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.

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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

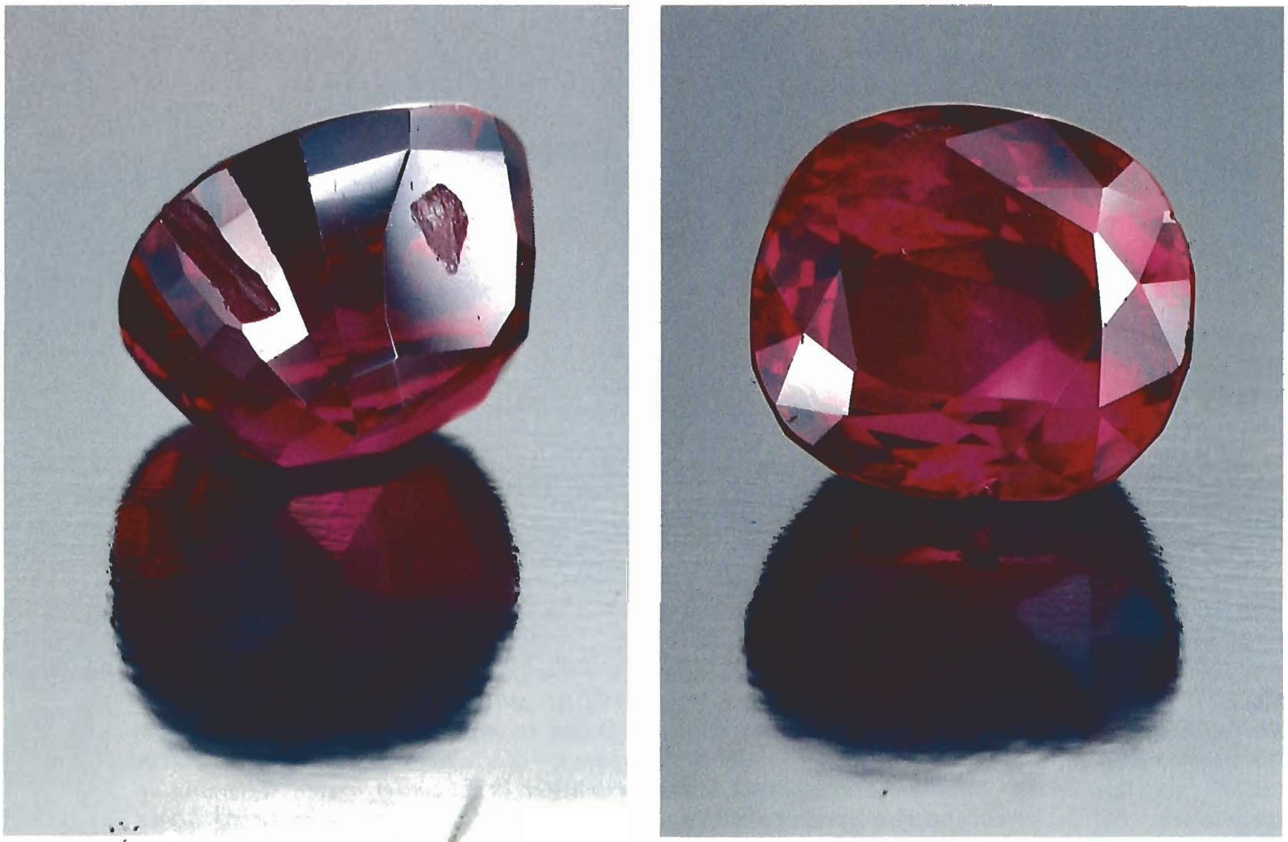


Figure 2. A 4.02-ct untreated Burmese ruby: the view on the left shows two of several large surface cavities present on the pavilion; the crown view on the right reveals that most of these cavities do not detract from the "face-up" beauty of this faceted ruby. Photo ©1984 Tino Hammid.

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

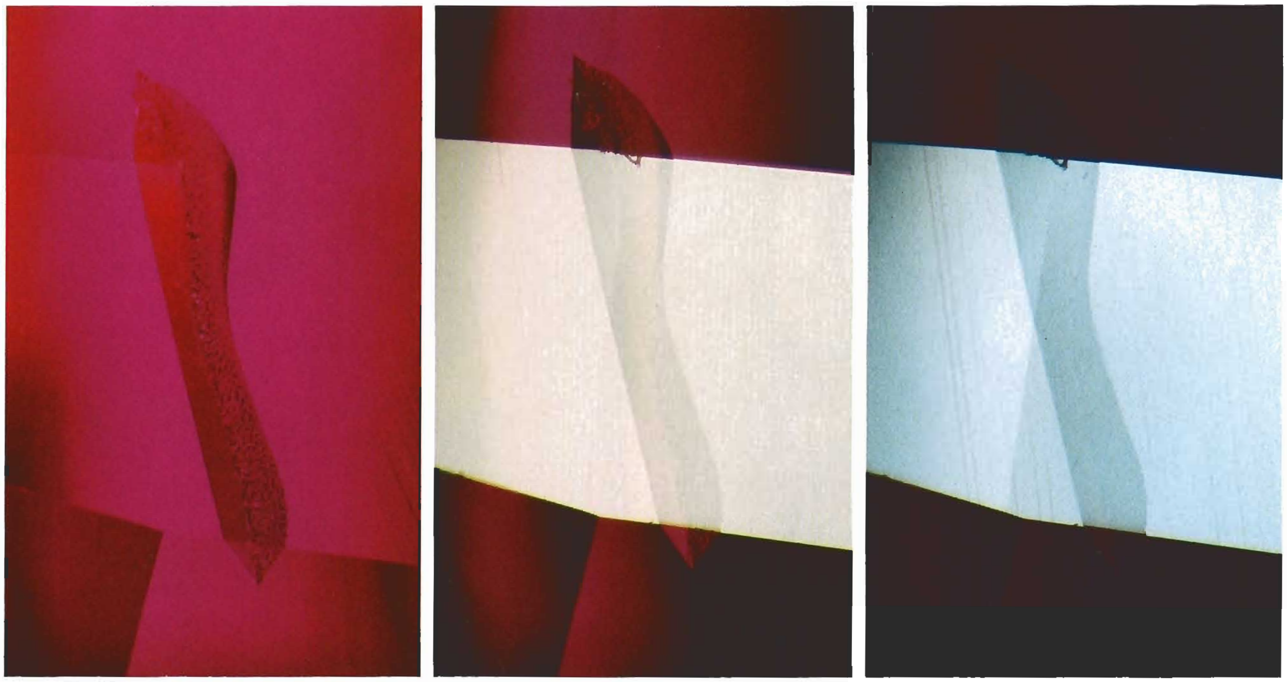


Figure 3. These three photomicrographs of a 2.8 × 0.4 glass-filled cavity in a 7.01-ct Burmese ruby illustrate how the appearance of the glass filling can change and be readily detected with different illumination techniques. On the left the difference in transparency of the glass and the ruby is evident 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×.

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.

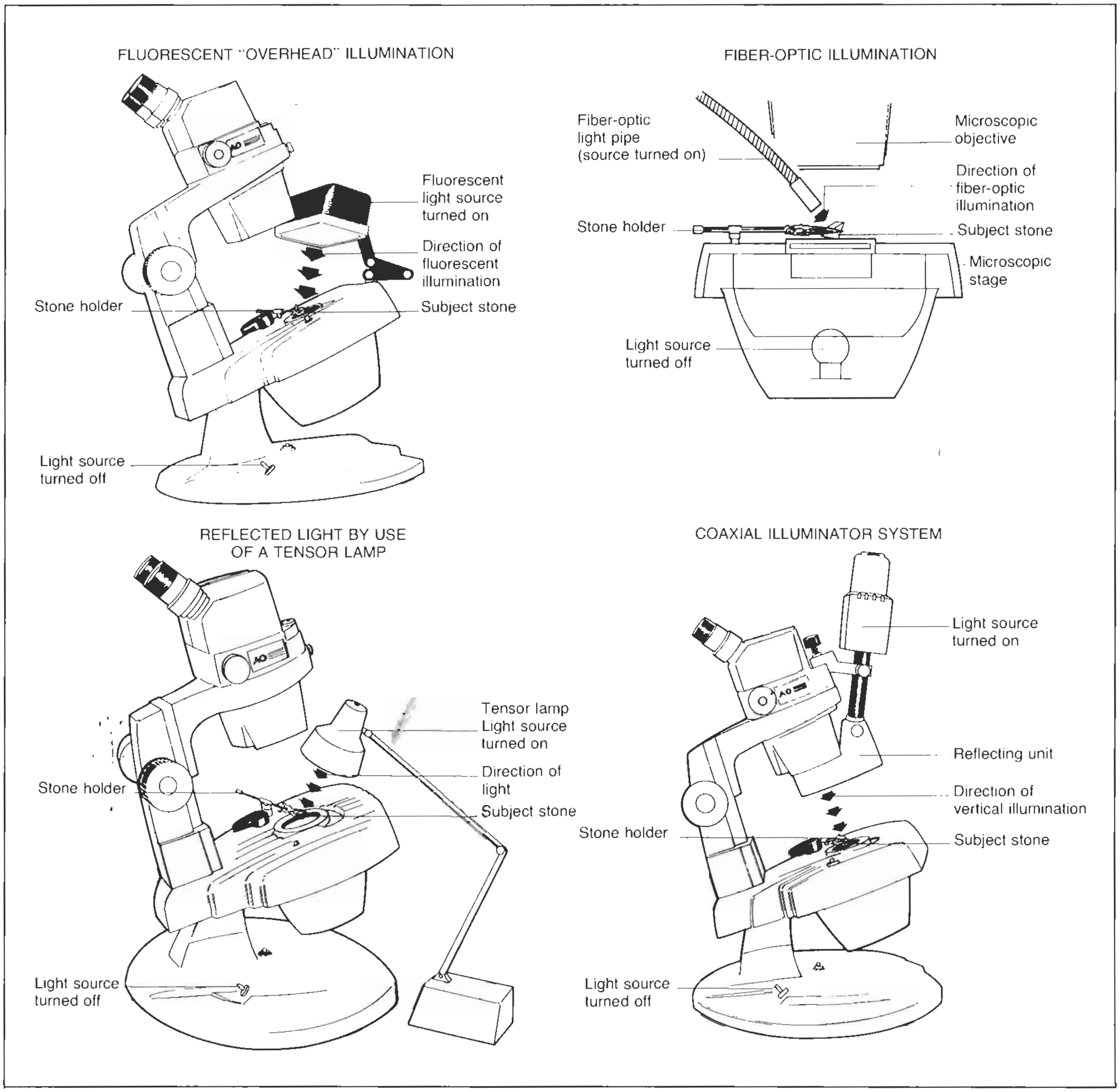


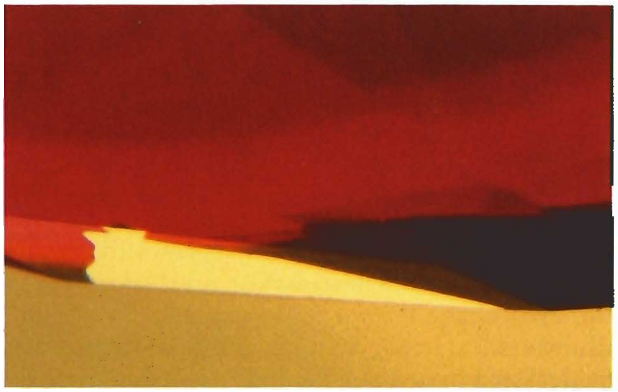
Figure 4. Reflected illumination is produced by positioning a light source near a 90° angle over the surface of the gemstone, so that only the surface is viewed; several methods can be used. For examining surface characteristics, the technique that is generally the easiest, fastest, and least harsh to 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 darkfield 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 strongly with the glass because of the differing refractive indices of the trapped gas and the glass filling.

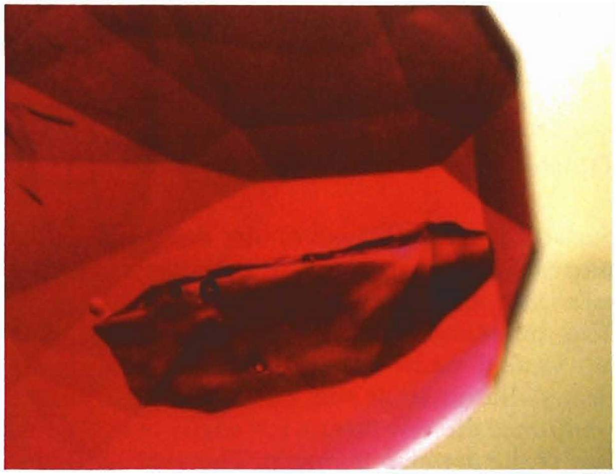
Figure 5. At specific viewing positions, the glass-filled cavity in this ruby from Thailand is observed to be colorless when immersed in methylene iodide. Diffused illumination, magnified 25×.



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 15×. Photomicrograph by Ricardo Cardenas.



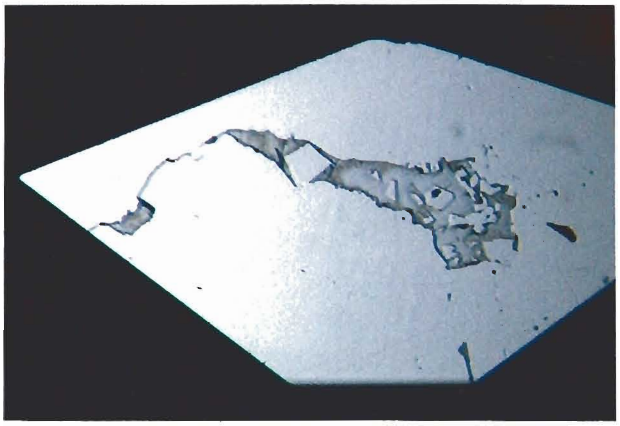


Figure 7. On the bezel facet of a Thai ruby, fiber-optic illumination is used to produce reflected light to accentuate very irregularly shaped glass-filled cavities that extend nearly half-way around the crown and deep into the interior. Magnified 50×.

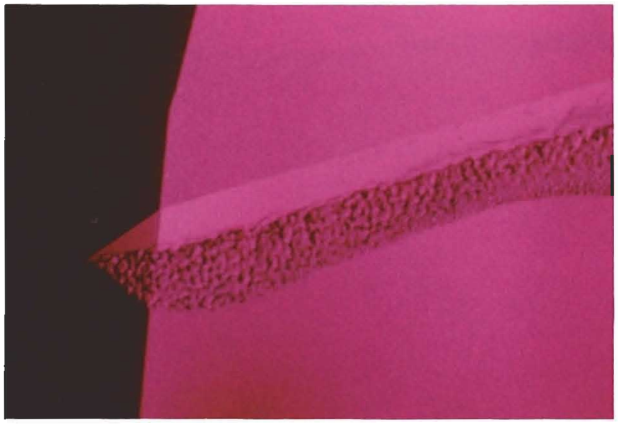


Figure 8. Uneven voids of trapped gas form one side of the junction between a large glass filling and the surrounding Burmese ruby. Dark-field and oblique illumination, magnified 100×.

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 × 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 ultraviolet 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.

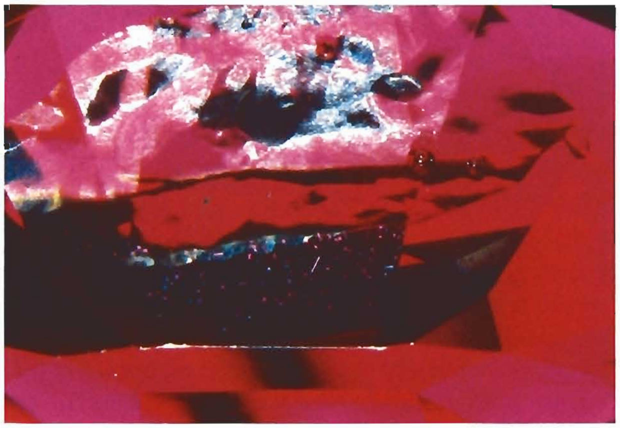


Figure 9. The uneven junction between this large glass-filled cavity and the surrounding Thai ruby is exemplified by a "heat-wave" appearance. Dark-field and oblique illumination, magnified 30×.

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).

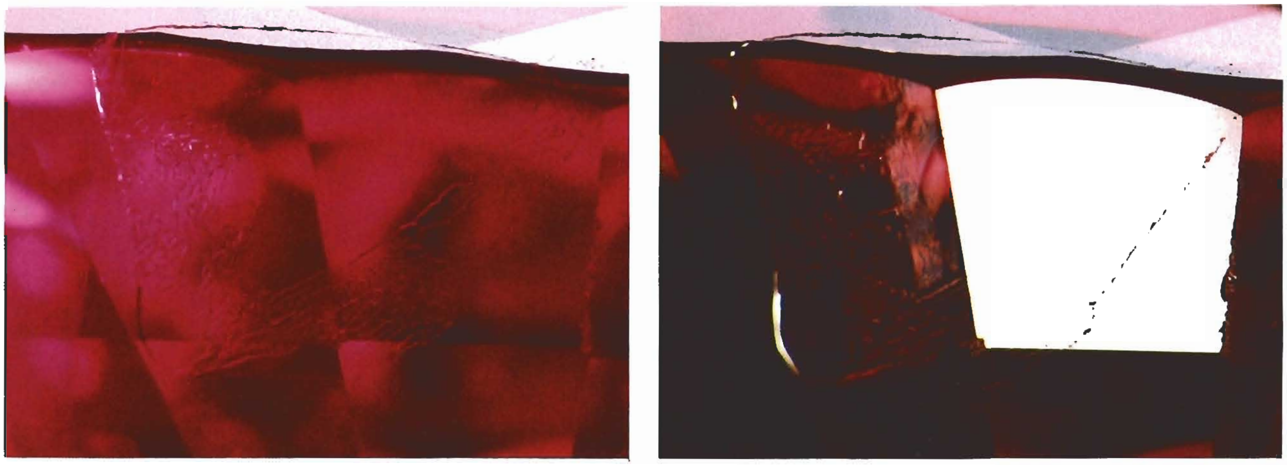


Figure 10. The ruby inclusion in ruby in these two photomicrographs could be mistaken for a glass-filled cavity. On the left, a large area of the ruby inclusion is seen in dark-field illumination with oblique illumination concentrated on the crown to accentuate an area of partial separation. The view 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×.

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°C for four to eight hours (Abraham, 1982). Because some of the inclusions that commonly occur in natural rubies have melting points below 1600°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 artifically 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.

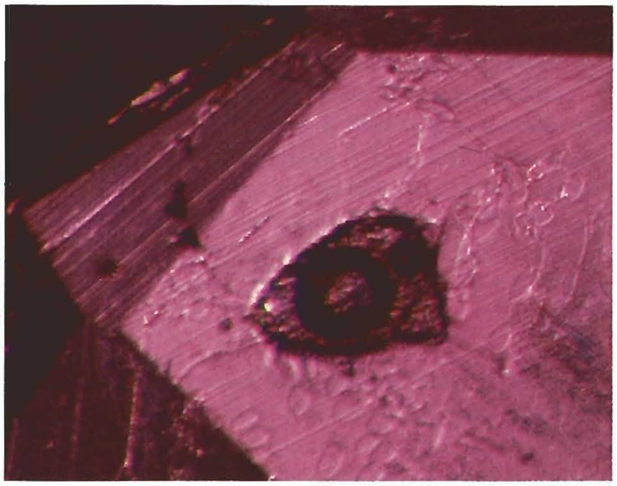
Out of dozens of faceted rubies with "natural" glass inclusions that were examined for this study, only the stone described above contained a glass inclusion that broke the surface. The most diagnostic visual characteristic of the natural glass inclusions in comparison to the artificially induced glass 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.



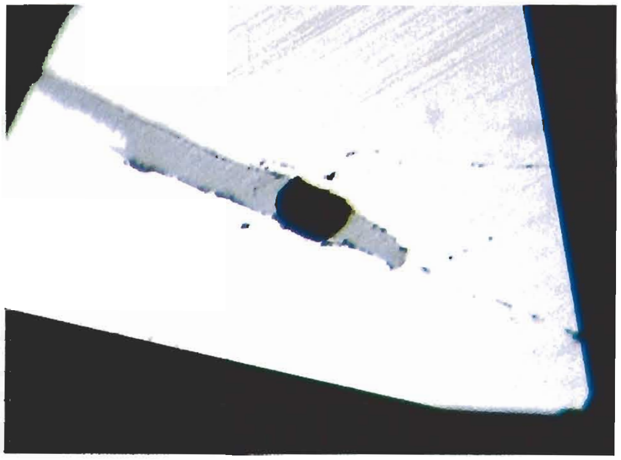


Figure 13. Reflected illumination accentuates one of the more than two dozen irregularly shaped glass-filled cavities in this Thai ruby that extend deep within the stone. The black area is a portion of the cavity that was not filled with glass. Dark-field and fiber-optic illumination. Magnified 75×.

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 alternative 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.

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×.

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_2O	MgO	Al_2O_3	SiO_2	K_2O	CaO	FeO[c]	TiO_2	Cr_2O_3	MnO	V_2O_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

[a] *These 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).*

[b] *Values represent the average of three analyses for each inclusion which were in close agreement with one another.*

[c] *Total iron reported as FeO.*

[d] *The 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.*

[e] *below 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 numerous 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 artifically 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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