DURABILITY TESTING OF FILLED EMERALDS

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Researchers treated 128 emeralds with nine emerald fillers—Araldite 6010, cedarwood oil, paraffin oil, unhardened and surface-hardened Opticon, a mixture of cedarwood oil and Canada balsam, surface-hardened Norland Optical Adhesive 65, and the solid fillers Gematrat and Permasafe—and then exposed them (along with 14 unfilled emeralds) to common conditions of wear and cleaning. All emeralds were held for about six years, and most were then subjected to one of the following durability tests: exposure to long-wave UV radiation (a component of sunlight), to mild heat and incandescent light in a display case, to five chill-thaw cycles, and to a desiccation environment; ultrasonic cleaning with either warm water or BCR; and cleaning with steam or mild chemical solvents. Changes were evident in about 35% of the filled emeralds after the mild exposure tests (i.e., time, UV radiation, display case); those with liquid fillers were especially susceptible. The desiccation environment made fissures visible in a majority of emeralds. Hard fillers damaged their host emeralds by expanding cracks during durability testing, while chill-thaw cycling extended cracks in both filled and unfilled emeralds. Emeralds with liquid fillers were most susceptible to appearance changes due to ultrasonic cleaning and exposure to ethanol or acetone. Some observations on the effectiveness of different fillers on emerald appearance are also provided.

The finest emeralds are renowned for their saturated, slightly bluish green color (figure 1). However, this beauty comes with disadvantages. Compared to diamonds, sapphires, and rubies, emeralds are softer and more brittle; they also are almost invariably included. As a result, emerald inclusion scenes are commonly romanced as *jardins*—the French word for "gardens"—by the retail world. Because inclusions and, especially, surface-reaching fissures detract from emerald's transparency and distinctive color, emeralds have been oiled—or *filled*—for centuries (see, e.g., Jennings et al., 1993; Weldon, 1997) to make these features less obvious.

In addition, open fissures in emeralds can collect polishing compounds, skin oils, and dirt. Internal fluid inclusions can break open (see, e.g., Koivula, 1980); likewise, solid inclusions can be plucked out during fashioning. Consequently, the vast majority of fashioned emeralds in the market today have some type of filling.

Over the last few decades, different sources and trading centers have tended to use different fillers for emeralds: cedarwood oil and Canada balsam in Colombia, paraffin oil (mineral oil) in Zimbabwe and Zambia, and Opticon in Brazil (see, e.g., Ringsrud, 1983; Kammerling et al., 1991; Koivula et al., 1993, 1994a; Kennedy, 1998; for more on the history of emerald filling, see the *G&G* Data Depository at www.gia.edu/gemsandgemology). Although these practices require disclosure, for many years fillers were used to enhance the appearance of emeralds without much public comment. In the 1990s, however, controversies erupted over the use of epoxies and similar substances to fill emeralds, as little was known about their durability and they were considered synthetic or "unnatural" by some in the trade. When these controversies were brought to the attention of consumers (see, e.g., Costanza, 1998; "Jewelry scene…," 1998), most of whom did not know that emeralds are customarily filled, the emerald market plummeted (see, e.g., Drucker, 1999).

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GEMS & GEMOLOGY, Vol. 43, No. 2, pp. 120–137.

Figure 1. Their saturated slightly bluish green color makes emeralds such as the Colombian stones in this suite quite popular with consumers. However, emeralds are commonly filled, and consumer and seller alike should be aware of potential durability problems under conditions of normal wear and care. Necklace (46.5 ct) and earrings (17.5 ct) courtesy of Grando, Inc., Los Angeles; photo by Harold & Erica Van Pelt.

In the late 1990s, GIA began a systematic study of emerald fillers. The goal was to understand what these filling substances were, how to distinguish them from one another, and how to characterize their effects on emeralds. The first article, Johnson et al. (1999), examined 39 possible filling substances and characterized their physical, optical, and spectroscopic properties. The second article, McClure et al. (1999), showed how to determine the extent to which an emerald is filled (an important factor in evaluating the quality of the emerald). The present article examines the changes in filled emeralds with time and with consumer-focused durability testing.

The durability and stability of 36 gem materials, including emerald, were reviewed by Martin (1987). Previous studies of filler durability were made by Kammerling et al. (1991) on cedarwood oil, Canada balsam, and surface-hardened Opticon in emeralds and other types of beryl; by Koivula et al. (1989) and Kammerling et al. (1994) on fracture filling in diamonds; and by C. M. Ou Yang on polymer-impregnated jadeite (see, e.g., Johnson and Koivula, 1996). Some specific durability tests were performed on emeralds with the solid fillers Gematrat and Permasafe ("New emerald process...," 1997; Ringsrud, 1998; Weldon, 1999), but information on these tests is limited.

BACKGROUND

What makes an emerald filler "ideal"? Participants at the First World Emerald Congress (held in Bogotá, Colombia, in 1998) agreed that it should be colorless and stable within the emerald (Lurie, 1998). It should also be permanent under routine conditions of wear and care, and yet easily removed if the emerald needs to be evaluated for recutting (Federman, 1998a).

Physical properties used to discriminate among fillers include their solid or liquid nature (liquids ooze out of fissures or move when approached by a hot point), viscosity, scent, and other properties not easily ascertained within an emerald, such as specific gravity. Optical properties include color and refractive index (RI); the latter determines how visible a filled feather is and whether it shows a "flash effect." Clues to the identity of the filling substance may also be provided by Fourier-transform infrared (FTIR) and Raman spectroscopy. For more on these properties, see Johnson et al. (1999) and Notari et al. (2002).

For the purpose of the present study, nine fillers were chosen to represent four important classes of commercial filling substances.

1. *Soft (liquid) fillers*: Araldite 6010 (sometimes called "palma"), cedarwood oil, unhardened Opticon, and paraffin oil
2. *Semi-hard (slow-flowing and possibly solidifying) fillers*: the 50:50 mixture of cedarwood oil and Canada balsam
3. *Surface-hardened fillers*: Norland Optical Adhesive 65 (a long-wave UV–setting adhesive, typically used fully hardened, but surface-hardened in this study) and Opticon
4. *Hard fillers*: Gematrat (Johnson and Koivula, 1997; Federman, 1998b) and Permasafe ("New type…," 1998; Michelou, 1999; Weldon, 1999)

This study did not include any of the less common fillers from Johnson et al. (1999), colored fillers such as green Opticon or Joban oil, or fillers developed since this study began, such as Groom's ExCel or ExCel 1.52 (see, e.g., Roskin, 2002, 2003; Gomelsky, 2003; "Myth of the month…," 2006). In addition, this study did not test the claim that emeralds become more brittle after treatment under pressure, the ease of removal of the filler and subsequent refilling, or the properties of emeralds that had been enhanced by more than one filler. The main objective was to determine whether the appearance of an emerald treated with a specific filler changed with time, exposure to a variety of environments, or cleaning.

MATERIALS AND METHODS

Samples. The study collection consisted of 142 fashioned emeralds, ranging from 0.16 to 4.24 ct and averaging slightly less than 1 ct. All important gem sources were represented: 49 from Colombia, 23 from Zambia, 12 from Brazil, and six from Zimbabwe. The remaining 52 were from unknown sources (see *G&G* Data Depository). These were mainly emerald cuts, but they also included cabochons and brilliant cuts of various shapes. Many of these samples were donated; the rest were taken from GIA collections. All had eye-visible, surface-reaching fissures, and most would have been graded as having moderate-to-significant enhancement after filling.

Most of the emeralds were cleaned (to remove preexisting stains or fillers in fissures) by Arthur Groom–Gematrat in New York, using a proprietary method. However, 16 emeralds filled with Permasafe and five filled with Gematrat were acquired already treated. Fourteen of the cleaned emeralds were retained unfilled for comparison purposes. Most of the remaining emeralds were treated at GIA using fillers acquired for Johnson et al. (1999) from sources listed in table 1 of that article. These fillers were: Araldite 6010 prepolymer resin; Merck cedarwood oil for clearing; Opticon 224 prepolymer resin, both without its catalyst and with surface hardening; Schroeder paraffin oil; a 50:50 mixture of cedarwood oil with Sigma Canada balsam; and Norland Optical Adhesive (NOA), type 65. The physical, optical, and spectroscopic properties of these fillers can be found in Johnson (1999). Most samples were filled at GIA using either a "Mini Oiler" (see, e.g., Koivula et al., 1994b) or a "Color Stone Oiling Unit" (again, see Johnson et al., 1999).

Fourteen emeralds were filled with NOA 65 and then exposed to long-wave UV radiation; however, leakage from some samples showed that the filler had not solidified below the surface. Hence, NOA 65 is considered a surface-hardened filler throughout this article, although it may not be so for other gem materials (or other emeralds). This incomplete hardening of the filler may have been due to the experimental procedure used here, as the output intensity of the long-wave lamp may not have reached the energy density recommend by Norland Optical. (Although NOA type 65 was used for this study based on information received from the emerald trade, the company currently recommends that type 71 be used for gemstone filling.)

Fifteen emeralds used in this study were filled with paraffin oil in vacuum chambers by Colgem Ltd. Eighteen were filled with a 50:50 mixture of cedarwood oil and Canada balsam by Ron Ringsrud using heat, vacuum, pressure, and refrigeration to approximate processes used in Colombia. Fourteen were filled with Opticon and then surface hardened

TABLE 1. Types of filled emeralds subjected to the 10 durability tests.

Filler type	Time only[a]	Long-wave UV	Display case	Chill-thaw cycling	Desiccation	Ultrasonic cleaning in water	Ultrasonic cleaning in BCR	Steam	Ethanol and acetone	Totals
None	2	1	2	2	2	1	1	1	2	14
Araldite 6010	1	2	1	2	2	1	1	2	1	13
Cedarwood oil	3	2	1	1	2	1	1	1	1	13
Unhardened Opticon	3	2	2	2	1	1	1	1	2	15
Paraffin oil	4	1	2	2	1	1	1	1	2	15
Canada balsam mixed with Cedarwood oil	4	2	1	2	2	1	2	2	2	18
Norland Optical Adhesive 65	2	2	2	2	1	1	1	1	2	14
Surface-hardened Opticon	2	2	2	2	2	1	1	1	1	14
Gematrat	1	1	2	1	1	1	1	1	1	10
Permasafe	2	2	2	2	2	1	1	2	2	16
Totals	24	17	17	18	16	10	11	13	16	142

[a] *Although all samples were stored for about 6 years, two samples were examined for both the time test and a different durability test (nos. 4477 and 4481). These two additional samples are not included in the "Time only" total.*

by Ray Zajicek. Details of their methods are provided in the *G&G* Data Depository. Five emeralds were filled with Gematrat by Arthur Groom–Gematrat. Twenty-one emeralds, mentioned above, were obtained pre-filled with Permasafe or Gematrat. All filling work was performed in 1998 and early 1999.

The filled emeralds were rechecked after treatment for standard gemological properties (such as RI, specific gravity, and weight), and 57 stones with larger fissures were selected for FTIR characterization of their fillers. Macrophotographs of 110 emeralds were taken and then the emeralds were set aside to await durability testing. These durability tests were performed in 2004–2006, following a period of about six years to allow for changes of the fillers with time.

Durability Testing. Ten tests were chosen to assess the durability of the various commercial emerald fillers: time alone (~6 years), exposure to long-wave UV radiation (a component of sunlight), exposure to heat and incandescent light in a display case, multiple chill-thaw cycles, one year in a desiccation environment, ultrasonic cleaning with either warm water or buffing compound remover (BCR), and cleaning with steam or two mild organic solvents. These tests, which are described in detail in box A, were selected to mimic likely causes of changes in the appearance of filled emeralds in retail and consumer environments. Note that all 142 samples were exposed to the passage of time and, where photos were available, checked against those photos before further durability testing. Detailed observations of changes with time alone were made of 26 samples treated with the different fillers or left untreated and then classified into four degree-of-change categories: obvious, slight, very slight, and no changes observed (see below). The degrees of change due to time in the remaining samples were not categorized but were assessed for their appropriateness for additional durability testing. Then, 118 emeralds were each subjected to an additional exposure or cleaning test (again, see box A).

Durability tests are typically conducted by cutting each sample into multiple parts and testing each part (see, e.g., Johnson and Koivula, 1996). However, the fissures in the emeralds were not evenly distributed throughout the stones, and a goal of this study was to monitor the effect of the durability tests on the overall appearance of fashioned emeralds. Therefore, this study took a different approach, and instead compared emeralds to photographs.

The original emerald-filler study began with 181 emeralds, and at least two emeralds were intended for each filler and each durability test. However, after the original filler study (Johnson et al., 1999), some samples were set aside for other experiments. The remaining 142 samples discussed here were examined and allocated such that each filler was represented in each test (table 1); however, the most-changed samples were allocated to the time test (with the rest randomly distributed among the remaining tests).

Imaging Protocol. Usable photos were taken of 115

BOX A: DURABILITY TESTING

For this study, 10 tests were conducted—five representing exposure during normal wear, display, and storage of emerald-set jewelry; and five representing techniques that might be encountered in cleaning an emerald—as described below.

1. Exposure to the passage of time

Goal: There is anecdotal evidence that some emerald fillers deteriorate or leak out with time, which this test sought to investigate.

Test description: The best method for assessing the impact of time is, simply, to allow time to pass. In an examination of tests for archival materials in other disciplines, we found no other test that exactly duplicated time's effects (see, e.g., "Rate of paper degradation …," 2001). The sample emeralds were kept in a sealed container (a zippered plastic bag) in ambient conditions (usually in the dark, but occasionally exposed to fluorescent lighting, in an office in southern California with heating/air conditioning on workdays only). This also provided a standard for comparison for changes from more active tests.

After noting how much time had passed since filling, 26 of the emeralds were compared against a photo of their appearance immediately following filling.

2. Exposure to long-wave UV radiation

Goal: Long-wave UV (at about 365.4 nm) may have an effect on filled emeralds (as previously shown for fracture-filled diamonds; see, e.g., Kammerling et al. 1994). This type of radiation is also found in sunlight, so long-wave UV testing mimics one aspect of long-term exposure to sunlight. (Short-wave UV was not used, because it is not a significant component of sunlight.)

Test description: Seventeen emeralds were placed face-up, about 2.5 cm away from the filtered source of long-wave UV radiation from a GIA four-watt long-wave/short-wave unit, within a viewing cabinet. Emeralds were exposed for 200 hours (corresponding to 3,400 hours [~9 months] of exposure to sunlight, according to Kammerling et al., 1994). After this time, the emeralds were reexamined.

3. Exposure in a display case

Goal: The appearance of a filled emerald may change over time in the light and mild heat of a display environment. This test was an attempt to monitor that effect.

Test description: A display case was set up with a black velvet background and placed under three 50-watt halogen lights (using the manufacturer's recommendation for distance of 4 feet, [~1.2 m]); temperatures of 25.9–26.3°C were recorded in the case. Seventeen emeralds were arranged in the center of the case (directly under a light), and exposed to 720 hours of illumination (equivalent to thirty 24-hour days) in 128-hour continuous intervals, then reexamined.

4. Exposure to chill-thaw cycling

Goal: Temperature changes (such as might be caused by wear in cold climates) may affect filled emeralds. This test was also performed on fracture-filled diamonds by Kammerling et al. (1994).

Test description: Eighteen emeralds were placed in two layers of sealed clear plastic bags in aluminum foil (as barriers to humidity changes) sitting on ice in a refrigerator overnight (measured air temperature 9°C). The bags were removed and allowed to thaw for an hour or so, then the emeralds were examined while in their inner bags to check for drastic damage. The emeralds were wrapped again and rechilled, for a total of five chill-thaw cycles.

5. Exposure to dry air (desiccation)

Goal: There are many claims in the trade press that emerald fillers can "dry out." To test these reports, the filled emeralds were exposed to a desiccation environment (storage at ambient temperature in a dry chamber with a silica gel desiccant). This test was designed to simulate consumer storage (e.g., in a bank vault) and is relevant to wear in dry climates.

emeralds after cleaning and, as appropriate (since some were left unfilled), before filling; "before" photos were not available for 21 emeralds that were acquired already filled. Shortly after filling, 110 samples were photographed; 24 filled samples were photographed after six years had elapsed and before the durability tests that followed. Due to other exigencies, not all samples could be photographed immediately before filling, after filling, or after the time test. Therefore, the comparison used to gauge the effect of the durability test on the emerald's appearance was either a photo taken immediately after filling or one taken six

Test description: Sixteen emeralds were placed on transparent glass dishes in a clear-windowed closed chamber with a desiccant (a 40 g unit of Hydrosorbent silica gel that included indicator beads; see www.dehumidify.com). The emeralds were examined visually once a week through the windows of the chamber, and were removed and checked for damage monthly, then returned to the chamber. After one year, the emeralds were removed from the chamber and reexamined.

6. Cleaning: ultrasonic cleaning in water

Goal: Ultrasonic cleaners use vibration in a heated liquid (e.g., water or a jewelry cleaner) to loosen and "shake off" dirt particles. The combination of heat, vibration, and the immersion liquid may affect the appearance of a filled emerald.

Test description: Ten emeralds were placed loose in three batches in beakers with 40 mL of tap water in a Gesswein Ultrasonic Cleaner model 87 and allowed to "clean" for 30 minutes, while the temperature was monitored (it increased from 33°C to 63°C during the process). The emeralds were rinsed in tap water, dried in air, and reexamined.

7. Cleaning: ultrasonic with cleaning solution

Goal: Typical jewelry cleaning with a cleaning solution in an ultrasonic cleaner may have a greater impact on the appearance of a filled emerald than vibrating in water alone. This test was an attempt to monitor that effect.

Test description: Eleven emeralds were placed loose in three batches in beakers of common jewelry cleaner Oakite Buffing Compound Remover (BCR; see, e.g., http://www.landainternational.com/catalog/prod226.shtml) in a Gesswein Ultrasonic Cleaner model 87 and allowed to clean for 30 minutes, while the temperature was monitored (it increased from 39°C to 63°C during testing). The emeralds were rinsed several times in tap water, allowed to dry in air, and reexamined.

8. Cleaning: steam

Goal: Since jewelry is often steam cleaned (although this cleaning technique is usually not recommended for emeralds), we wished to see whether steam cleaning affects the appearance of a filled emerald. These emeralds were cleaned for shorter times than tests involving filled diamonds (see, e.g., Koivula et al., 1989; Kammerling et al., 1994) or other beryls (Kammerling et al., 1991) due to the less durable nature of emeralds.

Test description: The tables of 13 emeralds were steam cleaned for 30 seconds, using a Gesswein portable steam generator, with the emeralds held in rubber-tipped tweezers. After drying in air, they were reexamined.

9. Cleaning: mild chemical solvent (ethanol)

Goal: Since fillers are carbon-based (i.e., organic) chemicals, often they can be dissolved by various alcohols (which are also organic chemicals). Hence, we wished to see whether exposure to a common mild solvent such as ethanol would affect the appearance of emeralds filled with the different substances.

Test description: Sixteen emeralds were placed in high-purity ethanol (denatured, high-purity liquid chromatography [HPLC] grade) in two beakers held for 24 hours in a fume hood. Room temperature was 21°C. The emeralds were removed from the ethanol, dried in air, and then reexamined.

10. Cleaning: stronger, but still relatively mild chemical solvent (acetone)

Goal: Ethanol is considered a very mild solvent for organic chemicals such as oils and resins. Hence, a slightly stronger common solvent may show a more pronounced effect on the appearance of filled emeralds, and it is common practice to try first with the weakest solvent. Acetone is also a component in fingernail polish remover, so this test might have bearing on some accidental damage in the home. Possibly, cleaning in acetone alone might have different results than cleaning in acetone after ethanol.

Test description: The 16 emeralds used in test 9 were examined (compared to macrophotographs to categorize their appearance) and then placed for 24 hours in two beakers filled with spectroscopic-grade acetone (Aldrich Chemical Company no. 15,459-8) in a fume hood at 22°C. The emeralds were then removed from the acetone, dried in air, and compared with the pretest images.

years after filling and immediately prior to the durability test. This protocol necessitated that we split the reporting of the data for each durability test into two categories: one in which the comparison includes the effects of time (i.e., "test + time") and one in which the comparison photo already shows the effect of time (i.e., "test"). In most cases, photos were also taken after the durability tests.

Although filled emeralds can look quite different owing to choices of lighting among the various photographers (e.g., figure 2) and the use of film (as in the earliest images) or digital (such as those taken

Figure 2. This emerald, filled with a mixture of cedarwood oil and Canada balsam (no. 4728; left), had an obvious change due to ultrasonic cleaning in BCR (right). However, the appearance of the emerald in these photos, along with all the emerald photos, was influenced by changes in the choice of positioning, intensity of light, film, and processing choices by the different photographers. Therefore, the fissures visible parallel to the long axis of the emerald are not as evident in the right image, and the emerald's color looks different.

Figure 3. Changes in emerald appearance after durability tests (before, left; after, right) were divided into four categories: obvious (no. 4706, 0.79 ct, ultrasonic cleaning in water); slight (no. 4633, 1.09 ct, ultrasonic cleaning in BCR); very slight (no. 4936, 2.95 ct, steam cleaning); and no observed changes (no. 4757, 0.46 ct, ethanol and acetone cleaning).

immediately before and after the durability testing), the positions of fissures did not change. In this article, the backgrounds have been made uniform to facilitate the comparisons and the color of some images has been adjusted to more closely match the actual color of the stone at the time of the observation. The images were not otherwise manipulated.

Observations of Overall Appearance. It was usually possible to reproduce the overall appearance of an emerald in a photo by holding the stone under a high-intensity incandescent lamp, shifting its position, and then comparing the appearance of the emerald itself to its archived image on a computer monitor. The following factors were noted: any change in visibility of fissures and other inclusions to the unaided eye; any discoloration or change in transparency of the filler; and overall changes in transparency and color distribution in the emeralds.

For comparison purposes, changes in emerald appearance (with the table up) due to durability testing were put into four categories (figure 3), listed here from greatest to least change:

- *Obvious*: The after-testing emerald differed from the before-testing image at first glance, and varying the lighting environment could not make the emerald match the photo.
- *Slight*: The after-testing emerald resembled the before-testing image at first glance, but further examination of the emerald showed some change.
- *Very slight*: Only subtle changes were seen in careful examination of the after-testing emerald and the before-testing image. These were confirmed by microscopic examination of the emerald.
- *No observed changes*: No changes were seen, even with careful examination. Note, however, that microscopic examination, or photography from a different direction (e.g., of the pavilion side), might have revealed differences in appearance.

Spectroscopy. Infrared spectra were taken in reflectance mode using a Nicolet Magna 550 Fourier-transform infrared (FTIR) spectrophotometer and its successors; details of spectral acquisition methods were published in Johnson et al. (1999). FTIR spectra were recorded for 57 emeralds (not all of which are included in table 1) with evident filled fissures. The goals were to see if quantitative measurements of filler loss could be made and to monitor any change in the FTIR spectra due to durability testing. All FTIR data are provided in the *G&G* Data Depository.

RESULTS

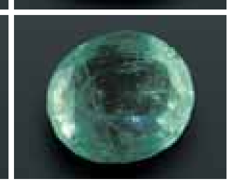
Initial Effectiveness of Emerald Fillings. Although this research did not focus on the effectiveness of the fillers, we did observe the changes in appearance they produced. The most dramatic examples for eight of the fillers—those that had the greatest impact on apparent clarity—are shown in table 2. It is possible that a professional filling laboratory would have been even more effective. The examples provided in table 2 show that the presence of a filler can improve the apparent color distribution in emeralds, by getting rid of "white" areas caused by air-filled feathers.

Durability Testing. The results for the durability tests are provided in table 3. The following types of changes were seen: Feathers were more evident, had opened up at the surface (cavities in the fissures were visible with magnification), leaked (oily fluid leaking out of fissures was visible with magnification), delaminated (a new opening along one side of the filler in the fissures was seen with magnification), extended (the length of the fissures increased), and new feathers were seen. Also, the filler deep within fissures could crystallize or turn cloudy. As expected, these durability tests had no observed impact on the unfilled emeralds, with one exception (no. 4806), which reacted to the chill-thaw cycles.

FTIR spectra proved not to be useful for tracking differences over time, since almost all filled emeralds tested had some filler left after several years, and we found that the amount of filler indicated in the spectra depended on the path light took through the emerald. In no case did we see any changes besides intensity in the spectral features of the filler.

Time. Thirteen of the 23 filled emeralds showed *no observed* change with time (see table 3). The emerald filled with Araldite 6010 showed a *very slight* change, a cloudy band throughout the stone (figure 4). *Slight* changes were seen in six emeralds: two filled with cedarwood oil (emptying of feathers), two filled with paraffin oil (whitening at the surface or crystallization at depth: figure 5), one filled with a mixture of cedarwood oil and Canada balsam (feather more evident), and one filled with surface-hardened NOA 65 (feathers leaking fluid onto their surface). Three emeralds showed *obvious* changes (feathers opening up) due to time alone—two filled with unhardened Opticon and one filled with paraffin oil (figure 6).

TABLE 2. Changes in emerald appearance according to filler type.[a]

Filler/Sample no.	Before filling	After filling
Araldite 6010 No. 4508[b]		
Cedarwood oil No. 4479[b]		
Unhardened Opticon No. 4578[c]		
Paraffin oil No. 4922[d]		
A 50:50 mixture of Canada balsam and Cedarwood oil No. 4495[b]		
Norland Optical Adhesive 65 No. 4710[e]		
Surface-hardened Opticon No. 4923[d]		
Gematrat No. 4708[e]		

[a] *Due to lack of "before" images, emeralds filled with Permasafe are not included in this table. All photos in this table were taken by Maha Calderon.*
[b] *From Colombia.* [c] *From Zambia.* [d] *From Zimbabwe.* [e] *From Brazil.*

Exposure to Long-Wave UV Radiation. No changes were observed in 13 of the 16 filled emeralds with exposure to long-wave UV radiation, and none showed *obvious* changes. An emerald filled with

TABLE 3. Observed changes in the emeralds categorized according to durability tests and filler type.[a]

Durability test	No filler	Soft (liquid) fillers				Semi-hard fillers
		Araldite 6010	Cedarwood oil	Unhardened Opticon	Paraffin oil	Cedarwood oil mixed with Canada balsam
Time only	No observed change (4477, 4502, 4596)	Very slight (4584)	No observed change (4481,4719); Slight (4479, 4704)	No observed change (4515); Obvious (4763, 4799)	No observed change (4774); Slight (4599, 4640); Obvious (4747)	No observed change (4702, 4742, 4917); Slight (4800)
Long-wave UV	No observed change (4707*)	No observed change (4566); Very slight (4506)	No observed change (4744); Slight (4777)	No observed change (4585, 4937)	No observed change (4563)	No observed change (4598); Slight (4770)
Display case	No observed change (4477*, 4587)	No observed change (4574)	Slight (4638*)	No observed change (4486); Slight (4594*)	No observed change (4493); Very slight (4934)	No observed change (4492)
Chill-Thaw cycling	No observed change (4472*); Slight (4806)	No observed change (4950*); Slight (4508)	No observed change (4481*)	No observed change (4500); Slight (4478)	No observed change (4511*, 4801)	No observed change (4751); Obvious (4505)
Desiccation	No observed change (4755, 4919)	No observed change (4570*); Slight (4775)	Very slight (4507); Slight (4920)	Obvious (4807*)	Very slight (4593)	Slight (4470, 4715)
Ultrasonic cleaning in water	No observed change (4568)	Slight (4931)	Obvious (4576*)	Obvious (4706)	Slight (4739)	Slight (4495)
Ultrasonic cleaning in BCR	No observed change (4930)	Obvious (4600)	Obvious (4804)	Slight (4722)	Obvious (4484)	Slight (4633); Obvious (4728)
Steam	No observed change (4636)	No observed change (4592); Slight (4938)	Very slight (4513*)	No observed change (4918)	Slight (4952*)	No observed change (4483*, 4569)
Ethanol	No observed change (4720, 4786)	Obvious (4797)	Obvious (4735)	Obvious (4578, 4814)	Slight (4922); Obvious (4716)	Slight (4639); Obvious (4773)
Ethanol + Acetone	No observed change (4720, 4786)	Obvious (4797)	Obvious (4735)	Obvious (4578, 4814)	Obvious (4716, 4922)	Obvious (4639, 4773)

[a] *Sample numbers are given in parentheses. Note that although all samples showed the effect of time, some samples only had comparison photos that were taken prior to the time exposure, so the changes reported reflect both the effect of time and the additional test (i.e., test + time). However, some samples had comparison photos taken only after the time exposure, so the changes reported reflect only the difference seen with the additional durability test (i.e., test only, as indicated by an asterisk).*

Araldite 6010 showed a *very slight* change, with a feather near the tip slightly more evident. Two emeralds showed *slight* changes: One filled with cedarwood oil and one with a mixture of cedarwood oil and Canada balsam had feathers open up.

Display Case Environment. Nine of the 15 filled emeralds showed *no observed* change. Two emeralds showed *very slight* changes: One filled with paraffin oil showed crystallization similar to that seen in figure 5, while feathers looked more evident in a Permasafe-filled emerald. Three emeralds had *slight* changes: Feathers were more evident in a cedarwood oil–filled emerald, a surface feather had opened up in an emerald filled with unhardened Opticon, and a deep feather appeared to be opening up in an NOA 65–filled emerald. One of the two Gematrat-filled emeralds showed an *obvious* change (figure 7), with feathers opening up at the surface.

Figure 4. A 1.48 ct emerald filled with Araldite 6010 (no. 4584; left, immediately after filling) showed a very slight change with time (center): a cloudy band throughout the stone that became more evident (right; magnified 15×).

Surface-hardened fillers		Hard fillers—rigid solids	
Norland Optical Adhesive 65	Surface-hardened Opticon	Gematrat	Permasafe
No observed change (4733); Slight (4573)	No observed change (4586, 4785)	No observed change (5347)	No observed change (5583, 5587)
No observed change (4772, 4794)	No observed change (4504, 4575)	No observed change (5344)	No observed change (5586, 5589*)
No observed change (4565); Slight (4494)	No observed change (4567, 4622)	No observed change (4473*); Obvious (4708)	No observed change (5585); Very slight (5574)
No observed change (4810, 4949*)	No observed change (4942*); Slight (4745)	Obvious (4816*)	No observed change (5578, 5579)
No observed change (4796)	No observed change (4805); Very slight (4923)	Obvious (91843)	No observed change (5582); Slight (5452*)
Slight (4444*)	Very slight (4475)	No observed change (5357*)	No observed change (5573)
Slight (4710)	Very slight (4729*)	Slight (5356)	No observed change (5581)
No observed change (4749)	Very slight (4936)	Slight (5350*)	No observed change (5588); Very slight (5580)
No observed change (4581, 4757)	No observed change (4721)	Slight (4795)	Very slight (5575); Slight (5576)
No observed change (4757); Slight (4581)	Slight (4721)	Slight (4795)	Very slight (5575); Obvious (5576)

Chill-Thaw Cycles. One of the two unfilled emeralds showed a *slight* change in appearance, with more extended fractures. Eleven of the 16 filled emeralds had *no observed* change. Three filled emeralds showed *slight* changes: Feathers were slightly more evident in an emerald filled with Araldite 6010, there was a fresh-looking feather on the bezel of an emerald filled with unhardened Opticon, and filler was oozing out of an emerald filled with surface-hardened Opticon. An emerald filled with a mixture of cedarwood oil and Canada balsam (figure 8) had an *obvious* appearance change, with a glassy feather on the pavilion now visible through the crown. Feathers had extended and cracked further in an emerald filled with Gematrat, causing an *obvious* change in appearance (figure 9). The changes in this last emerald and the unfilled one that was altered are particularly significant in that the emeralds themselves—not just the fillers—were damaged.

Desiccation. Four of the 14 filled emeralds had *no observed* changes. Three emeralds showed *very slight* changes: One filled with cedarwood oil and one filled with surface-hardened Opticon showed very slightly more evident feathers; and one that was filled with paraffin oil showed surface feathers opening up subtly. Five emeralds showed *slight* changes: One filled with Araldite 6010, one filled with Permasafe, and two filled with a mixture of cedarwood oil and Canada balsam showed slightly more evident feathers; while one that was filled with cedarwood oil showed feathers appearing to open up at depth. Two filled emeralds—one with unhardened Opticon (figure 10) and one with Gematrat—showed *obvious* changes, in the form of more prominent feathers.

Ultrasonic Cleaning in Water. The two emeralds filled with Gematrat or Permasafe had *no observed* changes. The emerald filled with surface-hardened Opticon had a *very slight* change, with feathers open at the surface. Four emeralds showed *slight* appearance changes: Surface-reaching feathers were opened up more in the emeralds filled with Araldite 6010 and paraffin oil; and fissures were more evident in the emerald filled with a mixture of cedarwood oil and Canada balsam and the one filled with NOA 65. The emerald filled with cedarwood oil (figure 11) not only had *obvious*, open fissures, but with magnification it also revealed material leaking onto its surface. Similarly, several feathers had

Figure 5. A 0.74 ct emerald filled with paraffin oil (no. 4599; left, after filling) showed a slight change with time (center): crystallization at depth (right, magnified 35×).

Figure 6. This 3.57 ct emerald filled with paraffin oil (no. 4747; left) showed obvious changes due to time alone (center). Feathers, especially to right of center, were observed as more open (right, magnified 40×).

opened up in the unhardened Opticon–filled emerald (again, see figure 3), an obvious change.

Ultrasonic Cleaning in BCR. All the filled emeralds except the one that was filled with Permasafe showed changes with this test. The emerald filled with surface-hardened Opticon showed a *very slight* change, with open feathers more cleaned out at depth. Four emeralds showed *slight* changes: One filled with unhardened Opticon, one filled with a mixture of cedarwood oil and Canada balsam (again, see figure 3), and one filled with Gematrat (figure 12) had feathers emptied out. An emerald filled with NOA 65 (figure 13) showed slightly more iridescent glassy feathers. Four filled emeralds showed *obvious* changes: One with Araldite 6010 (figure 14), one with cedarwood oil, one with paraffin oil, and one with a mixture of cedarwood oil and Canada balsam were partly emptied.

Figure 7. A 1.65 ct Gematrat-filled emerald (no. 4708; left, after filling) showed the most obvious change in the display-case test (right), with feathers opening up at the surface.

Steam Cleaning. Perhaps because of the short time used in this test, differences in appearance were slight at most, and longer steaming may have resulted in further changes (see, e.g., Kammerling et al., 1991). Six filled emeralds had *no observed* changes. Three filled emeralds showed *very slight* changes: One with cedarwood oil had a little opening up of surface-reaching fissures; one with surface-hardened Opticon (again, see figure 3) had very slightly more evident feathers; and one with Permasafe had a very small crack forming at the end of a hollow tube. Three emeralds—one each filled with Araldite 6010, paraffin oil, and Gematrat—showed *slight* changes (i.e., more evident feathers).

Mild Chemical Solvents. As the same samples were used for both ethanol and acetone, the results will be provided together.

One emerald filled with NOA 65 had *no observed* changes after both tests. An emerald filled with Permasafe showed *very slight* changes, with one small fissure slightly emptied out. Three emeralds showed *slight* changes after acetone cleaning, with feathers open or more visible at the surface: one with NOA 65, one with surface-hardened Opticon (this sample had no observed change after ethanol cleaning), and one with Gematrat. Three emeralds showed *slight* changes with ethanol, but *obvious* changes with acetone, in which the filler was completely cleaned out relative to the post-ethanol appearance; these included ones filled with paraffin oil, a mixture of cedarwood oil and Canada balsam,

Figure 8. A 0.27 ct emerald (no. 4505; left, before filling), which was filled with a mixture of cedarwood oil and Canada balsam (center), had an obvious appearance change after five chill-thaw cycles (right): A glassy feather on the pavilion was visible through the crown.

Figure 9. A 0.47 ct Gematrat-filled emerald (no. 4816; left, after filling) showed obvious changes after five chill-thaw cycles (center). The photomicrograph (magnified 40×) shows that some of the fissures have opened up and become more extensive.

Figure 10. This 0.95 ct emerald (no. 4807; left) was filled with unhardened Opticon (center) and showed an obvious change, in the form of more prominent feathers (right), after a year in a desiccation chamber.

Figure 11. A 1.09 ct emerald filled with cedarwood oil (no. 4576; left) showed an obvious change after 30 minutes of soaking in water in an ultrasonic cleaner (center). Examination with 30× magnification and reflected light shows the raised material leaking from the dark fissures (right).

and Permasafe (figure 15). The remaining six filled emeralds showed *obvious* changes (i.e., emptying) with ethanol alone; these included one filled with Araldite 6010 (figure 16) one filled with cedarwood oil, both filled with unhardened Opticon, one filled with paraffin oil, and one filled with a mixture of cedarwood oil and Canada balsam (figure 17).

Although we did not specifically test for the ease with which a filler could be removed (or reapplied), the FTIR spectra confirmed that ethanol and acetone could remove some fillers such as Araldite 6010 and cedarwood oil (see *G&G* Data Depository).

Figure 12. A 1.49 ct emerald filled with Gematrat (no. 5356; left, after filling) showed a slight change following 30 minutes of ultrasonic cleaning in BCR (right), with feathers somewhat emptied out.

Figure 13. This 1.50 ct emerald filled with surface-hardened NOA 65 (no. 4710; left, after filling) showed a slight change—slightly more iridescent glassy feathers—after 30 minutes of ultrasonic cleaning in BCR (right).

Figure 14. The fissures in this 0.74 ct emerald filled with Araldite 6010 (no. 4600; left, after filling) had been partly emptied out following 30 minutes of ultrasonic cleaning in BCR, an obvious change (right).

DISCUSSION

What Conditions Affect the Appearance of Filled Emeralds? The results of the five exposure tests (time and exposure to long-wave UV [i.e., "sunlight"], the mild heat and light in a display case, chill-thaw cycling, and desiccation) and five cleaning tests (ultrasonic in water, ultrasonic in BCR, steam, and soaking in ethanol followed by soaking in acetone) give some guidance as to the safety of exposing emeralds to certain environmental conditions and to various cleaning techniques.

About 40% of the filled samples categorized (10 of 23) showed noticeable changes (from very slight to obvious) due to time alone. However, it should be noted that about half the samples in the time test were in the soft category, and that those emeralds had the most dramatic changes. Therefore, all categories of fillers are not equally represented in this statistic. A better gauge of the emerald fillers is that about 35% (19 of 54) of the filled emeralds changed in appearance without exposure to any particularly harsh conditions (i.e., with exposure only to time, long-wave UV, or the mild heat and light of a display case).

The exposure test that changed the highest percentage of samples was a year in a desiccation environment after the basic time test. Desiccation made feathers appear more evident in 10 of the 14 filled emeralds, more than 70%. This suggests that filled emeralds, like opals and pearls, should not be kept in safe deposit boxes or other "dry" environments, and emeralds worn in dry climates may need to be clarity enhanced more frequently. The chill-thaw cycles led to permanent damage of two emeralds themselves (i.e., not just their fillers). Although this test did not have the highest percentage of emeralds that showed changes, it produced the most catastrophic changes. It is, therefore, important to avoid severe changes in temperature with any emerald, since this is the only test that affected an unfilled emerald used as a control sample.

Ultrasonic cleaning in either water or BCR, and soaking in solvents such as ethanol and acetone, affected the appearance of most of the filled emeralds (29 of 33; ~90%). Thus, cleaning filled emeralds risks changing their appearance. Steam cleaning is also risky, as noted by Kammerling et al. (1991), but it was done very gently in this study. In general, it should be considered potentially dangerous.

Grouping Fillers by Viscosity. Rather than treat all the fillers individually, it made sense to consider them in groups to see whether any results could be generalized. In Johnson et al. (1999), we grouped emerald fillers by their spectral properties; in this study, however, the changes seen involve fillers leaking, solidifying, or delaminating from feather walls (and sometimes cracking the emeralds). Therefore, these fillers were grouped by their viscous properties—that is, their ability to flow. (Although fillers can discolor and react with the atmosphere, these properties may not be associated with their viscosity.) The results by filler type are given in figure 18, which also suggests the probable durability behavior of untested fillers with similar viscosity.

Soft Fillers. Only soft fillers showed obvious changes with time (however, it is possible that changes in other emeralds in subsequent durability tests may

Figure 15. This 0.26 ct emerald filled with Permasafe (no. 5576; left, after filling) had a slight change after soaking in ethanol (center), but an obvious change after exposure to acetone (right).

Figure 16. A 0.80 ct emerald filled with Araldite 6010 (no. 4797; left) showed obvious changes following a day in ethanol (center). After a day in acetone (right), not only did the fissures look empty, but there was also no evidence of filler in the emerald's FTIR spectrum.

have been influenced by the time factor). In addition, emeralds with soft fillers showed obvious changes with desiccation, ultrasonic cleaning, and organic solvents. Soft fillers can crystallize (see, e.g., figure 5), leak out (see, e.g., figure 11), harden (i.e., become rigid), or evaporate. In general, fissures looked emptier with time and other exposure tests, and especially after cleaning in organic solvents. Of the soft fillers, unhardened Opticon showed the most instances of obvious changes with exposure tests (3 of 10 cases); but one of 10 emeralds filled with paraffin oil also showed an obvious change, due to time alone.

Semi-Hard Filler. The semi-hard filler (a 50:50 mixture of cedarwood oil and Canada balsam) showed better results than soft fillers during the exposure tests; with one of 11 samples showing an obvious change (when subjected to the chill-thaw cycles; figure 8). The feathers in this sample became more evident, and some filler leakage was noted. Obvious changes were seen with ultrasonic cleaning and soaking in organic solvents in three of the five samples. Although Canada balsam solidifies over decades (see, e.g., figure 19), there was no evidence of solidification in these samples over about six years.

Figure 17. This 1.00 ct emerald, filled with a mixture of Canada balsam and cedarwood oil, looks yellowish in fissures after filling (no. 4773; left), but much of this color went away (along with the filler) after soaking in ethanol (right).

Surface-Hardened Fillers. No obvious changes were seen in the emeralds with surface-hardened fillers, although several showed slight changes. For instance, filler was oozing out of emerald no. 4745 after chill-thaw durability testing, suggesting that the hard surface of the Opticon had cracked, which allowed the softer filler at greater depths to escape.

Solid Fillers. There were no obvious changes from time alone in emeralds treated with the hard fillers Gematrat and Permasafe; but three of 16 emeralds (all three filled with Gematrat) showed obvious changes with other types of exposure (display case, chill-thaw cycles, and desiccation). Feathers became more evident, showing separation of the filler from the emerald (i.e., delamination along the width; figure 20) and extension of fissures at the edges of the filled areas (again, see figure 9). Although slight changes in the samples treated with Permasafe were observed under these conditions, one emerald (no. 5587), which showed no macroscopic change over time, revealed fissures extending in length beyond the filled area when examined with the microscope. Thus, further fracturing of emeralds with both of these hard fillers was observed under various conditions, suggesting that hard fillers in general might cause such problems due to differential thermal expansion (like granite being cracked by ice).

One emerald treated with Permasafe showed obvious changes (partial emptying of fissures) after cleaning with ethanol and acetone (again, see figure 15). Otherwise, appearance changes related to the cleaning of emeralds with hard fillers were slight at most.

Nature of Appearance Changes and Damage in Emeralds. The changes that cause the greatest concern are those that damaged the emeralds themselves, by feather extension (again, see figure 9). (Fissure widening may also damage emeralds, but this study generally did not distinguish widening from fissures opening up, delaminating, or becoming more evident, all of which could be due to

Figure 18. The observed changes in the filled emeralds varied dramatically (from none to obvious) depending on the viscosity of the filler and the type of durability test. Generally, cleaning the filled emeralds led to much more noticeable differences in their appearance than the exposure tests.

Figure 19. This magnified (20×) image of Canada balsam (poured on a slide in the mid-20th century) shows cracks, gas bubbles, and an irregular surface. Anecdotal evidence indicates that Canada balsam solidifies and gets darker over decades.

changes in the filler rather than the emerald.) The next level of concern is for changes that occur within filled fissures (cloudy or crystallizing filler), as the changed material invariably affects the apparent clarity of the emerald and may be hard to remove. Open, leaking, and more evident feathers also cause worries for jewelers since these are likely to dismay customers.

Most of the exposure conditions (e.g., the long-wave UV component of sunlight, mild heat and light [as approximated by a display-case environment], along with cold and temperature fluctuations [chill-thaw cycling]) did not significantly affect the *appearance* of most filled emeralds. However, repeated exposure to cold should be avoided, since this extended the fissures in two emeralds, and one sample showed the filler delaminating from the walls of the fissures (again, see figure 20).

Figure 20. Delamination, or separation of the filler in fissures from the host emerald, makes this fissure in a Gematrat-filled emerald (no. 4816) more obvious after chill-thaw testing. Photomicrograph by Shane F. McClure; magnified 25×.

Two emeralds filled with paraffin oil showed filler crystallization at depth (again, see figure 5) under mild conditions (time, display case exposure). Cloudy filler was seen in one sample filled with Araldite 6010 (figure 4); Johnson et al. (1999) noted that such resins form cloudy emulsions with water in emeralds, which might account for the change seen here. Since cloudy or crystallized material might require additional effort to remove from a filled emerald, these emeralds might need extra attention during refilling.

The most common exposure-related appearance change, with 16 cases, was the greater visibility of preexisting feathers. These changes apparently did not represent damage to the emerald (as seen by comparing "before filler" images to "after testing" images), but they exposed its natural (prefilled) state after the filler had leaked out or evaporated (again, see figures 8 and 10). Four cases of more evident fissures after testing involved surface-hardened or hard fillers; these represent some change besides leakage or evaporation. The most obvious explanation would be that the hard filler separated from the emerald surface, thus letting out filler (seen as leakage) or letting in air.

Another common change, with 11 examples seen in the exposure tests, was the apparent opening up of preexisting feathers. In most of these cases presumably the fissures were already open at the surface (again, see figure 6) so that fillers evaporated; but fissures opening wider is another possible cause for this change.

Four emeralds with more evident or open feathers after the exposure tests contained hard fillers: two with Gematrat (figure 7), and two with Permasafe. The changes occurred during the display-case and desiccation tests. As with sample no. 5587 mentioned above, which cracked microscopically over time, these samples suggest that hard fillers may cause appearance changes—or even damage emeralds—without being subjected to particularly harsh circumstances.

CONCLUSIONS

Durability testing was performed on 142 emeralds using nine fillers. About 35% of the filled emeralds changed in appearance due to rather mild durability testing. The desiccation test affected the highest percentage of the samples subjected to those condi-

Figure 21. Emeralds create memorable pieces of jewelry such as these two rings (left, 3.30 ct; right, 16.16 ct). However, to help preserve their beauty, filled emeralds need to be treated with care and not subjected to extreme environments. Courtesy of Grando Inc., Los Angeles; photo by Harold & Erica Van Pelt.

tions, but the chill-thaw cycles led to the most damage to individual stones.

Every filler type showed changes with one or more types of exposure. In most cases after testing, the filled emeralds resembled their unfilled condition, with feathers that were opening or more visible. Emeralds with soft fillers were the most likely to be affected. Such changes might not damage the emeralds, but they could distress a customer who had not realized the emerald was filled. A few of the emerald fillers showed crystallization at depth (paraffin oil) or cloudiness (Araldite 6010). In other emeralds, many with hard fillers, the fissures appeared to have been extended or broadened. The surface-hardened fillers showed the least damage from exposure tests, with no obvious changes.

In the cleaning tests, a desirable filler would be durable during jewelry cleaning (e.g., ultrasonic tests), but easily removed with the "right" solvent. However, almost every filler that was easily removed (with either ethanol alone, or ethanol and acetone) was also easily changed by ultrasonic cleaning, which is probably the most common method used for cleaning jewelry. Surface-hardened and hard fillers were the most durable in jewelry cleaning.

The following limitations of this study should be made clear to the reader: (1) Only a limited number of samples with each filler were tested; (2) the study did not include tests independent of the time factor; (3) it did not test any fillers first in use after 1998, such as the successors of Gematrat (the ExCel types), NOA 71, or "Perma"; and (4) the data for acetone are not independent of the ethanol results. Additionally, although this study dealt with emeralds that were filled after faceting, recent reports describe significant durability problems related to emeralds filled while in the rough or preformed state (Roskin, 2007). Finally, variations in locality of origin, prior filling history, and original clarity of the emeralds could also affect the outcome of these durability tests. It is clear that more work remains to be done.

Fillers add risk by hiding or disguising existing durability problems. There is also the risk involved in cleaning and filling the emerald—and removing damaged fillers. None of the fillers used for this study were stable to all the tests, but the results imply that the best candidate with regard to the durability of the filled emerald's appearance under conditions of normal wear and care appears to be a surface-hardened liquid. Additional concerns apply, though. For example, surface-hardened liquids may be difficult to remove in the event of an appearance change, or a client's desire to have an untreated stone; and viscous liquids usually require pressure if they are to be introduced into emeralds, creating additional risks in the filling process (see, e.g., Kennedy, 1998).

Although emeralds are often set with diamonds (figure 21), these results show that emeralds should not be treated in the same manner. Emerald appearance can be quite variable over time and quite susceptible to environmental conditions.

So what should a jeweler tell a client? The bottom line is that filled emeralds—which are most emeralds—require maintenance and disclosure. Here is a possible script:

"Like pearls, and unlike most diamonds, your emerald is a delicate stone. It has probably had its fissures filled and sealed in some fashion. You should clean it only with soap and water, and avoid ultrasonic cleaning or harsh chemicals. If you notice a change, bring it back and we will be happy to have it resealed (just as we would help you by cleaning your jewelry, or replacing watch batteries). If you are concerned about the extent to which it is enhanced, we can get a laboratory report for you."

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Dr. Johnson is the principal of Mary Johnson Consulting, San Diego, California. Most of the research on which this article is based was performed while she was manager of Research and Development at GIA in Carlsbad.

ACKNOWLEDGMENTS

The author wishes to thank the following individuals for sharing their knowledge of emerald enhancements: Ricardo Alvarez Pinzon, Luis Ernesto Vermudez, and others at Treatment World Emerald Gemológico Universal, Bogotá, Colombia; Dr. Rodrigo Giraldo, Centro Gemológico para la Investigación de la Esmeralda, Bogotá; Carlos Osorio, Mineralco, Bogotá; Jaime Rotlewicz, C. I. Gemtec, Bogotá; the staff of Alagecol (Asociación de Laboratorios Gemológicos), Bogotá; Darrold Allen, Gemological Laboratory of Los Angeles, California; Kenneth Scarratt, AGTA Gemological Testing Center, New York City; Amnan Gad, Amgad Inc., New York City; Michael and Ari Gad, Gad International Ltd., New York City; Morty Kostetsky, Arigad Gems, New York City; Dr. Kumar Shah, Real Gems Inc., New York City.

The company Eichhorn (San Jose, California) donated emerald samples. Arthur Groom and Fernando Garzon (Arthur Groom-Gematrat, New York) provided emeralds, cleaning services, and Gematrat filling. David Kaassamani (Kaassamani and Co. Intl., South Lake Tahoe, California), Daniel Sauer (Amsterdam Sauer, Rio de Janeiro), Dr. R. Shah (Real Gems Inc., New York), Maurice Shire (Maurice Shire Inc., New York) provided emeralds. In New York, Abe Nassi provided useful insights. Many thanks also to the staff of Proexport Colombia (Bogotá), including Ana Maria Llerras and Cristina Montejo, for their hospitality while the author was in Colombia.

Colgem Ltd. (Ramat-Gan, Israel; through the help of Israel Eliezri), Ron Ringsrud (Constellation Colombian Emeralds, Saratoga, California), and Ray Zajicek (Equatorian Imports, Dallas, Texas) filled some of the emeralds. Ray Zajicek also provided useful comments on this manuscript. Zamrot Ashalim Engineering Ltd. (Ramat-Gan, Israel) and Jairo Vaca Camacho (Bogotá) provided equipment to assist with the emeralds that were filled at GIA.

Dr. Henry Hänni, and J.-P. Chalain, SSEF Swiss Gemmological Institute, Basel, and Dr. Lore Kiefert, then with SSEF, provided hospitality and information about the identification techniques used in their laboratory. The author also thanks the organizers of the First World Emerald Congress in Bogotá for their warm hospitality.

Former senior research associate Sam Muhlmeister performed emerald filling at GIA in Carlsbad, with assistance from analytical equipment supervisor Shane Elen. Adolfo Miranda of Col Quimicos Ltda., Bogotá, provided data sheets on Ciba-Geigy Araldite 6010.

Many current and former GIA colleagues provided support for this project. Shane McClure, Maha DeMaggio, John Koivula, Dino DeGhionno, Kim Rockwell, and Jo Ellen Cole, GIA Carlsbad, determined gemological properties. Also in Carlsbad, early FTIR and Raman spectra were collected by Shane Elen and Sam Muhlmeister; recent spectra were taken by research scientist Dr. Christopher M. Breeding, who also provided helpful comments on parts of this manuscript. Steam cleaning was performed by staff gemologist Eric Fritz. Dr. Peter Buerki (former research scientist) provided useful comments and calculations; Mike Moon (former research technician) and Arizona research scientist Dr. Troy Blodgett helped set up the display case test. Margot McLaren of the Richard T. Liddicoat Gemological Library and Information Center, Carlsbad, located auction records; and Dr. James Shigley, Tom Moses, Dr. Ilene Reinitz, and Phil York gave suggestions that improved this manuscript. We also wish to thank the manuscript reviewers for their monumental efforts.

Unless otherwise noted in the figure captions, all photographs were taken by Maha Calderon (former staff gemologist in Carlsbad), Don Mengason and Shane McClure of the GIA Laboratory in Carlsbad, Elizabeth Schraeder (formerly of the GIA Laboratory in New York), Robert Weldon of the Richard T. Liddicoat Library and Information Center in Carlsbad, and the author.

GIA thanks Jewelers' Circular-Keystone, *Radnor, Pennsylvania, and Kyocera Corp., Kyoto, Japan, for financial support of this research project. Michael Scott generously donated a Renishaw Raman microspectrometer to GIA, which was used in this research.*

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