THE BIRON HYDROTHERMAL SYNTHETIC EMERALD

By Robert E. Kane and Richard T. Liddicoat, Jr.

A new synthetic emerald grown in Western Australia is now commercially available as faceted stones. Infrared spectra revealed the presence of water, thereby confirming that these synthetic emeralds are synthesized by a hydrothermal process. Chemical analysis showed that they contain vanadium as well as lesser amounts of chromium. This new synthetic exhibits some characteristics that are distinctly different from other synthetic emeralds and therefore must now be considered when identifying emeralds. In addition to distinctive inclusions such as gold, the Biron synthetic is inert to ultraviolet radiation, has a specific gravity of 2.68–2.71, and refractive indices of $\epsilon = 1.569$ and $\omega = 1.573$. This article examines in detail the gemological properties of the Biron hydrothermal synthetic emerald and discusses means of identifying this new synthetic.

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Emerald was first synthesized by Ebelman in 1848 by adding natural emerald powder to a molten boric acid flux, which produced very small prismatic emerald crystals as the mixture cooled. In the ensuing years, the flux growth of synthetic emerald was achieved by many researchers (Nassau, 1980; Sinkankas, 1981). In 1957, the growth of minute beryl crystals by a hydrothermal process was first reported (Wyart and Šćavnicăr, 1957). Although many processes for growing synthetic emerald hydrothermally have been described since then (summarized in Sinkankas, 1981), until recently only three major productions of hydrothermal synthetic emerald have been commercially available to the jewelry trade: Linde (patented process now owned by Regency), Lechleitner (full synthetic in addition to overgrowth), and, most recently, those grown in the Soviet Union (see Takubo, 1979).

The synthetic emerald reported on here represents a new hydrothermal process that can yield unusually clean faceted stones (figure 1) from remarkably large single crystals (figure 2). This material will be commercially available in the latter part of 1985. This new hydrothermal emerald is being synthesized in Western Australia and marketed as faceted stones under the trade name Biron. Note that this is not the same material as the vanadium-doped synthetic emerald that was grown several years ago in Melbourne, Australia, by Taylor (1967).

The manufacturer reports that research on the Biron synthetic emerald began in 1977 in Western Australia. Since then, a few brief notes based on the examination of a very small number of stones have appeared in the literature (Brown, 1981 and 1983; Brown and Snow, 1984; Darragh and Willing, 1982; Tombs, 1983). In the interest of providing detailed information to the gemological community on the properties and identifying characteristics of this synthetic emerald, however, the manufacturer, Biron Minerals Pty., Ltd., and the distributor made available to

Figure 1. These faceted Biron hydrothermal synthetic emeralds are representative of many examined in this study. The stones shown here have a high clarity and range in weight from 1.20 to 3.00 ct. Photo © Tino Hammid.

GIA 202 samples of the new Biron synthetic emerald. The samples included 150 faceted stones of various shapes and cuts (ranging from 0.05 ct to 3.00 ct), 50 preforms (weighing from 1.50 ct to 5.00 ct), and two rough crystals (96.08 ct and 108.05 ct). These specimens were examined carefully and subjected to several gemological tests; a few were also chemically analyzed. A detailed study of the inclusions present was also conducted. The results of these examinations and tests are reported below and summarized in table 1.

VISUAL APPEARANCE

The faceted Biron synthetic emeralds studied varied in hue from green to slightly bluish green in moderate to vivid saturation (figure 1). The well-cut stones were relatively consistent in color with vivid saturation. As would be expected, small stones and those that were cut shallow were considerably lighter in tone.

Nearly all of the faceted Biron synthetic emeralds examined were very transparent. When examined with the unaided eye and overhead illumination, they ranged from stones that appeared to be completely free of inclusions to those that had areas of visible inclusions.

PLEOCHROISM

Using a calcite dichroscope, we observed dichroism in strongly distinct colors of green-blue parallel to the c-axis and yellowish green perpendicular to the c-axis. These results are typically observed in other synthetic emeralds, as well as in many natural emeralds.

SPECTRAL EXAMINATIONS

The visible-light absorption spectra of several of the faceted Biron synthetic emeralds were examined with a GIA GEM Instruments spectroscope unit. The observed spectra appeared to be essentially the same as the well-known absorption spectra of emerald described by Liddicoat (1981, p. 194), which are the same for both natural and synthetic emerald.

When looking down the optic axis direction, we observed in all of the stones tested a vague general absorption from 400.0 nm to approximately 480.0 nm, a superimposed sharp line at

Figure 2. An exceptional example of the Biron hydrothermal synthetic emerald crystals grown in Western Australia. This crystal measures 3.50 cm long by 1.6 cm wide, and weighs 96.08 ct. Photo by Tino Hammid; © W. L. Cotton.

477.0 nm, a broad band of absorption between 580.0 and 615.0 nm, and lines in the red situated at 637.0, 646.0, 662.0, 680.5, and 683.5 nm. We observed a similar absorption when we examined the spectrum perpendicular to the optic axis; however, the sharp line at 477.0 nm was absent. The same absorption features also occur in natural emeralds.

When the Biron synthetic emeralds were placed over the opening of the iris diaphragm on the spectroscope unit, a red transmission was observed. This transmission ranged from weak to very weak, depending on the position of the stone and of the light source, as well as on the size of the stone. We have observed that this phenomenon is typical of many synthetic emeralds and is also exhibited by some natural emeralds, inasmuch as it is occasionally observed in very fine-color emeralds from Chivor, and in medium to light emeralds from Gachalá, in Colombia.

Infrared absorption spectra were obtained by Dr. George Rossman, of the California Institute of Technology, using a Nicolet series 60SX Fourier transform infrared spectrometer system. The spectra, taken from several samples of Biron synthetic emerald, revealed the presence of water, thus confirming that these synthetic emeralds are grown by a hydrothermal process. All natural emeralds and hydrothermal synthetic emeralds contain some water, whereas flux-grown synthetic emeralds contain no water (Nassau, 1980).

COLOR-FILTER REACTION

Several of the Biron synthetic emeralds were tested with a Chelsea color filter. All of the stones tested revealed a strong red appearance under the filter, as is also the case with many other hydrothermal and flux-grown synthetic emeralds. Unfortunately, many natural emeralds from various sources show the same reaction. Therefore, the color-filter reaction alone provides no indication of the synthetic origin of this material.

SPECIFIC GRAVITY, REACTION TO ULTRAVIOLET RADIATION, AND REFRACTIVE INDICES AND BIREFRINGENCE

Traditional gemological tests for the distinction of synthetic emerald from natural emerald have always considered microscopic examination of characteristic inclusions to provide definitive proof of origin. However, this test is often considered the most difficult to master because of the similarities of some of the inclusions (such as "fingerprints" and "veils") found in both synthetic and natural emeralds. Consequently, many gemologists and jewelers have relied on magnification the least, and have arrived at an identification on the basis of refractive indices, birefringence, reaction to ultraviolet radiation, and specific gravity. However, with the new Biron synthetic emerald, as well as with other newer hydrothermal synthetic emeralds, such as the Russian material (Takubo, 1979), some of these standard tests no longer provide even a vague indication of synthetic origin.

Specific Gravity. The specific-gravity values for the Biron hydrothermal synthetic emeralds were determined by the hydrostatic method with a Voland diamond balance. The sample stones showed slight variations in density from 2.68 to 2.71. All of the faceted synthetic emeralds were

TABLE 1. The gemological properties of the Biron hydrothermal synthetic emerald.

Properties that overlap with those of natural emeralds from differing geographic localities	Pleochroism	Strong: green-blue parallel to the c-axis and yellowish green perpendicular to the c-axis.
	Absorption spectrum[a] (400–700 nm)	Optic-axis direction: absorption lines at 477.0, 637.0, 646.0, 662.0, 680.5 and 683.5 nm; a vague general absorption from 400.0 to 480.0 nm and a broad band of absorption between 580.0 and 615.0 nm. Perpendicular to optic-axis direction; same as above, with the exception that the 477.0 nm line is absent.
	Color-filter reaction	Strong red
	Specific gravity	2.68–2.71
	Luminescence to long- and short-wave U.V.	Inert
Key identifying properties	Refractive indices and birefringence	$\epsilon = 1.569$, $\omega = 1.573$ (+0.001) 0.004–0.005
	Inclusions	Various forms of fingerprints, veils, and fractures; single occurrences of large two-phase inclusions; nail-head spicule inclusions with liquid and gas phases; several forms of gold; phenakite crystals; numerous types and appearances of growth features; white particles forming comet-tails and stringers or randomly scattered throughout; and, rarely observed, seed plates.

[a] *As observed through a hand-held type of spectroscope.*

also tested in a standard 2.67 (specific gravity) heavy liquid (methylene iodide diluted with benzyl benzoate). Before we present the results, a brief discussion is necessary concerning the factors that can influence the specific-gravity values of beryl.

Studies on the chemical composition of natural beryls (Bakakin and Belov, 1962; Goldman et al., 1978; Schaller et al., 1962) state that both filling of structural voids and substitution by Cr, Fe^{3+}, Fe^{2+}, Mg, Li, other ions, and water molecules can occur in the crystal structure of beryl. These ions and water molecules appear to be a major cause of variation in specific gravity and refractive index among natural beryls (Flanigen et al., 1967). Just as with natural emeralds, the specific gravity and refractive indices of hydrothermal synthetic emeralds are also dependent in part on the amount of impurity ions and molecules they contain. Because of the different synthesis techniques used, these properties frequently differ from one manufacturer to another.

From our observations, the specific-gravity values of flux-grown synthetic emeralds of various manufacture are often lower than the values of their natural counterparts; such stones usually float in the 2.67 liquid, thus providing some indication of their synthetic origin. In contrast, the values obtained for many hydrothermal synthetic emeralds are slightly higher, with the stones sinking in the 2.67 liquid, thereby overlapping with the specific-gravity range of natural emeralds. All of the Biron hydrothermal synthetic emeralds examined by the authors in this study had densities greater than 2.67. Because many natural emeralds have similar specific-gravity values, the specific gravity of the Biron hydrothermal synthetic emeralds provides the gemologist with absolutely no indication of the synthetic origin of the material.

Reaction to Ultraviolet Radiation. All of the Biron hydrothermal synthetic emeralds were exposed to long-wave (366 nm) and short-wave (254 nm) ultraviolet radiation. To insure observation of even the weakest fluorescence, we performed the test in a completely darkened room, placing the synthetic emeralds on a black pad raised to within a few inches of the ultraviolet lamp inside a standard ultraviolet viewing cabinet. The faceted Biron synthetic emeralds did not exhibit any visible fluorescence under these conditions.

It has been stated that the presence of iron in either natural or synthetic emeralds can quench chromium fluorescence, slightly increase specific gravity, and raise refractive indices and birefringence (Fryer, 1969/70; Kane, 1980/81; Gübelin, 1982). We suggest that, because of the lack of detectable iron in the Biron hydrothermal synthetic emerald (see table 2), something other than iron must be responsible for the inert reaction of the material when exposed to long-wave and short-wave ultraviolet radiation. Rather, the lack of fluorescence appears to be due to the high concentrations of vanadium (see table 2). This conclusion is supported by Linares's experiments on the flux growth of synthetic emerald (1967). Linares used

TABLE 2. Chemical analyses of two faceted Biron hydrothermal synthetic emeralds.[a]

	Oxide component (wt.%)[b]								
Catalog no.	Na_2O	MgO	FeO	Al_2O_3	V_2O_3	Cr_2O_3	SiO_2	Cl	Total[c]
GIA 120[d]	nd[f]	nd	nd	18.1	0.7	0.3	66.4	0.3	85.8
GIA 14622[e]	nd	nd	nd	18.2	0.6	0.2	65.4	0.3	84.7

[a] *These samples were analyzed with a MAC electron microprobe at an operating voltage of 15 KeV and beam current of 0.05 μA. The raw data were corrected by using the Ultimate correction program of Chodos et al. (1973). Analyst: Carol M. Stockton, GIA Research Dept.*

[b] *Values represent the average of three analyses for each sample.*

[c] *These totals are low (less than 100%) because no analysis was made for light elements (of atomic number below 11) present in beryl. Ideally, BeO should be about 14.00 wt.%.*

[d] *Sample synthesized in 1982.*

[e] *Sample synthesized in 1984.*

[f] *Not detected; below the detection limits of the instrumentation used (approximately 0.1 wt.%).*

various ratios of a lead oxide–vanadium oxide flux system ($PbO-V_2O_5$), in addition to chromium oxide (Cr_2O_3), for his synthetic-emerald experiments. When the synthetic emeralds grown from these fluxes were exposed to ultraviolet radiation, no chromium fluorescence was observed. Linares speculated that considerable vanadium was incorporated into the synthetic emerald during the growth process; the vanadium then interacted with the chromium to quench any fluorescence that might have been caused by the chromium.

Flanigen et al. (1967) also reported the absence of fluorescence in their experimental vanadium flux (V_2O_3) synthetic emerald. In contrast, they reported that their Linde hydrothermal synthetic emerald, which contained no vanadium, showed a bright red fluorescence when exposed to both long- and short-wave ultraviolet radiation. The absence of fluorescence has also been observed in vanadium-doped synthetic ruby and synthetic alexandrite (Linares, 1967).

An inert reaction to ultraviolet radiation has frequently been used as an indicator of natural origin for emeralds, since many natural emeralds are inert to either long-wave or short-wave U.V. and many hydrothermal and flux synthetic emeralds are not. However, with the introduction of the Biron synthetic emerald, which is also inert to such radiation, the absence of fluorescence can no longer be used as an identifying criterion.

Refractive Indices and Birefringence. Refractive indices were obtained using a GEM Duplex II refractometer in conjunction with a sodium light source. The Biron synthetic emeralds were determined to be uniaxial negative with a refractive index of $\epsilon = 1.569$ and $\omega = 1.573$ (+0.001), with a corresponding birefringence of 0.004–0.005. These low values provide some indication of synthetic origin. Although an identification should not be based solely on this property, these optical values are very unlikely to be observed in a natural emerald. For a comparison of refractive index and birefringence values of natural emeralds from numerous different geographic localities, see Gübelin (1982, p. 13, table 3). Interestingly, the values recorded for the Biron synthetic emerald are low for a hydrothermal synthetic emerald and are more typical of flux-grown products.

INCLUSIONS

The Biron hydrothermal synthetic emeralds were all examined thoroughly with a gemological binocular microscope in conjunction with various sources of illumination. Several types of characteristic inclusions were observed; some were reminiscent of synthetic emeralds of different manufacture, while several others identified by the authors appear to be unique to the Biron synthetic emerald.

The faceted Biron synthetic emeralds examined ranged in clarity from those with prominent inclusions, growth features, and color zoning, to those that were remarkably clean and appeared to be nearly flawless, with perhaps only minor, nondescript growth features.

Two-Phase Inclusions. Evident in some of the Biron synthetic emeralds examined were two-phase inclusions consisting of a fluid and a gas bubble. These two-phase inclusions were observed to have three distinct appearances: (1) forming "fingerprint" patterns and curved (wispy) "veils"; (2) as large, irregular voids containing one or more gas bubbles; and (3) trapped within the tapered portion of "nail-head spicules."

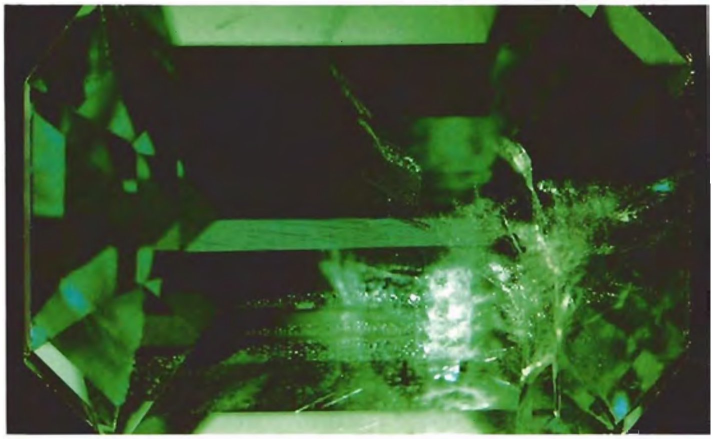


Figure 3. Overview of a 1.70-ct faceted Biron synthetic emerald showing secondary "fingerprint" and "wispy veil" inclusions and irregular growth features in the center of the stone. Dark-field illumination, magnified 13×.

Fingerprints, Veils, and Fractures. As with other hydrothermal synthetic emeralds, the Biron typically contains various types of secondary growth defects commonly referred to as fingerprints and veils. The term *wispy veil* is also often used to describe such inclusions in synthetic emeralds and other synthetic gem materials. The Biron synthetic emeralds exhibited fingerprint and veil patterns of various appearances (figures 3 through 6).

In contrast to flux-grown synthetic emeralds, in which the fingerprints and veils are healed fractures with flux fillings, the fingerprints and veils in hydrothermal synthetic emeralds generally consist of many small two-phase inclusions that are usually concentrated at curved and planar interfaces; although flux inclusions may be similar in appearance, they are completely solid. These fingerprints and veils in the Biron synthetic emerald are healing fissures that are in some cases remarkably similar in nature and appearance to those observed in some natural emeralds (figure 4). The mechanism that produces this healing process in natural minerals has been well documented (see Eppler, 1959, 1966; and Roedder, 1962, 1982, 1984); for illustrations of the formation process of these secondary inclusions, see Roedder (1982, 1984) and Koivula (1983). Although the conditions required to heal a fracture resulting in a fingerprint-like pattern in a natural or synthetic crystal are different, the mechanism should be the same.

One or two of the faceted Biron synthetic emeralds exhibited areas of somewhat dense concentrations of wispy and planar fingerprints and veils of various forms that often originated from a common central point, extending outward in a spiral arrangement. This is illustrated in figure 3; interestingly, this stone was probably the most included of all the 200 examined, yet the wispy

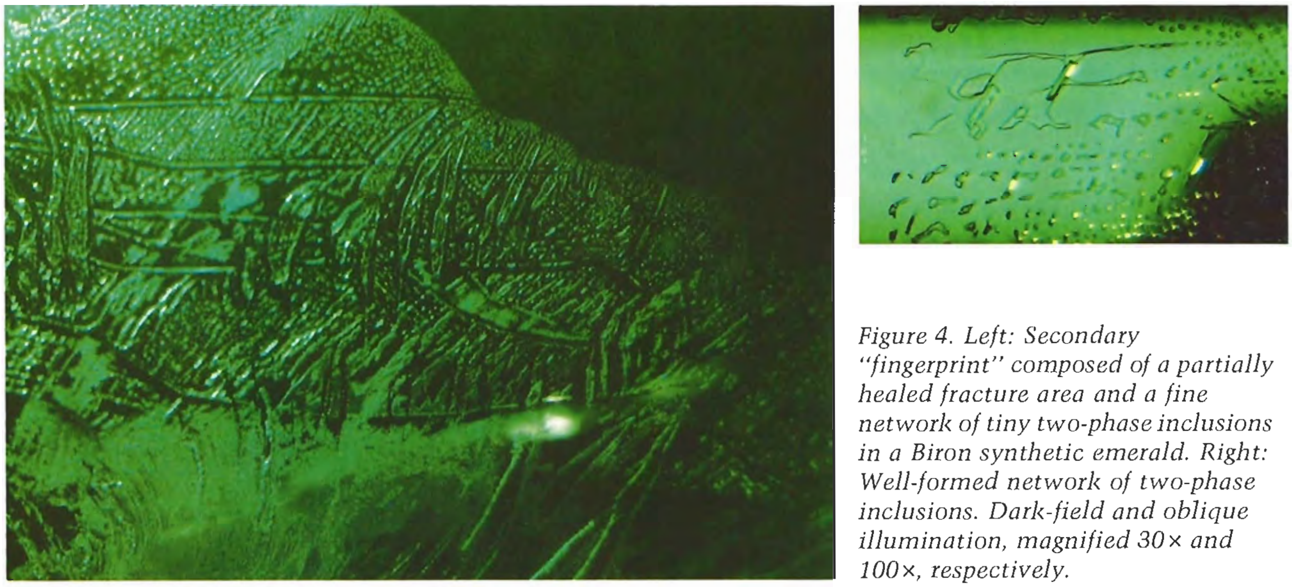


Figure 4. Left: Secondary "fingerprint" composed of a partially healed fracture area and a fine network of tiny two-phase inclusions in a Biron synthetic emerald. Right: Well-formed network of two-phase inclusions. Dark-field and oblique illumination, magnified 30× and 100×, respectively.

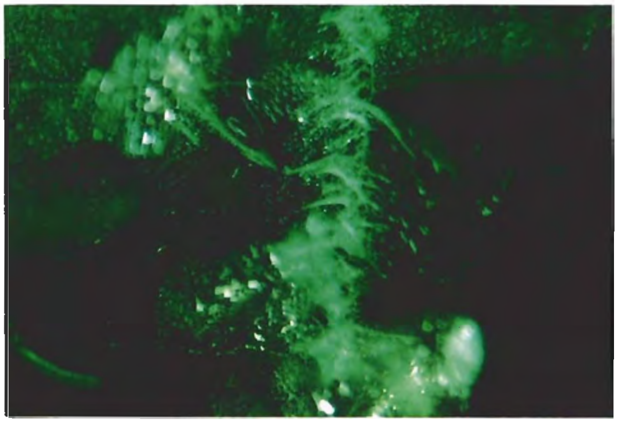


Figure 5. These spiral arrangements of small "fingerprints," frequently referred to as a helix pattern, in the Biron synthetic emeralds should not be confused with very similar-appearing inclusions in some natural emeralds. Dark-field illumination, magnified 20×.

veils occupied less than one-half of the faceted stone. This clarity is in contrast to many other synthetic emeralds, both flux and hydrothermal, which (with the exception of some Inamori flux synthetic emeralds and Russian hydrothermal and flux synthetic emeralds) are typically very heavily included.

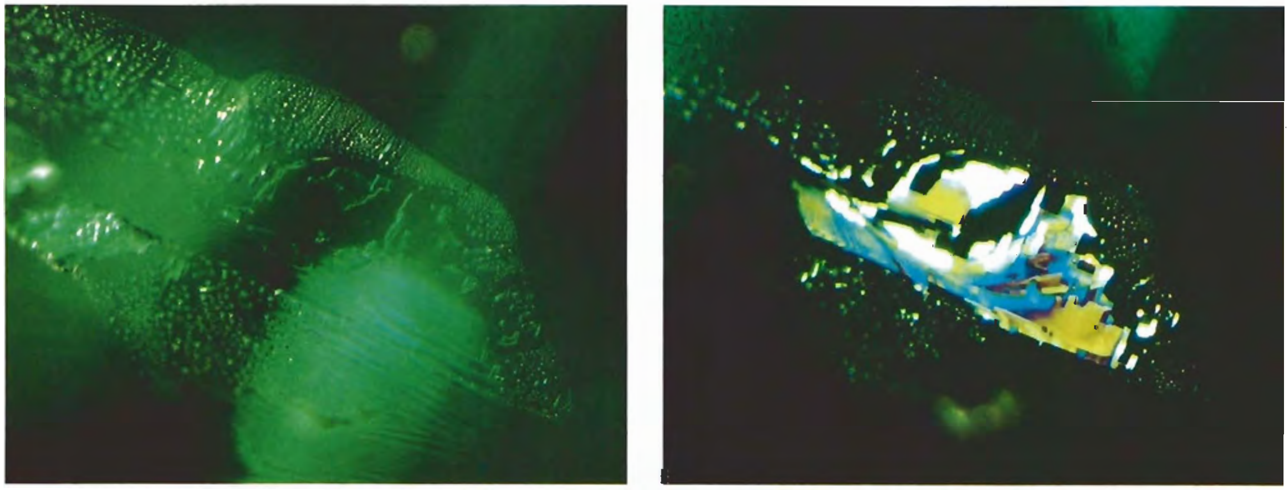
Observed in several of the Biron synthetic emeralds were spiral arrangements of a small fingerprint pattern (figure 5), sometimes referred to as a helix pattern. This type of spiral growth pattern is also occasionally observed in natural emeralds (Gübelin, 1974; Fryer et al., 1983) and therefore may be confusing to the gemologist.

Some of the Biron synthetic emeralds contained areas of partially healed fracture-fingerprint patterns that, when tilted to specific viewing angles in dark-field or reflected light, exhibited a multicolored display of interference colors (see figure 6). The same phenomenon is occasionally observed in some natural emeralds that contain ultra-thin layers of two-phase (liquid and gas) inclusions; in the natural stones, however, the patterns are quite distinctive, ranging from minute to large in randomly oriented, rounded, irregular forms (figure 7).

Also observed were fractures and healed fractures, some of which were similar in appearance to the epigenetic staining that is observed in many natural gem materials, including emeralds. Thus, these fractures do not provide any evidence of synthetic origin.

Single Irregular Two-phase Inclusions. In a few of the faceted Biron synthetic emeralds, rather unusual, large, individual two-phase inclusions were observed (figure 8). Frequently trapped within a tapered, irregular, flattened void that exhibited sharp angular to slightly rounded edges was a fluid and a large gas bubble. None of these bubbles was mobile under normal viewing conditions.

Figure 6. A Biron synthetic emerald with a secondary "fingerprint" pattern consisting of a network of two-phase inclusions and a partially healed fracture. On the left, the partially healed fracture is almost invisible when viewed in dark-field illumination only. However, as is shown on the right, when fiber-optic illumination is used to vertically light this area, interference colors are seen. Magnified 40×.



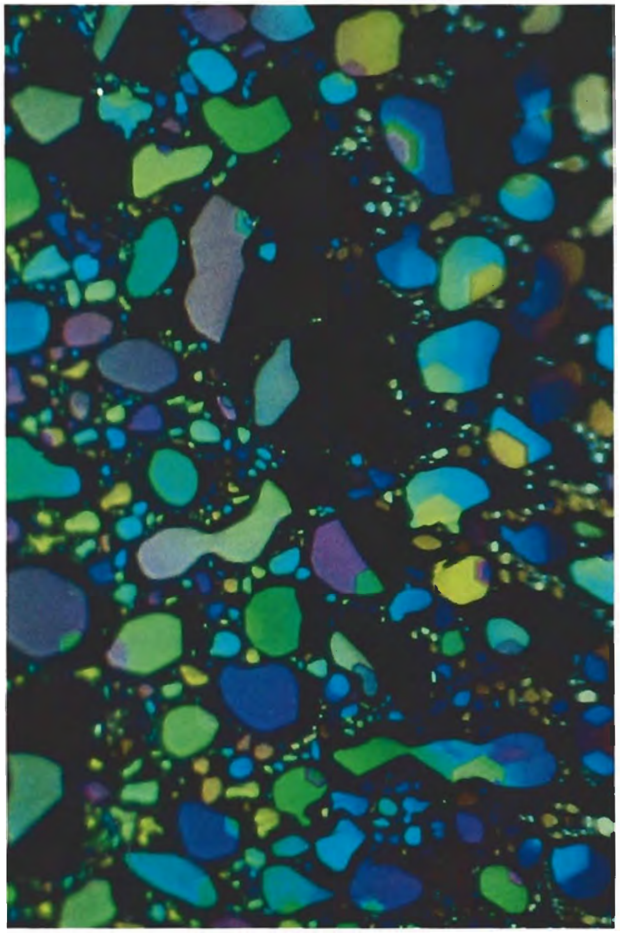


Figure 7. A natural emerald with ultra-thin films of two-phase (liquid and gas) inclusions. Such thin-film inclusions are occasionally observed in natural emeralds; however, they are generally quite distinctive and should not be confused with inclusions displaying a similar phenomenon in Biron synthetic emeralds, such as the one shown in figure 6. Vertical illumination with a fiber optic light source only, magnified 80×.

Figure 8. Captured within this Biron synthetic emerald is a large, well-formed, two-phase inclusion. Note also the fingerprint patterns at either end of the inclusion. Dark-field and oblique illumination, magnified 40×.

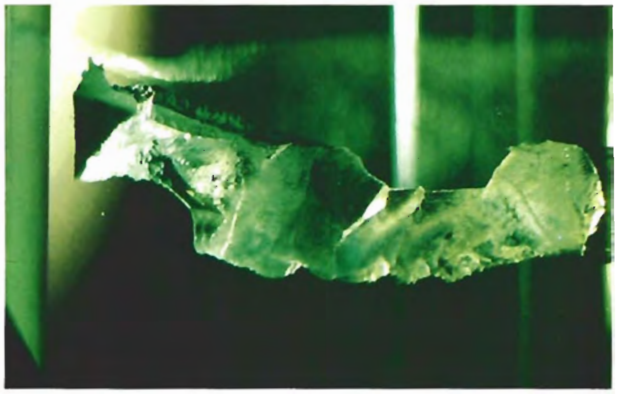


Figure 9. During the faceting of this Biron synthetic emerald, a very large two-phase inclusion was brought to the surface, releasing the liquid and gas phases and leaving only a deep void. The frosted appearance on the inner walls of the void is in part a result of residue left in the cavity. Dark-field and oblique illumination, magnified 25×.

Several of the faceted Biron synthetic emeralds contained large voids that broke the surface in a very small area of the stone; in a few stones, these voids extended almost the entire length from the table to the culet. They were identical in appearance to many of the voids that contained the two phases. Undoubtedly, when the inclusions were brought to the surface during faceting, the gaseous and liquid phases were released, leaving only a void or very deep cavity with a frosted white appearance on the inner walls (figure 9).

Nail-Head Spicules. Also common in the Biron synthetic emeralds is the presence of a fluid and a gas bubble contained within a cone-shaped void that frequently starts at its widest end on a crystalline inclusion and tapers gradually to a point. These inclusions, referred to here as nail-head spicules, have long been observed in hydrothermal synthetic emeralds from various manufacturers (Nassau, 1978, 1980; Anderson, 1980; Liddicoat, 1981; Sinkankas, 1981).

In the Biron synthetic emeralds, the "head of the nail" is formed by a single crystal, a group of phenakite crystals, or gold crystals (see figures 10 – 12). As is common with virtually all other hydrothermal synthetic emeralds, the nail-head spicules in the Biron synthetics are often observed in single or multiple occurrences that

Figure 10. This large nail-head spicule in a Biron synthetic emerald consists of a cone-shaped void that is filled with a fluid and a gas bubble. Although not visible at this viewing angle, the spicule is capped by a poorly developed, ghost-like phenakite crystal. Dark-field illumination, magnified 50×.

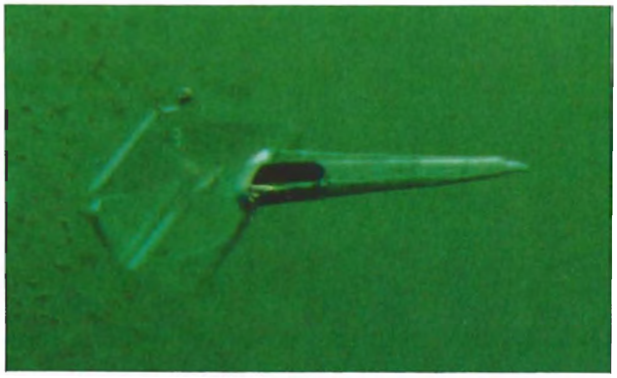


Figure 11. This Biron synthetic emerald contains a nail-head spicule with a large, distinct phenakite crystal at the base. Dark-field illumination, magnified 60×.

parallel the c-axis. Examination of both hydrothermal and flux synthetic emeralds revealed that nail-head spicules develop most readily when the synthetic emerald is initially started on a seed plate inclined at an angle to the crystallographic axes, as is the case with the Biron synthetic emeralds.

Gold. Several of the faceted Biron synthetic emeralds contained metallic-appearing inclusions. SEM-EDS analyses were performed on a number of these inclusions that reached the surface on each of five different faceted stones. These inclusions represented the range of sizes, shapes, textures, and colors of the metallic inclusions observed in the Biron synthetic emeralds that were studied. The analyses identified gold as the major constituent in

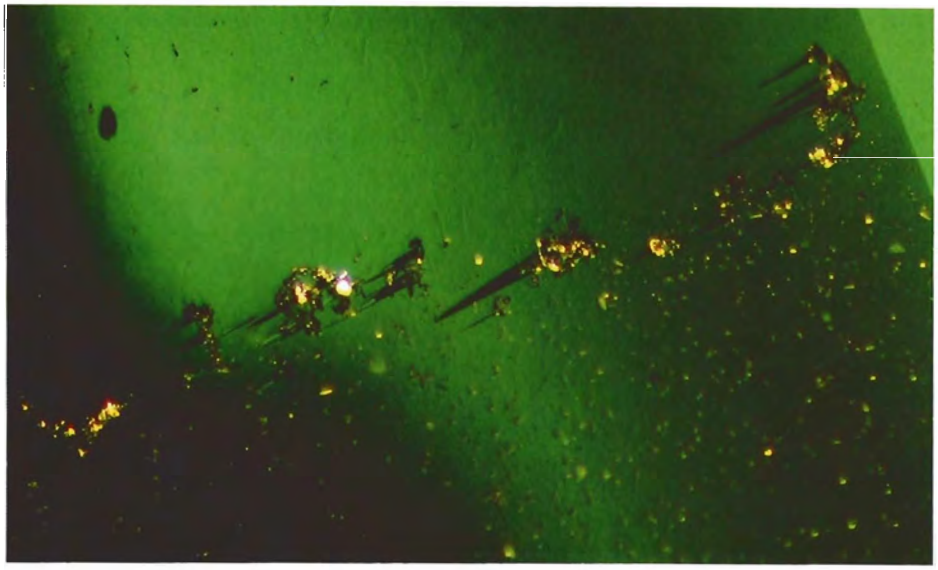


Figure 12. Multiple growth of nail-head spicules at the edge of a large plane of gold inclusions in a Biron synthetic emerald. Dark-field and oblique illumination, magnified 50×.

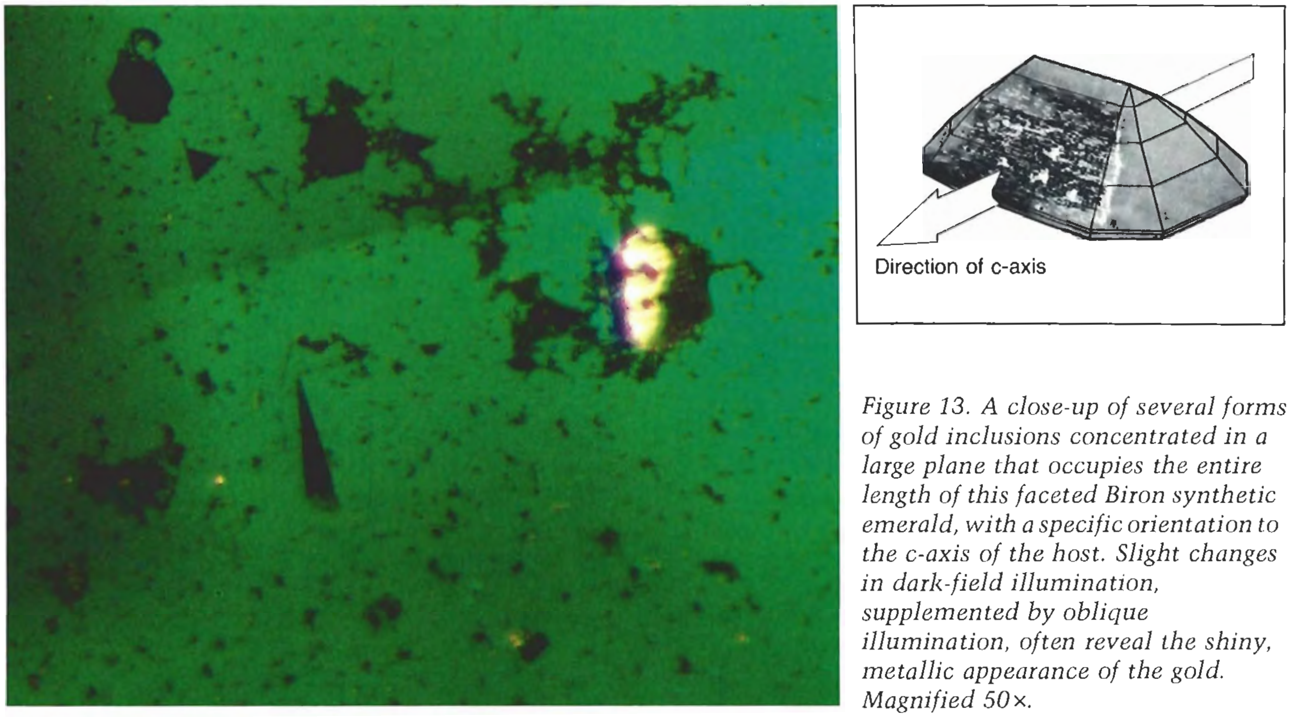


Figure 13. A close-up of several forms of gold inclusions concentrated in a large plane that occupies the entire length of this faceted Biron synthetic emerald, with a specific orientation to the c-axis of the host. Slight changes in dark-field illumination, supplemented by oblique illumination, often reveal the shiny, metallic appearance of the gold. Magnified 50×.

all of the metallic inclusions tested; minor amounts of nickel and copper were also detected. Evidence of platinum was found in a small number of the gold inclusions analyzed.

Metallic inclusions are typically associated with some synthetic gem materials—for example, platinum in Chatham flux-grown synthetic corundum (Kane, 1982), platinum crystals in the early Chatham flux-grown synthetic emeralds (Liddicoat, 1981, pp. 139–140, 170), and platinum inclusions (as observed by the authors) in the newer hydrothermal synthetic emeralds from the Soviet Union. For a material to occur as an inclusion, its constituents must be present in the growth environment. With hydrothermal synthetic growth of emerald, the steel pressure vessel (frequently referred to as a hydrothermal bomb, because it occasionally explodes) is lined with a nonreactive precious metal to prevent contamination from the steel. The Linde hydrothermal synthetic emerald process used gold to line the growth vessel (Flanigen and Mumbach, 1971). The presence of gold as an inclusion in the Biron synthetic emerald suggests that gold or a gold alloy is used as a vessel liner in the Biron process as well.

Although gold as an inclusion in hydrothermally grown synthetic emeralds is not common, it is not unknown. Gübelin (1960/1961) reported gold inclusions in Lechleitner's synthetic emerald overgrowth product.

The gold inclusions in the Biron synthetic emeralds were observed to occur in a rather surprising diversity of distinct forms and appearances (figures 12 through 14): thin, flat plates with hexagonal and triangular outlines, ranging from very symmetrical to distorted forms; flattened, slightly rounded needles in various lengths; large, rather dense planes composed of minute individual grains; and granular and dendritic-appearing aggregates and larger, slightly angular grains resembling natural "native gold." They ranged in color from "grayish silver" to black to distinctly "yellowish gold," depending on the viewing angle and lighting conditions. The true yellowish color of the gold inclusions could generally be seen by adjusting the viewing position while supplementing the dark-field illumination with a fiber-optic light source.

As is illustrated in figure 13, in many of the faceted Biron synthetic emeralds the metallic (and other) inclusions were observed to be concentrated in planes that occupied the entire length of the stone and were close to parallel with one of the long pavilion planes, with a somewhat specific orientation to the c-axis of the host (possibly related to growth parallel to the seed plate).

Phenakite Crystals. Observed in several of the Biron synthetic emeralds were various forms of transparent colorless crystals. These inclusions were identified as phenakite by their characteristic

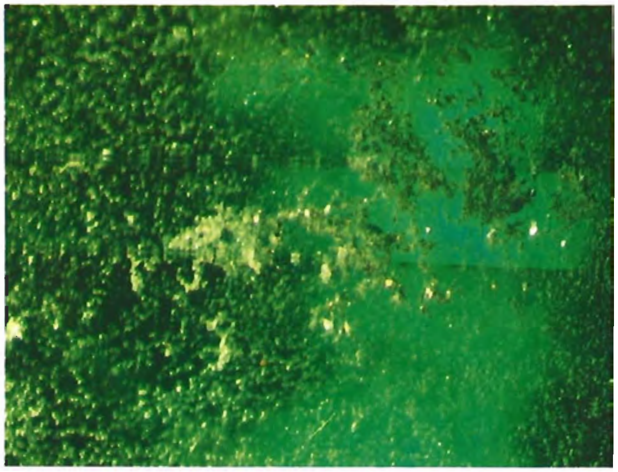


Figure 14. This faceted Biron synthetic emerald contains several large, dense planes of dendritic-appearing aggregates of gold inclusions that border both sides of a seed-plate area. Dark-field and oblique illumination, magnified 50×.

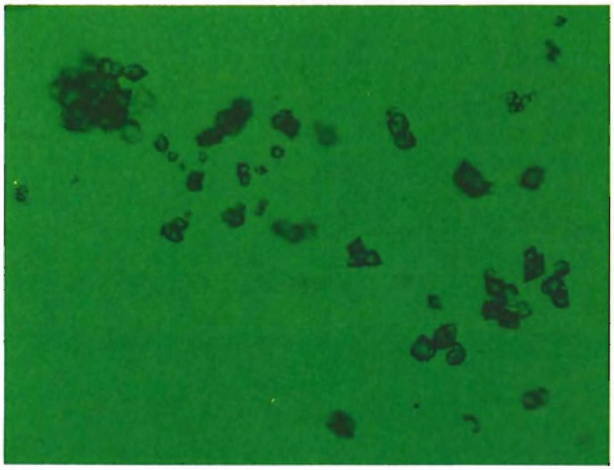


Figure 15. Small single crystals, groups, and aggregates of phenakite are confined to an area that almost parallels one of the long pavilion planes of this Biron synthetic emerald preform. Dark-field illumination, magnified 50×.

crystal habits and the visible difference in relief caused by the higher refractive indices of phenakite (1.654–1.670) compared to those of the synthetic emerald host material.

The formation of phenakite inclusions in synthetic emeralds is somewhat common and is easily explained by the fact that phenakite is a beryllium silicate with a chemical formula of Be_2SiO_4 that is closely related to that of beryl ($Be_3Al_2Si_6O_{18}$). Eppler (1958) stated that phenakite crystals form in synthetic emeralds because of a local deficiency of aluminum oxide (Al_2O_3) in the melt or solution at higher temperatures.

The transparent colorless phenakite crystals in the Biron synthetic emeralds ranged from minute crystallites to well-formed single crystals as large as 0.3 mm long, and were observed in several different forms. Both well-defined single phenakite rhombohedrons with minor prism faces and less-defined phenakite crystals were observed to form the base of some of the nail-head inclusions (again, see figures 10 and 11). Phenakite crystals were also encountered as small isolated crystals, as well as in groups and aggregates that were often arranged in a somewhat definite plane or confined to areas close to and parallel with one of the long pavilion planes of several of the Biron synthetic emerald preforms (figure 15). The small phenakite crystals often exhibit prominent rhombohedral faces with well-developed first-order or second-order prism faces.

Phenakite inclusions in synthetic emerald often display angular and varied crystal forms that might be confusing to the gemologist. If carefully examined with the microscope, however, these crystals should not be mistaken for other crystalline inclusions, such as calcite, that are common in some natural emeralds. In many of the Biron synthetic emeralds examined, the phenakite crystals exhibited very small but distinctive prism faces that distinguish these inclusions from what might otherwise appear to be calcite rhombohedrons, which do not possess such prism faces. Additional distinctions between calcite and phenakite inclusions in emerald are provided by the fact that calcite is highly birefringent (0.172), and will exhibit vivid high-order (brighter) interference colors when examined under cross-polarized illumination, in contrast to the weakly birefringent phenakite inclusions (0.016), which show slightly to obviously less-vivid colors. Calcite inclusions may also exhibit cleavages, which are absent in phenakite inclusions in synthetic emerald. Similar natural inclusions that have been identified as dolomite or dolomitic (E. Gübelin and J. Koivula, pers. comm., 1985; Cassadanne and Sauer, 1984) in emeralds from Santa Terezinha, Brazil, are nearly always closely associated with tiny black chromite grains.

The abundance and orientation of the phenakite inclusions in the Biron synthetic emeralds also provide evidence of synthesis. When numerous phenakite inclusions (as well as gold inclusions) are present, they are often oriented in closely spaced groups such as those illustrated in figure 15 (and again, see figure 13). Natural inclusions, such as calcite or dolomite in natural emeralds, generally do not occur in such concentrations and are frequently closely associated with other types of inclusions.

Once identified as phenakite, these characteristic inclusions provide proof of synthetic origin (either hydrothermal or flux), as phenakite inclusions are not known to occur in natural emeralds. In stones where the inclusions in question cannot be easily identified, other characteristics such as easily recognized typical inclusions and low refractive indices and birefringence should all be considered in making an identification as to whether the emerald is natural or synthetic.

Growth Features and Color Zoning. Observed in all of the Biron synthetic emeralds were various forms of growth features; in some, color zoning was also noted. The growth features vary greatly in appearance and prevalence. They were observed in one or a combination of the following forms: straight, parallel, and uniform; angular, straight, and intersecting; and irregular (see figures 16 and 17).

Because some of the faceted Biron synthetic emeralds contain only growth features, it is useful to be familiar with these inclusions and techniques of bringing them into view. Many of the growth features in the Biron synthetic emeralds are different from those previously known for other synthetic emeralds on the market, although some are remotely reminiscent of (but not as well defined as) those referred to as "Venetian blind" banding (Fryer et al., 1981). The growth features in the Biron synthetic emeralds ranged from being very difficult to observe under magnification

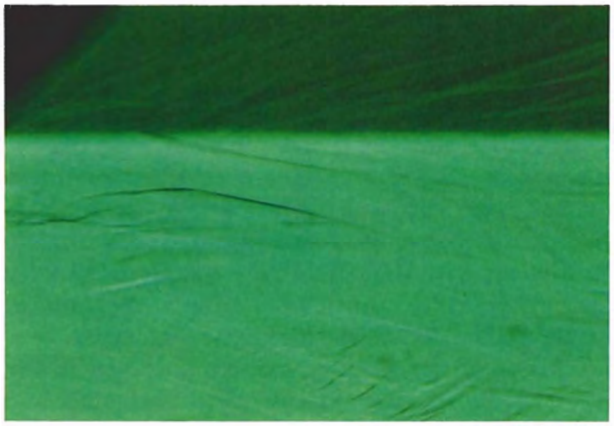


Figure 16. Growth features become evident in this faceted Biron synthetic emerald when the built-in iris diaphragm on the microscope stage is partially closed (over dark-field illumination) to create a shadowing effect. Magnified 50×.

Figure 17. Several forms of growth features surrounding an unusual two-phase inclusion in a Biron synthetic emerald are accentuated by shadowing dark-field illumination. Magnified 40×.

even when several different illumination techniques were used, to being easily seen with the unaided eye.

As is the case with most natural or synthetic materials, the nature of growth features can be very elusive. When a faceted stone is held in a certain manner and is viewed at specific angles, the growth features may be very evident. At other positions and viewing angles, they may totally disappear from view. Likewise, the appearance of an inclusion can be changed dramatically by employing different types of illumination. For routine examination, dark-field illumination usually provides the most effective means of lighting the interior of a gemstone. However, oblique, transmitted, and diffused illumination, as well as shadowing (often used in combination with one another or with dark-field), are most effective for examining color zones and growth features in many synthetic and natural gem materials.

Many of the growth features observed in the Biron synthetic emeralds are quite distinctive and different from those that occur in natural emeralds.

White Particles. Observed in many of the Biron synthetic emeralds were fine straight lines, irregular lines, and ill-defined v-shaped arrangements of stringers composed of minute white particles. Similar features, often referred to as "comet tails," also occur in other synthetic gems such as Kashan and Ramaura synthetic rubies (Kane, 1983) and in some natural gemstones, although very rarely if at all in natural emeralds. The comet-tail inclusions in the Biron synthetic emeralds were generally faint, in contrast to their appearance in synthetic rubies, where they are usually seen very easily in dark-field illumination. In many of the Biron synthetic emeralds, the comet tails were only visible when fiber-optic illumination was used (figure 18). They were observed to occur in several forms: trailing behind inclusions such as a fingerprint pattern; aligned with growth features, sometimes in multiple occurrences extending the entire length of the stone; and randomly oriented in one or two areas.

In many of the cleanest faceted Biron synthetic emeralds, the only inclusions were a few randomly oriented small, white, dust-like particles and faint growth features. The white particles were often sparsely placed in a random orientation throughout the synthetic emerald. Often one stone would contain particles of various sizes, ranging from minute at 45× to being easily seen at 45× (still visible, but quite small, at 10×). Although the white particles observed in many of the Biron synthetic emeralds are rather nondescript in appearance, they provide a good indication of synthetic origin. Natural emeralds that are flawless or very clean would not be expected to exhibit such inclusions.

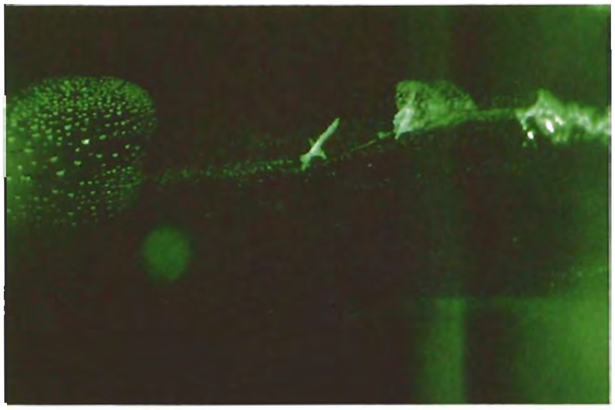


Figure 18. Typical of many Biron synthetic emeralds are these minute white particles arranged in stringers and "comet-tails," which may only become visible when viewed with fiber-optic illumination. Magnified 50×.

Seed Plates. A few of the faceted Biron synthetic emeralds contained what appeared to be seed plates. One stone contained a very lightly colored or near-colorless area that was free of inclusions, ranged in width from 0.8 to 1.1 mm, and extended through the entire stone. This zone was bordered on both sides by thin, dense planes of minute white particles and numerous larger gold crystals interspersed throughout the plane. On both sides of the seed plates, the planes of gold inclusions were very different in appearance; one is shown in figure 14. The other side exhibited larger, slightly angular gold crystals that were distinctly yellow in color. Extending through these planes of inclusions were nearly straight, parallel growth features. A few minute, white, nail-head spicules were observed extending away from one side of the dense inclusion planes, oriented at approximately 30° to the seed plate. This seed-plate area was chemically analyzed and is believed to be a natural beryl seed plate, as discussed below.

Another faceted stone showed a near-colorless zone, probably the seed plate, near the culet. From the many faceted Biron synthetic emeralds examined, it appears that the seed-plate areas are usually removed during cutting. It is likely, however, that the planes of gold inclusions and dense concentrations of minute white particles closely paralleled seed plates in the rough crystal.

CHEMISTRY

Microprobe chemical analyses of two of the faceted Biron synthetic emeralds showed consistency with previous data on other hydrothermal synthetic emeralds, in particular the Linde and Regency material, except with respect to vanadium content (see table 2). Earlier commercial hydrothermal synthetic emeralds contained no vanadium at all, whereas the Biron product contains appreciable amounts (more than double their chromium content). Because of the variable, but sometimes significant, content of vanadium in natural emeralds (Stockton, 1984), this in itself is not a satisfactory identification criterion.

Chlorine is present in the Biron synthetic emeralds, it was also reported by Hänni (1982) and Stockton (1984) in the Linde and Regency hydrothermal synthetic emeralds. The presence of chlorine probably comes from the chloride hydrate ($CrCl_3-6H_2O$) that is used to supply chromium as a coloring agent (Nassau, 1980, p. 151). As this element has not been detected in either natural or flux-grown synthetic emeralds, it serves as an identifying characteristic of the hydrothermal origin of the Biron synthetic.

A third faceted Biron synthetic emerald was analyzed in several different areas. An additional phase of beryl was identified and probably represents a natural beryl seed on which the synthetic emerald was grown. As compared to the analyses made on either side of the seed, which were in close agreement with those reported in table 2, this phase contains no Cr_2O_3, V_2O_3, or Cl, but does have appreciable FeO and minor amounts of Na_2O and MgO.

IDENTIFICATION AND SUMMARY

The "Biron process" produces single synthetic emerald crystals of remarkable size and clarity (see figure 1). This new hydrothermal synthetic emerald will be commercially available as preforms and faceted stones in substantial quantities before the end of 1985. As is the case with many new sophisticated synthetic gem materials, the Biron hydrothermal synthetic emerald possesses its own unique set of characteristics, some of which are not typically associated with synthetic emeralds. In this article, we have presented the key properties of this material (summarized in table 1). In doing so, we have found that some of the traditional gemological tests for the distinction of natural emerald from its synthetic counterpart do not apply. Specifically, the Biron synthetic emerald is inert to long- and short-wave ultraviolet radiation (as are most natural emeralds), and its specific gravity (2.68 to 2.71) overlaps with that of most natural emeralds.

There are, however, other means by which the Biron synthetic emerald can be identified from its natural counterpart:

1. *Characteristic inclusions.* Although by comparison to other synthetic emeralds, both flux-grown and hydrothermal, the Biron hydrothermal synthetic emerald possesses a much greater clarity (most of the stones in the study sample ranged from remarkably clean to slightly included), inclusions provide the most effective means of identification for the gemologist. To date, the following types of inclusions have been observed in the Biron hydrothermal synthetic emerald: fingerprints, veils, and fractures; single occurrences of large two-phase inclusions; nail-head spicule inclusions with gas and liquid phases; several forms of gold; phenakite crystals; numerous types of growth features; white particles in the form of comet tails and stringers or simply scattered throughout the stone; and (rarely observed) seed plates.
2. *The low refractive indices and birefringence.* [$\epsilon = 1.569$ and $\omega = 1.573$ $(+0.001)$ and 0.004–0.005]. These optical values are very unlikely to be observed in a natural emerald. However, an identification should not be made solely on the basis of this property, but in conjunction with the inclusions present.
3. *The characteristic chemistry, in particular the presence of chlorine (Cl).* The gemological laboratory with access to a microprobe or an energy-dispersive X-ray fluorescence spectrometry (EDXRF) system to analyze for Cl, which is present in Biron synthetic emeralds, can rely on this minor element as definitive proof of synthetic origin, inasmuch as Cl has not been reported in natural emeralds (it has not been found to occur in flux-grown synthetic emeralds either).

This study was conducted on over 200 samples of Biron hydrothermal synthetic emerald which were produced over the past few years. The manufacturer reports that he can control the clarity of the material and is currently synthesizing much "clean" material similar to many of the synthetic emeralds described here. Although some of the properties of the Biron synthetic emerald are different from those of other synthetic emeralds, and the Biron synthetics generally contain fewer inclusions, identification of this new synthetic does not have to be difficult. If the modestly equipped professional gemologist becomes thoroughly familiar with the inclusions and other properties of the Biron synthetic emerald, and employs meticulous study of even the most subtle internal characteristics, this new synthetic emerald can be identified.

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