., Canoga Park, CA 91304; (818) 716-0489.

Burma emporium. The 22nd Burma Gem, Jade and Pearl Emporium will be held in Rangoon at the Inya Lake Hotel in February 1985. For information on this event, please contact the organizer: Myanma Gems Corp., 66 Kaba Aye Pagoda Rd., Rangoon, Burma. Telephone: 60904. Telex: 21506 GEMCOR BM.

Australian jewelry fair. The Australian International Watch, Clock and Jewelry Fair will be held in Sydney at the Wentworth and Hilton Hotels February 16–20, 1985. Further information can be obtained from World Trade Promotions Pty. Ltd., 291 Sussex Street, Sydney, N.S.W. 2000, Australia.

Basel fair, Switzerland. April 11–18, 1985, are the dates set for the annual European Watch, Clock and Jewelry Fair held in Basel, Switzerland. For additional information on this event, the organizers may be contacted at P.O. Box CH-4021, Basel, Switzerland. Telex: 62685 FAIRS CH.

AGTA makes stand on gemstone treatment. At their August 30, 1984, meeting in Dallas, Texas, the Board of Directors of the American Gem Trade Association authorized release of the following statement:

The Board of Directors of the American Gem Trade Association, in full support of the principles of gemstone treatment disclosure, recommends to its members and the trade that gemstone purchasers be made aware that natural stones are processed from the moment they are extracted from the earth by one or more of the following traditionally accepted trade practices:

- a. shaping, cutting, and polishing
- b. heating to effect a permanent change of color
- c. the application of colorless oil
- d. bleaching
- e. and more recently,
- f. nondetectable irradiation to effect a permanent change of color

It is not acceptable to offer for sale, without full disclosure, gemstones that have been subjected to the following treatments:

- f. dyeing, tinting, and laser drilling
- g. irradiation and heating when the color change is not permanent
- h. coating, glossing, and other surface modification
- i. impregnation, such as wax, paraffin, glass, plastic, and colored oil
- j. composite process, overgrowth, and surface diffusion

AGTA recommends to its members that all relevant information be readily provided to a prospective purchaser or consignee.

Any treatments not included in the list above, once brought to the attention of AGTA, will be considered as possible additions on a case-by-case basis. AGTA will be providing a more detailed list of all treatments, indicating the gemstones to which they apply.

GEMSTONES

By P. O'Neil, 176 pp., illus., publ. by Time-Life Books, Alexandria, Virginia, 1983. US\$19.95*

This book is one of Time-Life Books' Planet Earth series, which includes studies of the earth's geology, atmosphere, and oceans. This particular volume is an easy-to-read and beautifully illustrated introduction to gems and gemology.

O'Neil covers his topics in a series of chapters and photographic essays that include colored stones, diamonds, the diamond market, and gemstone formation and recovery. The introductory photo essay, "Riches in Rocks," establishes beauty, durability, and rarity as the distinguishing traits of a gemstone. The text and captions are brief, leaving the color photographs of rough and finished specimens of tourmaline, diamond, emerald, tanzanite, and 11 other gem materials to speak for themselves—and they do quite eloquently.

Chapter one, "The Flowers of the Kingdom," recounts some of the legends and histories of famous diamonds. It also includes a four-page mini-essay on gem mining in Sri Lanka. The accompanying photo essay, "The Inner World of Gemstones," is a visually stunning array of photomicrographs. The photos themselves reveal the wonder of gemstones under magnification, while the text explains how magnification can help us learn about gem formation.

Chapter two, "Earth's Crucibles of Creation," discusses gem formation, the origin and significance of optical and physical properties, the cause of color in gems, and synthesis. Excellent illustrations of unit cells and photographs of sample minerals elucidate "The Geometry of Gems," a photo essay on crystallography. The chapter ends with another excellent and attractive graphic essay on the rock cycle and gem deposit formation.

Vignettes and anecdotes of mining and trade from Mogok to Muzo to Yogo Gulch enliven chapter three, "The Lure of Colored Stones." "A

BOOK REVIEWS

Michael Ross, Editor

Deadly Quest for Emeralds" provides a dramatic, up-to-date account of emerald recovery in Colombia's Muzo Valley. Again, the pictures tell the story of rough terrain and grueling mining conditions, desperate smuggling, and sudden death.

Chapters four and five describe the evolution of the diamond market in the 20th century—from the initial scrambling of empire-builder Cecil Rhodes to De Beers's continuing struggle to maintain control of a geographically, economically, and politically diversified industry. The book closes with "A Gallery of Masterworks," eight outstanding examples of gem art bridging the period from Tutankhamen to Salvador Dali.

The treatment is essentially a journalistic survey rather than a comprehensive educational examination. The text is probably too general for the serious gemologist, but the book more than succeeds in communicating the excitement, beauty, and mystery of gemstones. This may inspire readers to a more serious investigation of gemology. This book is an excellent introduction to gemology—especially for young readers—and even the most avid gemologist would find it enjoyable.

CINDY RAMSEY
GIA Instructor

RECOVERY AND REFINING OF PRECIOUS METALS

By C.W. Ammen, 328 pp., illus., publ. by Van Nostrand Reinhold Co., New York, NY, 1984. US\$25.50

C.W. Ammen presents a practical guide to recovering and refining precious metals from both primary and

secondary sources. Jewelers will be especially interested in the sections on extracting and refining the precious metals from scrap jewelry, sweepings, and spent plating solutions. Ammen describes a variety of methods and "set ups," allowing readers to compare options and devise safe operations suited to their own particular needs. His explanations of wet chemical and electrochemical processes are straightforward and easily understood.

Special attention is given to the identification of "unknowns" using quantitative and qualitative analysis. Mr. Ammen also describes a variety of methods used in the recovery of precious metals from ores, black sands, old film, and catalytic converters, pointing out the particular hazards involved in each operation.

Although the text is fairly easy to read, the book does not lend itself to "cover to cover" readability. As a reference text, however, it is excellent—well organized and the material is complete. I recommend this book for the layman or jeweler interested in the recovery and refining of gold, silver or platinum.

JEAN PIERRE SAGET
GIA Instructor

OTHER BOOKS RECEIVED IN 1984

A Field Guide to Antiques and Collectibles, Jean Minar Paris, Prentice-Hall, 1984; 196 pp.; US\$8.95. This paperback book is aimed primarily at the flea market prowler and small town auctioneer who is looking for bargains. The period covered is 1880–1930 and the subjects range from silver to glass, with jewelry, clocks, and furniture sandwiched in. Although the chapter on jewelry is only 20 pages long, it gives the reader a series of tips on what to look for in terms of benchmarks and types of gems that might have been overlooked or undervalued by the dealer. Her two tenets are: "Never buy damaged" and "Never impulse buy." This is sound advice for any buyer.

Gem and Jewelry Year Book 1984, *Gem & Jewelry Information Centre of India (A-95, Journal House, Janta Colony, Jaipur-302 004)*; 1984; 216 pp.; US\$32.00. This tenth annual reference book of the Indian gem trade is divided into three parts. The first part covers India's gem trade, import and export statistics, machinery and equipment for the gem trade, a *Who's Who* in India, and a brief overview of the world's gem centers. Part two consists of eleven appendices covering such subjects as world organizations, study and training, mine localities, care of gemstones, India's tax and import information, and miscellaneous items of interest about gems. Part three contains a list of Indian gem and jewelry exporters, as well as a list (by country) of selected foreign importers and exporters. This is a useful resource manual for anyone dealing with the Indian gem trade.

Gemmology: Questions and Answers, *George W. Stevens, Gemmological Books and Instruments (Sydney, N.S.W. 2000, Australia)*, 1984, 85 pp.; US\$12.00. This spiral-bound, word-processor-typed booklet is the result of the author's efforts to study for and pass the exam given by the Gemmological Association of Australia. It is divided into two parts, Physical Gemmology and Applied Gemmology, and consists of posed questions with their answers in a random assemblage. An index for each part concludes

this work, which could serve as a supplemental study guide for some students of gemology.

The History of the Earth's Crust, *Don L. Eicher, A. Lee McAlester, and Marcia L. Rottman, Prentice-Hall, 1984, 198 pp.; numerous black and white photos, maps, sketches, and diagrams; US\$18.95*. One of a series of books published by Prentice-Hall on the earth sciences, this comprehensive work outlines and discusses modern theories on the formation of the earth's crust. The book moves chronologically from the earth's origin 5 billion years ago up to the appearance of Homo sapien. Easily understood by the lay reader, it is peppered with illustrations, photos, and graphs, and has an extensive bibliography and index.

Minerals and Rocks, 3rd ed., *J. F. Kirkaldy, Blandford Press, 1976, 184 pp.; 290 color illustrations plus numerous black and white diagrams and sketches; US\$9.95**. Eighty color pages of rocks and minerals begin this cap-sulized compendium of geology, followed by chapters that concisely present basic mineralogy and petrology concepts. A booklist of suggested reading, a glossary, and an index complete this pocket reference book.

Origin of Birthstones and Stone Legends, *M. T. Ghosn, Inglewood Lapidary (P.O. Box 701, Lomita, CA)*, 1984; 73 pp.; US\$2.95. This

book is comprised of lists and tables showing the various talismanic properties of several gemstones. Although there is no formal bibliography, the sources seem to be primarily biblical, with some mention of *The Curious Lore of Precious Stones* by Kunz and *Precious Stones* by W. B. Crow. The first 16 pages are devoted to Aaron's Breastpiece, with a final tally and consensus as to which gemstones were used for it. Other lists include stones of the Foundation, the Apostles, the Angels, the Twelve Tribes of Israel, and the Zodiac. The last page is given to a plea from the author for readers to submit knowledge of further gem legends and their sources.

Physical Geology: Principles and Perspectives, 2nd ed., *Edward A. Hay and A. Lee McAlester, Prentice-Hall, 1984, 463 pp.* This is a concise, current introduction to physical geology that covers the "essential principles of the subject—minerals, rocks, geologic time, earth structure, plate tectonics and land sculpture." Each of the 13 chapters is broken into sequential segments with important words and phrases highlighted and a multitude of drawings, photos, and diagrams. Each chapter ends with a summary outline and a list of additional reading. A glossary and index complete this fine textbook.

ELISE B. MISIOROWSKI
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Index to Volume 20

Numbers 1-4, 1984

SUBJECT INDEX

This index gives the first author (in parentheses) and *first page* of the article, Editorial Forum, 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.

A

- Abalone
 - pearls in (GTLN) 167
- Alexandrite effect, see Color change
- Amethyst
 - unusual natural inclusion in (GTLN) 106
- Anderson, Basil W. (Liddicoat) 1
- Aquamarine
 - from Minas Gerais, Brazil (Proctor) 78
 - occurrence in pegmatites (Shigley) 64
- Assembled stone
 - spinel-synthetic ruby doublet (GTLN) 228
- Asterism
 - in quartz (GTLN) 106
 - in quartz caused by growth phenomenon (GTLN) 228

B

- Beryl
 - dyed, as emerald substitute (GTLN) 167
 - with iridescent coating (GTLN) 45
 - occurrence in pegmatites (Shigley) 64
- Beryl, red
 - fake specimen (GTLN) 45
 - from Utah—history, geology, gemological properties, mineralogical data, inclusions, and production of (Shigley) 208
- Bixbite, see Beryl, red
- "The Black Ruby," see Spinel
- Book reviews
 - Castellani and Giuliano: Revivalist Jewellers of the 19th*

- Century* (Munn) 123
- Crown Jewels of Europe (Prince Michael of Greece)* 61
- The Emerald* (Mumme) 123
- Gem & Crystal Treasures* (Bancroft) 178
- Gemstones* (O'Neil) 247
- A Guide to Man-Made Gemstones* (O'Donoghue) 178
- Igneous Rocks* (Baker) 61
- Nature of Earth Minerals* (Tennissen) 61
- The Physics and Chemistry of Color* (Nassau) 123
- Recovery and Refining of Precious Metals* (Ammen) 247
- Brazil
 - emeralds from Santa Terezinha de Goiás (Cassedanne) 4
 - pegmatites of Minas Gerais (Proctor) 78
- Briolette of India diamond (Editorial Forum) 113

C

- Calcite
 - unusual gemstone with kaleidoscope effect (Hurlbut) 222
- Cat's-eye, see Chatoyancy
- Chatoyancy
 - in scapolite (GTLN) 45
 - in zircon (GTLN) 106
- Chrysoberyl
 - from Minas Gerais, Brazil (Proctor) 78
- Color
 - in freshwater pearls (Sweaney) 125
- Color change

- in pyrope-spessartine garnets (Manson) 200
- in spinel from Burma (GTLN) 228
- Color grading
 - of diamonds (Collins) 14
- Color shift
 - as differentiated from color change (Manson) 200
- Coral
 - dyed blue with plastic coating (GTLN) 45
- Corundum
 - color enhanced (GTLN) 228
- Cubic zirconia
 - inclusions in (GTLN) 167
- Cumingtonite-grunerite
 - as ornamental gem (GTLN) 106

D

- Diamond
 - coated (GTLN) 106
 - color grading by machine (Collins) 14
 - with large laser drill hole (GTLN) 45
 - phantom growth plane in (GTLN) 167
 - with step-like laser drill hole (GTLN) 45
 - unusual inclusion in (GTLN) 228
- Diamond, colored
 - color grading by machine (Collins) 14
- Diamond simulant, see Cubic zirconia
- Diamond, synthetic
 - chemical analysis of (Rossman) 163
 - magnetism in (Rossman) 163

synthesis and gemological
properties of (Koivula) 146
Diaspore
from Turkey (Editorial Forum) 113
Diopside
grayish lavender (GTLN) 106

E

Editorial
Anderson, B. W. (Liddicoat) 1
pegmatites (Liddicoat) 63
Emerald
chemical distinction of natural
from synthetic (Stockton) 141
natural and quartz imitation in
same necklace (GTLN) 228
oiled, reaction to heat (GTLN) 45
from Santa Terezinha de Goiás,
Brazil—location, history,
geology, mining, and
gemological properties of
(Cassedanne) 4
Emerald substitute
dyed beryl (GTLN) 167
Lechleitner synthetic emerald
overgrowth (GTLN) 167
quartz with green backing (GTLN)
228
Emerald, synthetic
chemical distinction from natural
(Stockton) 141
with iridescent coating (GTLN) 45
Enstatite (GTLN) 167
Estrela de Alva (Dawn Star)
aquamarine (Proctor) 78

F

Faceting
twinned calcite (Hurlbut) 222
First-order red compensator in
photomicrography (Koivula) 101
Fluorescence
in heat-treated ruby (GTLN) 106

G

Garnet
"fine green demantoids" (Editorial
Forum) 179
pyrope-spessartine, classification
of (Manson) 200
Gemmarum et Lapidum Historia
and gemstone treatment (Nassau)
22
General Electric synthetic diamonds
(Koivula) 146
Glass
as filling in rubies (Kane) 187
as inclusion in ruby (Kane) 187
Goethite
as inclusion in amethyst (GTLN)
106

H

Heat treatment
of aquamarine (Proctor) 78
early use of (Nassau) 22
of heliodor (Proctor) 78
of morganite (Proctor) 78
of ruby (GTLN) 106
of sapphire (GTLN) 228
of synthetic sapphire (GTLN) 106
Heliodor
from Minas Gerais, Brazil (Proctor)
78
Hematite
magnetic (GTLN) 45
Hemetine (GTLN) 45

I

Inclusions
in amethyst (GTLN) 106
in cubic zirconia (GTLN) 167
in diamond (GTLN) 106, 228
in emerald from Santa Terezinha
de Goiás, Brazil (Cassedanne) 4
of glass in ruby (Kane) 187
photography of, using first-order
red compensator (Koivula) 101
in quartz (GTLN) 106
in red beryl (Shigley) 208
in scapolite from Kenya (GTLN) 45
in spinel (Shigley) 34
in synthetic diamond (Koivula)
146
in taaffeite from Sri Lanka
(Gunawardene) 159
Irradiation
of topaz (Editorial Forum) 179

J

Jade, see Jadeite and Nephrite
Jadeite
detection of natural color in
(GTLN) 45

K

Kenya
cat's-eye scapolite from (GTLN) 45
Kunzite
from Minas Gerais, Brazil (Proctor)
78
occurrence in pegmatites (Shigley)
64

L

Lepidolite
with simulated matrix (Koivula)
42
Luminescence
in color grading of diamonds
(Collins) 14

M

Magnetism
in synthetic diamond (Koivula)
146, (Rossman) 163
Malaya, see Garnet
Marta Rocha aquamarine (Proctor)
78
Minas Gerais, see Brazil
Mineral fakes
manufactured lepidolite specimen
(Koivula) 42
synthetic ruby simulating red
beryl crystal (GTLN) 45
Mining
of emeralds at Santa Terezinha de
Goiás, Brazil (Cassedanne) 4
of pegmatite minerals in Minas
Gerais, Brazil (Proctor) 78
of red beryl from Wah Wah
Mountains, Utah (Shigley) 208
Morganite
occurrence in pegmatites (Shigley)
64

N

De Natura Fossilium and gemstone
treatment (Nassau) 22
Nephrite
artistically stained (GTLN) 106
dyed (GTLN) 45, (GTLN) 106

O

Opal
nickel-bearing (prase) from
Tanzania—gemological
properties and chemical and
X-ray analyses of (Koivula) 226
oolitic (GTLN) 228
sugar-treated (GTLN) 228

P

Padparadscha, see Sapphire
Papamel aquamarine (Proctor) 78
Papyrus Graecus Holmiensis and
gemstone treatment (Nassau) 22
Pearl substitute
glass (GTLN) 167
Mabe (GTLN) 106
mother-of-pearl to simulate Biwa
cultured pearls (GTLN) 167
Pearls
abalone (GTLN) 167
freshwater of North America—
history, harvesting, and
characteristics of (Sweaney) 125
hollow and filled (GTLN) 45
Pearls, cultured
dyed black (GTLN) 228
freshwater of North America—
history, characteristics, and
culturing of (Sweaney) 125

- freshwater from Tennessee,
X-radiograph of (GTLN) 228
"Keshi" (GTLN) 167
X-radiograph of (GTLN) 106
- Pegmatites**
definition, classification,
occurrence, gemstones, and
genesis of (Shigley) 64
of Minas Gerais, Brazil—history,
occurrence, geology, and mining
of (Proctor) 78
- Photomicrography**
Nikon award-winning picture
(Koivula) 140
use of first-order red compensator
in (Koivulua) 101
- C. Plinius Secundus (Pliny) and
gemstone treatments (Nassau) 22**
- Q**
- Quarto Centenario aquamarine
(Proctor) 78**
- Quartz**
asterism in (GTLN) 106
asterism due to growth
phenomenon (GTLN) 228
as imitation emerald (GTLN) 228
- R**
- Radioactivity**
in topaz (Editorial Forum) 179
- Ruby**
with glass-filled cavities,
detection and identification of
(Kane) 187
heat treated (GTLN) 106
- Ruby, synthetic**
flame fusion used to simulate red
beryl crystal (GTLN) 45
and spinel doublet (GTLN) 228
- S**
- Sapphire**
heat treated to produce red-purple
and pinkish orange
("padparadscha") stones (GTLN)
228
- Sapphire, synthetic**
Verneuil blue (GTLN) 106
- Scapolite**
cat's-eye from Kenya (GTLN) 45
- Sillimanite**
as inclusion in quartz (GTLN) 106
- Spectra**
of cape series diamond (Koivula)
146
of cobalt-blue spinel (Shigley) 34
of diamond (Collins) 14
of dyed nephrite (GTLN) 45
of emerald from Santa Terezinha
de Goiás, Brazil (Cassedanne) 4
of pyrope-spessartine garnets
(Manson) 200
of red beryl (Shigley) 208
of spinel (Shigley) 34
of synthetic diamond (Koivula)
146
of synthetic spinel (Shigley) 34
- Spectrophotometry**
applied to synthetic diamond
(Koivula) 146
- Spinel**
black (GTLN) 106
color change in (GTLN) 228
'cobalt-blue'—properties,
inclusions, chemistry, and
interpretation of (Shigley) 34
and synthetic ruby doublet
(GTLN) 228
- Sri Lanka**
taaffeite from (Gunawardene) 159
- Star effect, see Asterism**
- Stockholm Papyrus**
and gemstone treatments (Nassau)
22
- "Strawberry" quartz, see Quartz
- T**
- Taaffeite**
from Sri Lanka—inclusions in
(Gunawardene) 159
- Tanzania**
green opal from (Koivula) 226
- Topaz**
irradiated (Editorial Forum) 179
from Minas Gerais, Brazil (Proctor)
78
occurrence in pegmatites (Shigley)
64
- Tourmaline**
from Minas Gerais, Brazil (Proctor)
78
occurrence in pegmatites (Shigley)
64
treated with plastic (GTLN) 228
- Treatment**
of corundum to simulate ruby
(GTLN) 228
dyed black cultured pearls (GTLN)
228
early history of (Nassau) 22
glass-filled cavities in ruby (Kane)
187
iridescent coating on aquamarine
and synthetic emerald (GTLN)
45
irradiated topaz (Editorial Forum)
179
of tourmaline with plastic (GTLN)
228
of turquoise (GTLN) 167
- Turquoise**
treated with epoxy (GTLN) 167
- U**
- United States**
freshwater pearls from (Sweaney)
125
pearl culturing in (Sweaney) 125
red beryl from (Shigley) 208
- W**
- Wah Wah Mountains, Utah**
red beryl from (Shigley) 208
- X**
- X-ray fluorescence spectrometry**
used to distinguish natural and
synthetic emeralds (Stockton) 141
- X-radiography**
of pearls (GTLN) 45, 228
to separate cultured or imitation
from natural pearls (GTLN) 106,
167
- Z**
- Zircon**
cat's-eye (GTLN) 106

AUTHOR INDEX

This index lists, in alphabetical order, the names of authors of all articles that appeared in the four issues of Volume 20 of *Gems & Gemology*. Full citation is provided under the first author only, with reference made from joint authors.

C

- Cassedanne J.P., Sauer D.A.: The Santa Terezinha de Goiás emerald deposit, 4–13
Collins A.T.: Pitfalls in color grading diamonds by machine, 14–21

F

- Foord E.E., see Shigley J.E.
Francis C.A., see Hurlbut Jr. C.S.
Fryer C.W., see Koivula J.I.

G

- Gunawardene M.: Inclusions in taaffeites from Sri Lanka, 159–163

H

- Hurlbut Jr. C.S., Francis C.A.: An extraordinary calcite gemstone, 222–225

K

- Kampf A.R., see Shigley J.E.
Kane R.E.: Natural rubies with glass-filled cavities, 187–199
Kirschvink J.L., see Rossman G.
Koivula J.I.: The first-order red

- compensator: an effective gemological tool, 101–105
Koivula J.I., Fryer C.W.: Identifying gem-quality synthetic diamonds: an update, 146–158
Green Opal from East Africa, 226–227
Lepidolite with simulated matrix, 42–44

L

- Latendresse J.R., see Sweaney J.L.
Liddicoat Jr. R.T.
Basil W. Anderson, 1901–1984, 1
The magic of pegmatites, 63

M

- Manson D.V., Stockton C.M.: Pyrope-spessartine garnets with unusual color behavior, 200–207

N

- Nassau K.: The early history of gemstone treatments, 22–33

P

- Proctor K.: Gem pegmatites of Minas Gerais, Brazil: exploration,

occurrence, and aquamarine deposits, 78–100

R

- Rossman G., Kirschvink J.L.: Magnetic properties of gem-quality synthetic diamonds, 163–166

S

- Sauer D.A., see Cassedanne J.P.
Shigley J.E., Foord E.E.: Gem-quality red beryl from the Wah Wah Mountains, Utah, 208–221
Shigley J.E., Kampf A.R.: Gem-bearing pegmatites: a review, 64–77
Shigley J.E., Stockton C.M.: 'Cobalt-blue' gem spinels, 34–41
Stockton C.M.: The chemical distinction of natural from synthetic emeralds, 141–145
Stockton C.M., see Manson D.V. and Shigley J.E.
Sweaney J.L., Latendresse J.R.: Freshwater pearls of North America, 125–140

Indexes prepared by Dona Dirlam