Gems & Gemology

The quarterly journal of the Gemological Institute of America

Gems & Gemology

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ABOUT THE COVER: Recently, a small hillock near Katlang, Pakistan, has begun to produce fine gem-quality pink topaz. Authors Edward Gübelin, Giorgio Graziani, and A. H. Kazmi present an in-depth report on topaz from the Ghundao hill, the only known in-situ deposit of pink topaz in the world today. The finest-quality Pakistan pink topaz is reminiscent of the stones shown here. This necklace and the matching earrings represent more than 200 ct of fine pink topaz. The set is said to have been commissioned by King George III in 1795, and the stones are presumed to have originated in Russia. Photo ʻ 1984 Harold & Erica Van Pelt—Photographers, Los Angeles, CA. Jewelry courtesy Gary R. Hansen, Precious Gemstones, St. Louis, MO.

Typesetting for Gems & Gemology is by Scientific Composition, Los Angeles, CA. Color separations are by Effective Graphics, Compton, CA. Printing is by Waverly Press, Easton, MD.

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Subscriptions in the U.S.A. are priced as follows: $29.50 for one year (4 issues), $82.50 for three years (12 issues). Subscriptions sent elsewhere are $40.00 for one year, $115.00 for three years.

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TUCSON '87: DON'T MISS IT!

A 1,126-ct "padparadscha" sapphire crystal, a superb 667-ct emerald crystal from Muzo, the first tourmalines from Afghanistan, large quantities of aquamarine from Nigeria, many pounds of natural-color and dyed lapis lazuli, carats upon carats of treated blue topaz and synthetic (as well as natural) amethyst, emerald, ruby, and the like. Jeremejevite, parisite, taaffeite, cat's-eye opal, color-change garnet. The new, the rare, the unusual, and hundreds of thousands of carats of the better-known gemstones in a full range of qualities and colors. This is Tucson. That is, these are some of the items seen in recent years at the Tucson "show," really a multitude of gem and mineral shows and related activities that dominate the city of Tucson, Arizona, every February.

Ever since the mineral- and gem-collecting and lapidary hobbies started to gain in popularity a quarter of a century ago, a number of shows have been developed in various cities in Europe and the United States. In the U.S., those in Detroit, Pasadena, and Miami, among others, attracted significant numbers early on, but the one started by the Tucson Gem and Mineral Society in 1955 has become a unique happening and a must for the serious gem dealer or collector. Although it started as a show for hobbyists and still retains some elements of the hobby genre, "Tucson" is now one of the most important professional displays of gems and the jewelry arts in the world. It attracts top gem dealers, mineral dealers, collectors, and jewelers from every continent. While individual dealers have worked out of hotel rooms and lobbies in the area surrounding the convention center for almost two decades, separate "shows" that precede or coincide with the original show are now sponsored by the American Gem Trade Association (AGTA), the Gem and Lapidary Dealers Association (GLDA), and other organizations. During the first two weeks in February (the main shows go from the 6th to the 15th in 1987), thousands of dealers appear in Tucson selling everything from rough geodes off the backs of trucks to sophisticated pieces of jewelry that carry prices as high as six figures. The quantities of tourmaline, topaz, kunzite, and garnet of all colors and descriptions are mind boggling. Yet it is also the first opportunity for many to see new gem varieties, gems from new localities, and the results of new treatments and synthesis techniques. While for some Tucson is a source of information on price trends and shifts in supply, for others Tucson is the excitement of seeing the newest and the rarest.

Yet Tucson offers even more. The GIA, AGTA, and other organizations sponsor a variety of lectures and short courses during this period. Virtually all of the major gem and mineral publishers are represented, as are many of the jewelry manufacturing and tool suppliers. The Sonora Desert Museum, the scenic countryside, and the many fine hotels and restaurants all serve to make a working trip more pleasant, and the mild Tucson climate is invariably cooperative.

All in all, the Tucson show is one of the really exciting events of the colored-stone enthusiast's year. Our recommendation: Don't miss it!

Richard T. Liddicoat, Jr.
Editor-in-Chief

A SIMPLE PROCEDURE TO SEPARATE NATURAL FROM SYNTHETIC AMETHYST ON THE BASIS OF TWINNING

By Robert Crowningshield, Cornelius Hurlbut, and C. W. Fryer

Dr. Karl Schmetzer recently showed how near-flawless to flawless natural amethyst could be separated from synthetic amethyst on the basis of the presence of Brazil twinning in the natural stones. Whereas Dr. Schmetzer's procedure required a special apparatus, the authors have determined that a standard gemological polariscope is more than adequate to make the separation in most cases. Although some synthetic amethyst does show evidence of twinning, in the synthetic stones examined thus far it has taken a form that is distinctly different from the Brazil twinning seen in most natural amethysts. The presence of certain inclusions as well as the nature of the color zoning seen in natural versus synthetic amethysts is of primary use in making a separation. However, where there are no inclusions or color zoning, the presence of Brazil twinning in the natural amethyst will usually make the distinction.

ABOUT THE AUTHORS

Mr. Crowningshield is a director of the GIA Gem Trade Laboratory in New York City; Dr. Hurlbut is professor emeritus of mineralogy at Harvard University, Cambridge, Massachusetts; and Mr. Fryer is chief gemologist in the Research Department of the Gemological Institute of America, Santa Monica, California.

Since 1970, when synthetic amethyst first became available commercially, it has created problems in identification for gemologists. Although inclusions have proved reliable in distinguishing synthetic from natural in most "flawed" amethysts, until recently no test was available to separate the flawless or near-flawless stones that represent the bulk of the fine faceted stones on the market (figure 1). As a result, otherwise ethical jewelers and suppliers everywhere may have unwittingly sold thousands of synthetic amethysts that were represented to them as natural. In 1985, however, Dr. Karl Schmetzer described a procedure by which a distinction can be made (see also Schmetzer, 1986). Subsequently, the authors adopted Dr. Schmetzer's procedure for use with standard gemological equipment. This test alone is not always unequivocal but, when used in conjunction with other observations, such as color zoning, it presents an excellent method for the separation of most near-flawless synthetic and natural amethyst.

The procedure described by Dr. Schmetzer is based on the fact that most natural amethysts are repeatedly twinned on the Brazil law, while synthetic amethysts are usually grown as single crystals (Schneider and Droschel, 1983; Lind et al., 1983). In polarized light, a twinned stone will exhibit varying degrees of interruption in the spectral rings, while an untwinned stone will show undisturbed rings of spectral colors. While Dr. Schmetzer's description suggested that a special apparatus was required, we have found that a polariscope or standard polarizing microscope is adequate to observe the diagnostic twinning. To confirm the accuracy of our method, we examined more than 1100 natural and 200 synthetic amethysts. In this article, we describe how to apply these simpler procedures.

First, however, it is well to review twinning in amethyst as well as why synthetic quartz was made in the first place. Other tests useful in distinguishing natural from synthetic amethyst are also discussed briefly.
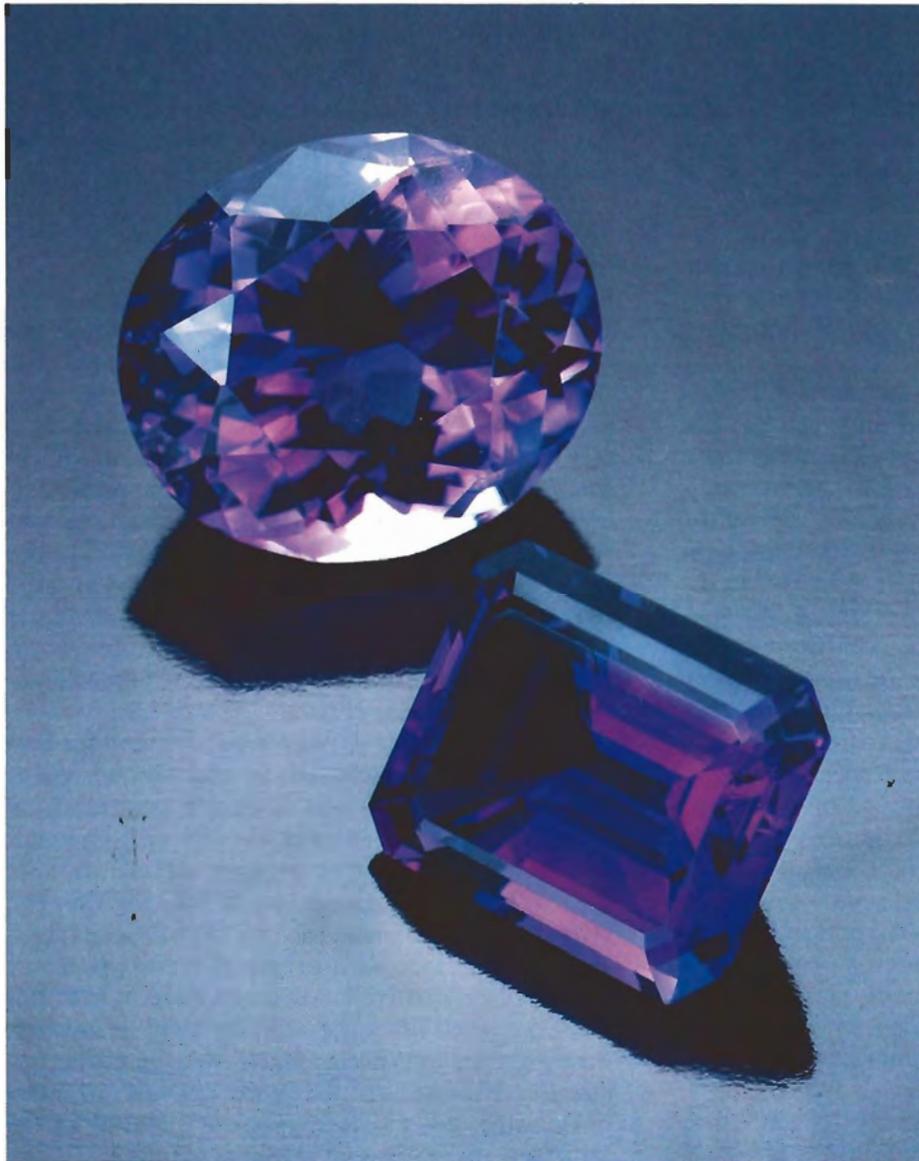
Figure 1. One of the major problems facing gemologists today is the separation of natural from synthetic amethyst, as illustrated by the 9.40-ct natural oval cut and the 5.48-ct synthetic emerald cut shown here. Photo © Tino Hammid.

TWINNING IN AMETHYST

The fact that almost all natural amethyst is twinned according to the Brazil law has been known for at least 150 years. The optical structure of amethyst was first described by Sir David Brewster in 1821 (Frondel, 1962), and was correctly interpreted as due to the polysynthetic twinning of right- and left-hand quartz. In the course of the 19th century, further descriptions were given by many other workers. A brief summary of these and later works is found in *Dana's System of Mineralogy* (Frondel, 1962): "Amethyst virtually always shows polysynthetic twinning on the Brazil law. Untwinned crystals have been noted. The twin lamellae, a fraction of a millimeter thick, are remarkably uniform and are arranged parallel to the terminal $\underline{r}$ or $\underline{r}$ and $\underline{z}$ faces. The lamellae are alternately right- and left-handed. They may give rise to sets of delicate striations, or to open polygonal markings on the rhombohedral faces, and cause a rippled, or fingerprint appearance on the fracture surfaces. The twinning can be studied in etched sections or, more conveniently, by optical means."

The last sentence of the above quotation, if applied to the study of gemstones, might better have been written: "The twinning can be studied in etched sections or more conveniently *and less destructively* by optical means." For etching is done with hydrofluoric acid, a harsh treatment of a gem. The twin lamellae are, however, made readily apparent by the process (figure 2).

Gemologists are familiar with the term *poly-*

synthetic twinning in connection with the repeated twinning of corundum and some feldspars. In the term *polysynthetic,* "synthetic" is not to be confused with its use meaning "man-made," but rather carries the classical meaning of "put together;" while "poly-" is a combining form meaning "many." Thus, the term *polysynthetic* conveys the meaning of "many thin crystals (lamellae) put together."

Quartz is optically active; that is, if polarized light moves parallel to the optic axis, the plane of polarization is rotated. The rotation is to the right, conventionally clockwise, in right-hand crystals and to the left in left-hand crystals. The shorter the wavelength, the greater is the rotation; violet light is thus rotated more than red light. As stated in the above quotation from *Dana's System of Mineralogy,* Brazil twinning results in alternating lamellae most commonly under faces of the major rhombohedron, r, the large triangular faces that terminate the quartz crystal. Figure 3 is a drawing of a section perpendicular to the optic axis that shows twinning under the major rhombohedron with the right-hand portions of the quartz shown in white and the left-hand portions of the quartz shown in black. If slices of quartz represented by this drawing were observed between crossed polarizers, they would take on the appearance seen in figure 4. One would see narrow parallel bands of alternating colors and shadow under the major rhombohedrons and broad swaths of color under the minor rhombohedrons.

With light moving parallel to the optic axis through the twinned areas, the rotation of polarization is alternately right and left. Because the lamellae are not of exactly the same thickness, the net rotation is always greater in one sense than the other, resulting in different colors for the right-hand and left-hand regions. The lamellae are thus striated and sharply defined, whereas the untwinned areas are of a single color. Twinning may be confined to isolated triangular areas, but frequently in amethyst it will be evidenced by straight lines crossing the stone. There may be only one set of parallel lines, or there may be two or three sets making angles of 60° or 120° with one another (again, see figure 4). These latter result from the meeting of the twinned areas under two or three of the rhombohedron faces.

In the authors' experience, untwinned crystals (as noted in the *Dana's* quotation above) are very rare. Although some natural untwinned faceted amethysts have been observed, they were probably cut from the area completely under the minor rhombohedron.

THE HISTORICAL DEVELOPMENT OF SYNTHETIC AMETHYST

Before World War II, Brazil was able to supply the world with the rock crystal necessary to make the oscillators used to control radio frequency. Since the oscillator must be free of twinning, the first step in manufacture was to inspect the raw crystals for Brazil twinning. This was done in an immersion tank, using a giant polariscope with polarizers one foot square. The hand-held quartz crystal was turned until the optic axis was parallel to the direction of light through the polariscope and the Brazil twinning, if present, was observed. Many crystals with twinning throughout were discarded, others with little or no twinning were passed on to the next operation, cutting.

During the war, however the demand for Brazilian quartz skyrocketed. In the United States alone, thousands of tons of quartz crystals were used in the manufacture of over 50 million small oscillator plates cut at precise crystallographic angles. In 1944, because quartz was high on the critical list of minerals, the U.S. Signal Corps initiated a quartz synthesis program. Private industry also became involved. Although success was not achieved until after the war, by 1950 hydrothermally grown synthetic quartz was in mass production. Now untwinned quartz crystals grown on untwinned seed plates supply the material for oscillators in radios, watches, clocks, radio-frequency filters, and other apparatus where frequency control of electrical circuits must be precise.

The successful synthesis of colorless quartz pointed the way to the manufacture (by the irradiation of iron-bearing synthetic quartz) of colored quartz (Balitsky, 1980). But with citrine and amethyst so abundant and relatively inexpensive, there would seem to be no incentive to synthesize these materials. Since about 1970, however, both have been made commercially in the Soviet Union and, later, in Japan. To date, most synthetic production is untwinned, single-crystal material.

DETECTION OF BRAZIL TWINNING WITH THE POLARISCOPE

It is to Dr. Karl Schmetzer, of the University of Heidelberg, West Germany, that credit must be
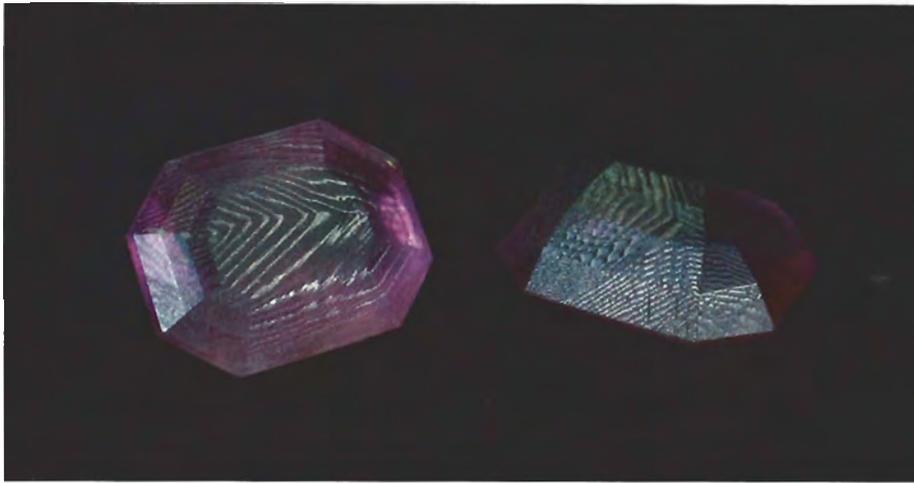
Figure 2. Etching an amethyst with hydrofluoric acid clearly reveals the presence of Brazil twinning in these two 18-ct stones. The test is, however, highly destructive and therefore not practical for gemologists. Photo by Shane McClure.

given for first promoting (1985) the optical test to differentiate flawless or near-flawless synthetic from natural amethyst. However, there is the implication by Schmetzer that to observe the twinning, one must use an "improved sample holder" with a horizontal immersion microscope. We have found that twinning can be equally well observed using a vertical polarizing microscope, but even more easily by simply using a standard gemological polariscope with the stone held in ordinary stone tweezers or even in one's fingers.

In adapting Schmetzer's procedure to the open polariscope, we have used several items that are readily available. Many times, the twinning effect can be seen without immersion. However, when immersion is necessary, a number of items are

useful. Since amethysts tend to be relatively larger than more costly stones, we have found small flared colorless glass votive candle holders, about two inches (5 cm) high and two inches in diameter, to be good immersion cells. They are also sold as oyster cocktail condiment holders for restaurant use. One is shown with a polariscope in figure 5. Various immersion liquids may be used, but the closer the refractive index of the liquid is to that of quartz, the better. However, water usually provides relatively good results.

To observe twinning in amethyst, the stone must be turned so that its optic axis is parallel to

Figure 3. This idealized illustration shows left-hand (black) and right-hand (white) portions of a twinned amethyst. Adapted from Schlössin and Lang, 1965.
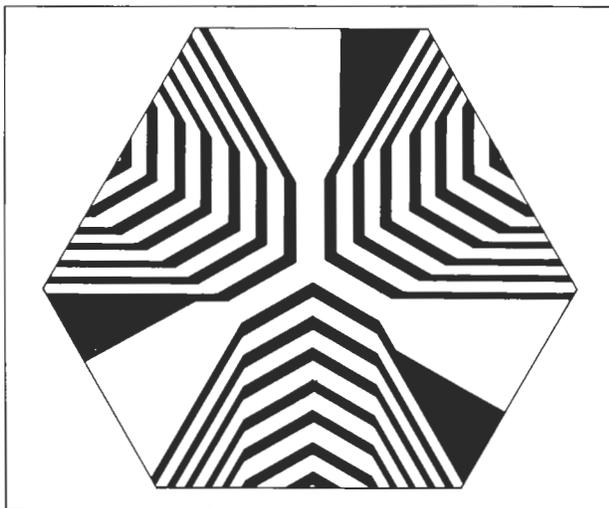

Figure 4. The twinning evident in this natural amethyst closely resembles the idealized drawing shown in figure 3. Note the narrow bands of color under the major rhombohedrons and the broad swaths of color under the minor rhombohedrons. Magnified 15 ×; photomicrograph by Robert Kane.
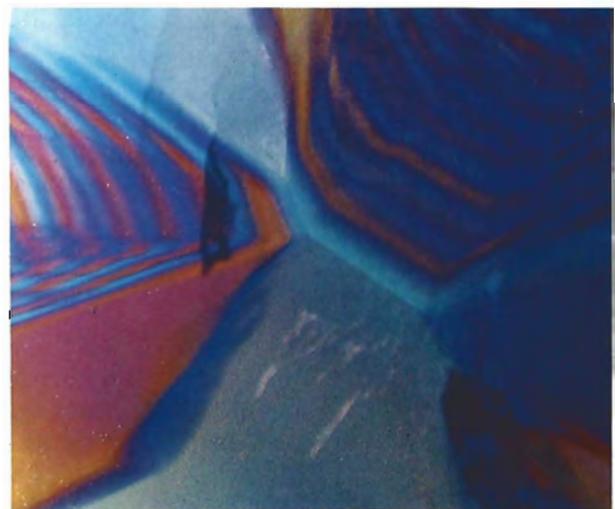
Figure 5. A simple polariscope and immersion cell are sufficient to identify Brazil twinning in near-flawless to flawless natural amethyst. Photo by David Hargett.

Figure 6. The difference between the twinned natural (oval) and the untwinned synthetic (emerald cut) amethyst is clearly seen looking in the optic axis direction of each under crossed polarizers. Photo by David Hargett.

the line of sight through the polariscope or microscope, which must have crossed Polaroids, that is, the dark position. The basic problem is thus one of crystallographic orientation. Cut amethysts usually are not oriented except for maximum weight retention, or best color, so that finding the optic axis direction is a challenge. This is the reason Dr. Schmetzer felt a special holder was necessary. Only rarely is a stone cut with the table perpendicular to the optic axis. Nevertheless, such is the case with the two stones in figure 6. The oval is a natural amethyst showing twinning, whereas the emerald cut shows the untwinned effect of a synthetic stone. The photograph was taken "dry," that is, the stones were not immersed.

Rarely in practice will the test yield such conclusive and dramatic results as easily—and without immersion. For one thing, the optic axis of the stone being tested may coincide with the point of a fancy shape or the girdle of any stone, making it difficult to maneuver with the tweezers to find the right direction. Another problem, more serious, is that if a natural stone has been cut so that it lies entirely under the minor rhombohedron, it will not exhibit twinning. Sometimes only a small area of the stone encompasses an area under the major rhombohedron, but the diagnostic twinning effect, although minimal, is still conclusive. As quoted from Dana above, there have also been reported rare untwinned natural amethyst crystals. These could not be detected by the Schmetzer test alone. Of course, mounted stones offer another problem. If the optic axis direction is obscured by the setting, they cannot be tested without unmounting. Herein lie the shortcomings of the test.

Figure 7 shows the twinning seen with the polariscope in a variety of natural stones. Equally good results can be obtained with a polarizing microscope (figure 8). In contrast, figure 9 illustrates three untwinned synthetic stones. The natural stone shown in figure 10 had to be maneuvered quite a bit, as it apparently was cut from material predominantly under the minor rhombohedron. However, even a tiny area of fine parallel colors shows the presence of twinning, and thus given our present knowledge proves natural origin.

Some synthetic amethysts, notably from Japan, do exhibit twinning (Balakirev et al., 1975). However, our observations thus far indicate that the twinning in these synthetics has a distinctly different appearance from that of natural amethyst. The twinning in the synthetics appears as
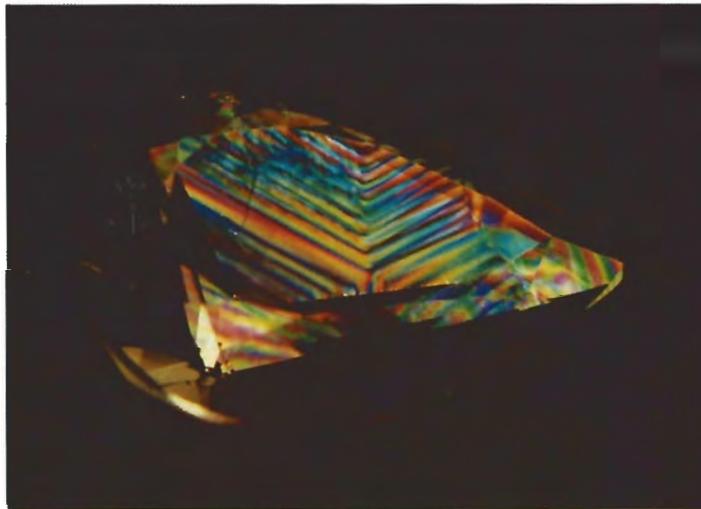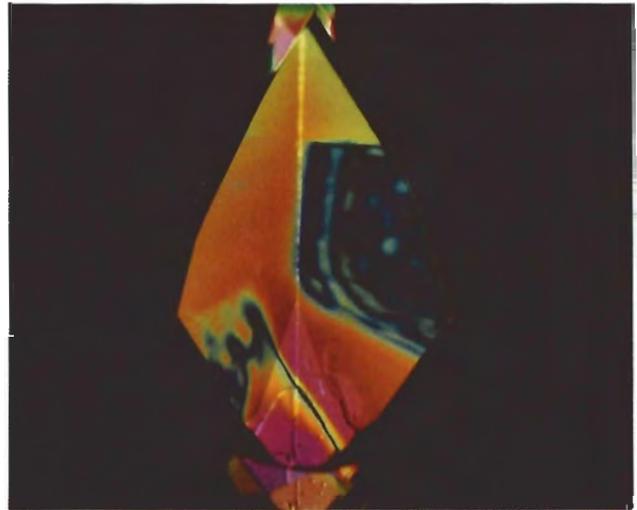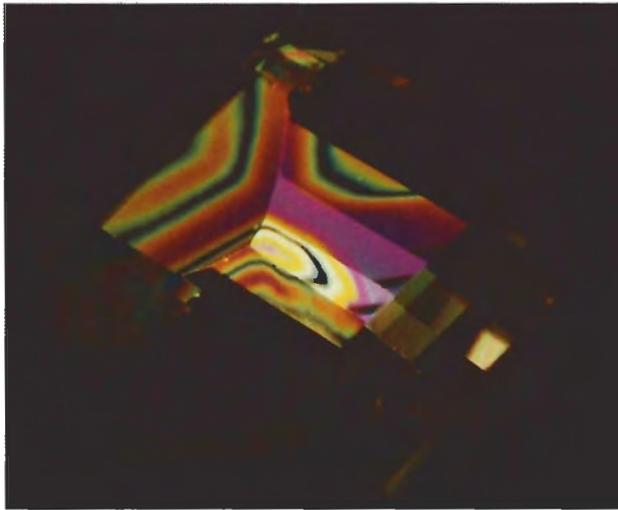
Figure 7. As these three examples of natural amethyst viewed through a polariscope indicate, the Brazil twinning may vary somewhat from one stone to the next. Often the stone will have to be maneuvered with the tweezers or in one's fingers to see the twinning clearly. While immersion may be helpful, these photos were all taken with the stones dry. Photos by Shane McClure.

irregular-shaped, small arrowhead-shaped, or flame-like areas (figure 11). Such stones will have definite zones of yellow or dark purple that coincide with these flame-like or irregular-shaped twinned areas (figure 12). Even in very small areas, however, the acute included angle of the twinning in the synthetics can be distinguished from the 60° or 120° angles characteristic of Brazil law twinning in natural amethyst.

Citrine that has been produced by heating natural amethyst will behave in the polariscope in the same manner as natural amethyst. Bi-colored quartz, sometimes called "ametrine" or amethyst/citrine (figure 13), usually behaves differently. Koivula (1980) noted that Brazil twinning is present in the amethyst zones, whereas the citrine zones are untwinned (figure 14). Thus, ame-

Figure 8. Twinning in natural amethyst can also be identified using a polarizing microscope with crossed polarizers. Magnified 6×; photomicrograph by John Koivula.
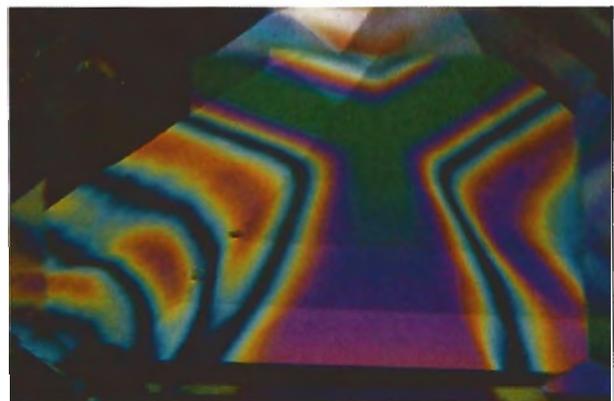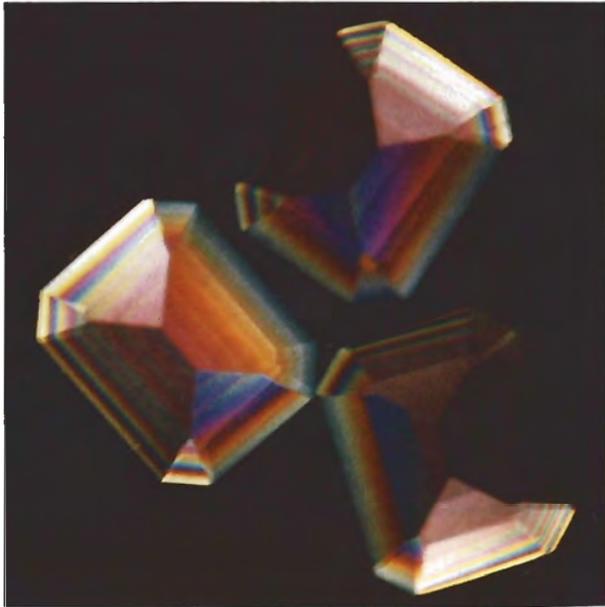
Figure 9. These untwinned synthetic amethysts provide a striking contrast to their twinned natural counterparts when viewed with the polariscope. Note the broad color bands that are characteristic of untwinned single-crystal material. Photo by David Hargett.

Figure 10. Even a small area of twinning, as shown here in rock crystal quartz, indicates natural origin. Photo by David Hargett.

thyst/citrine and citrine with twinning present can be identified as natural by this method.

OTHER EVIDENCE OF NATURAL VS. SYNTHETIC AMETHYST

Since some natural amethyst may be untwinned, one should consider evidence other than the ab-

sence of twinning before calling a stone "synthetic." The presence of recognizable inclusions, such as those described by Gübelin and Koivula (1986), proves natural origin. At one time, "fingerprint" inclusions were regarded as proof of natural origin. This is no longer the case since some synthetic crystals may also have liquid-filled "fingerprint" inclusions (figure 15), especially near the surface of the crystal. The presence of spicules, or

Figure 11. In the synthetic amethyst manufactured in Japan, a form of twinning appears as small irregular-shaped, arrowhead-shaped, or flame-like areas that are very different from the twinning seen in natural amethyst. Magnified 6×; photomicrograph by John Koivula.

Figure 12. Color zoning coincides with the flame-like or irregular-shaped twinned area in some synthetic amethysts of Japanese manufacture, as this photo of the stone in figure 11, taken without the polarizers, indicates. Magnified 6×; photomicrograph by John Koivula.

Figure 13. This bi-colored quartz is also known as "ametrine" or amethyst/citrine. Photo by David Hargett.
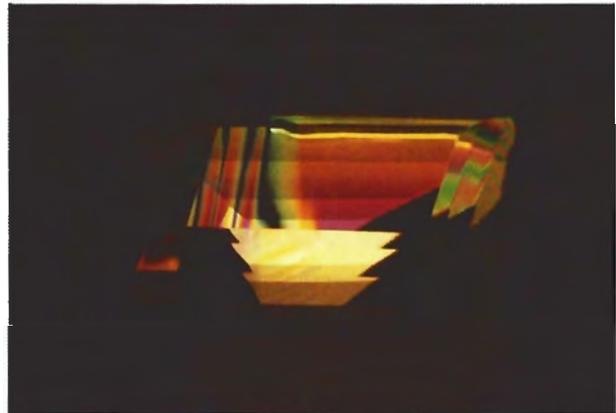
Figure 14. When amethyst/citrine quartz is viewed with a polariscope, the presence of twinning in the amethyst section indicates that the stone is natural. Photo by Shane McClure.

"nailhead," inclusions (observed very rarely) proves hydrothermal synthetic origin. Occasionally, portions of the seed crystal will occur in a synthetic stone and they are highly diagnostic. They usually appear as a slightly cloudy white or yellowish plane often peppered with high-relief "breadcrumbs" (figure 16). Although "breadcrumbs" may (very rarely) be found in natural amethyst, a gemologist seeing them in an otherwise flawless, untwinned stone would be well advised *not* to call it natural!

In the course of this study, 105 natural amethysts were examined with regard to color zoning.

The pigmenting of amethyst is associated with Brazil twinning, and thus characteristically the deepest color lies under the major rhombohedron, whereas the sections under the minor rhombo-

Figure 16. "Breadcrumb" inclusions, although seen (very rarely) in natural amethyst, usually provide a good clue that the host stone is synthetic, as shown here in a synthetic amethyst of Japanese manufacture. Magnified 45×; photomicrograph by David Hargett.

Figure 15. Liquid-filled fingerprint inclusions are now sometimes seen in synthetic amethyst, as shown here, as well as in natural stones. Magnified 20×; photomicrograph by David Hargett.
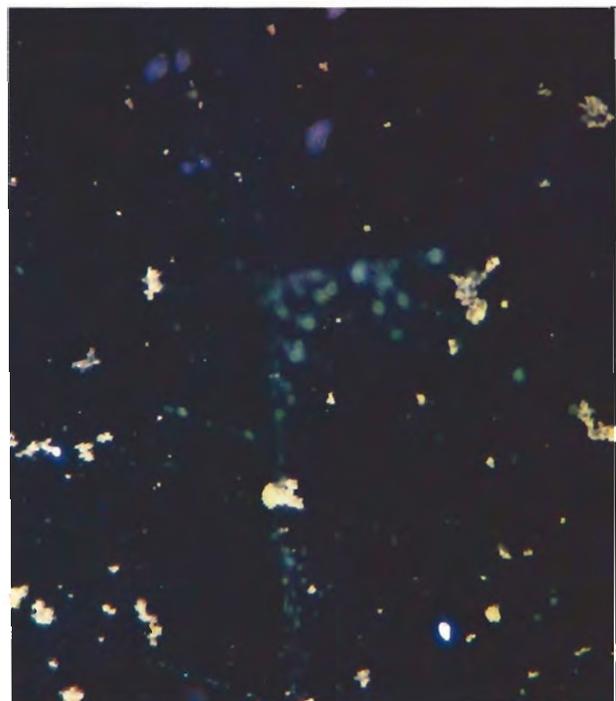
Figure 17. This basal section of amethyst clearly illustrates the deeply pigmented sectors under the major rhombohedron and the nearly color-less sectors under the minor rhombohedron that are characteristic of color zoning in natural ame-thyst. Photo by Cornelius Hurlbut.

Figure 18. When color zoning is seen in a syn-thetic amethyst (here, 10.86 ct), it is limited to darker and lighter shades of purple. Photo by Shane McClure.

Figure 19. The color zoning in natural amethyst (here, 7.04 ct) is typically straight or angular in two or three directions, and consists of zones of purple and violetish blue or colorless material. Photo by Shane McClure.

hedron may be colorless or nearly so (figure 17). Even under the major rhombohedron the color may not be uniform. According to Frondel (1962), "The amethyst color may be equally developed in successive twin lamallae, but more often alternate lamellae, either right or left, are selectively pig-mented."

Color zoning was present in all 105 natural amethysts examined. In a few, zoning was in one direction only, that is, parallel to but one rhombo-hedron face. In most, color zoning was parallel to two or three of the rhombohedron faces from which the stones were cut. Brazil twinning was present in all but two of the stones. One of these showed color banding parallel to two rhombo-hedron faces; the other had color banding parallel to three.

In the limited number (6) of faceted synthetic amethysts examined for color zoning, all were un-twinned. Five were of uniform color throughout, which is rarely if ever seen in natural amethyst (again, see figure 17). One showed imperfect color zoning parallel to a rhombohedron face that was interpreted as being parallel to the seed from which the crystal was grown. In addition to the cut stones, there was available a piece of synthetic rough which included the colorless seed plate cut parallel to a rhombohedron face. This was flaw-less, untwinned material with a faint color zoning parallel to the seed. The observations indicate an uncertain identity of an untwinned stone with one

direction of color zoning. But if the zoning is in two or three directions, a natural origin is indicated. It should be noted that the zoning observed in most synthetic stones is limited to darker and lighter shades of purple (figure 18); parallel zones of purple and violetish blue or colorless material and angu-lar zoning indicate natural amethyst (see figure 19). Other gemologists (e.g., Sondra Francis, pers. comm., who has studied this phenomenon in depth) report that many synthetic amethysts are indeed zoned but confirm the zoning differences noted above between natural and synthetic stones.

In recent years, gemological and mineralogical investigators have noted in print the rippled frac-ture surface of natural amethyst and even outlined a procedure for frosting the surface of an unknown amethyst (by slight regrinding with fine grit on a

soft wheel at low speed) so that it is possible to see with the unaided eye the twin lamellae of the natural stone (Schneider and Dröschel, 1983). Of course, the stone must then be repolished.

Considerable attention has also been paid in Europe to attempts to distinguish amethysts by infrared spectrometry (Katz, 1962; Chakraborty and Lehmann, 1978; Zecchini, 1976; and Lind and Schmetzer, 1983). Problems with specimen orientation, as well as the practical difficulties encountered in transmitting spectral signals through faceted gemstones, have thus far thwarted attempts to provide a routine method of identification through infrared spectra. However, new infrared instrumentation is now available, and results to date are promising for this approach to the separation of natural and synthetic amethyst.

CONCLUSION

While some "experienced" amethyst dealers have reported no difficulty in separating synthetic amethysts from natural stones merely by looking, others who have mastered the "Schmetzer" test have reported that their stock is badly mixed. One dealer stated that even parcels from his own cutting shops abroad have had as much as 25% synthetic amethyst mixed with the natural. It is the authors' hope that this article will serve to reassure the ethical trade that this no longer need be the case, that the practice of salting synthetics into parcels of natural stones can be effectively deterred.

Although the reader is reminded that the use of twinning cannot be 100% effective, in preparing for this article the authors tested more than 1300 amethysts of known origin (over 1100 natural and 200 synthetic). By noting inclusions, color zoning, and twinning, all the stones could be satisfactorily identified.

On the basis of information currently available, we conclude that the presence of Brazil law twinning in an otherwise flawless amethyst proves natural origin. However, twinning in the form of an acutely angled, flame-like pattern positively identifies synthetic origin. With practice, there should be no confusion between these twinning patterns.

In the absence of twinning, synthetic origin is probable, but further evidence is required to make a positive identification. Angular or straight zoning with colorless or violetish blue zones next to purple areas characterizes natural amethyst. The presence of zones of only light and dark purple or

the complete absence of zoning indicates synthetic origin, but does not provide conclusive proof of origin. Characteristic inclusions can also provide proof of origin.

If no other conclusive evidence of origin is available, infrared spectrometry appears to contain such proof, once the practical aspects of routine application have been resolved. Ongoing research in this area promises to solve the few remaining difficulties in identifying natural and synthetic amethyst. However, this study indicates that the overwhelming majority of stones on the market today can be distinguished by the methods already available.

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PINK TOPAZ FROM PAKISTAN

By Edward Gübelin, Giorgio Graziani, and A. H. Kazmi

In addition to the relatively recent discovery of significant amounts of emerald, aquamarine, and ruby, Pakistan has also begun to produce fine gem-quality pink topaz. In a small hillock of recrystallized limestone north of Katlang, narrow calcite veins encase pink topaz crystals up to 3 cm long accompanied by larger amounts of reddish brown, tan, and colorless topaz crystals. More than 70,000 ct of gem-quality pink topaz has been reported to date. The refractive indices, optic axial angle, unit-cell dimensions, and density of the topaz are influenced by a partial replacement of fluorine by hydroxyl ions. The color is due to trace elements—principally chromium (Cr^{3+}). Treatment experiments revealed that the color of the brown, tan, and colorless topaz from this source may be improved by irradiation and heat.

The occurrence of pink topaz in Pakistan was discovered less than 20 years ago. This attractive material (figure 1) has been reported on several occasions in the gemological literature (Afridi et al., 1973; Bank, 1976a and b; Petrov et al.; 1977a, b, and c; Jan, 1979), but details of the deposit itself have only recently become available. In this article, the authors report on their investigation of the geology and mineralogy of the pink topaz deposit near Katlang, and on the chemistry and the gemologically ascertainable properties of this material. As part of this study, the authors also investigated the other color varieties of topaz found at the deposit and their reaction to treatment.

LOCATION AND ACCESS

The topaz is found in one of two hills that rise abruptly from the fertile agricultural plain of the Mardan District in the neighborhood of a small village. This settlement of farmers and the topaz hillock both bear the same name— Ghundao—and are located about 4 km (2.5 mi.) north of the small town of Katlang (figure 2). The geographic coordinates of the topaz-bearing hill of Ghundao are latitude 34°24'N, longitude 72°06'E, which places it about 63 km (40 mi.) northeast of Peshawar and about 20 km north of the district capital Mardan "as the crow flies" (approximately 50 km southeast of the Swat Valley emerald deposits; see Gübelin, 1982). The hill is easily reached by automobile. The other hill, which contains no topaz deposits, lies about 1 km northwest of the Ghundao hill. The summit of Ghundao, the topaz hill, is approximately 80 m higher than the village, and the two hills are conspicuous features of an otherwise unbroken plain (figure 3).

GEOLOGY AND OCCURRENCE

The Ghundao hill, only about 340 × 275 m at its base, is composed primarily of strata of gray recrystallized limestones tilted to a near-vertical orientation, and intercalated

Figure 1. This fine specimen of pink topaz (7 cm × 3 cm) is from Katlang, in the Mardan District of Pakistan. From the collection of Bill Larson. Photo © Harold & Erica Van Pelt.

with phyllites and autoclastic limestone breccias (figure 4). There are three main lithologic units in the hill:

1. Light gray, thick-bedded, largely autoclastic limestone.

2. Dark gray, medium-bedded, fine-to-medium grained crystalline limestone; the lower part is composed of algal structures. This unit also contains some quartz, mica, and altered pyrite crystals.

3. Thin-bedded limestone and calcareous shale. The gray color of the rock is caused by

irregularly dispersed, dust-like bituminous inclusions.

These rocks have been grouped by previous workers (Martin et al., 1962; Afridi et al., 1973; Jan, 1979) with the lower Swat-Buner Schistose Group, and are believed to be of Silurian-Devonian age (Afridi et al., 1973, Jan, 1979). The algal structure in the limestone and the gastropod fossils found in the lower beds of the Ghundao hill support this assessment of age. The Ghundao limestones are probably a northern extension of the Silurian-Devonian rocks of Nowshera forma-

tion (which could be about 400 million years old), although they may comprise a different depositional facies.

Structurally, the Ghundao hill comprises a "mini" anticlinorium with the axes of the tight folds trending east-west and plunging eastward (figures 4 and 5). The limbs of the larger folds have themselves been tightly drag-folded and extensively faulted. The gray limestone has been intruded in places by veins of coarse-grained white calcite and quartz. These veins, in which the topaz is found, are of two types:

1. Short, narrow irregular veins (several centimeters wide and less than a meter long) of fine-grained white calcite, which cut randomly across the strike of the fold axes.

2. Much larger veins (as much as 2 m — 6 ft. — wide and several meters long) of coarser-grained calcite, which occur along fault planes that run parallel to the fold axes

(figure 6). These veins are interspersed by milky-white quartz, green muscovite, and green talc, as well as by minor amounts of a limonitized clay-like material. Topaz mineralization is mainly confined to this latter type of calcite vein. The veins appear to completely penetrate the hill conformably with the gray limestone strata.

The topaz mineralization is structurally controlled (figures 5 and 6) and forms typical saddle-reef type structures in the limonitized clay-like muscovite accumulations of the larger type 2 veins described above. At several places, the limestone has been invaded by stockworks of calcite and quartz veins which also contain beautiful, perfectly euhedral crystals of quartz and topaz, usually completely embedded in the calcite, but occasionally found protruding into cavities or crevices, or lying loose in the breccia debris (figure 7).

Figure 2. This map shows the location of the topaz hill at Ghundao, in the Mardan District of Pakistan, and the geological setting of the surrounding area. Artwork by Cecile Miranda.
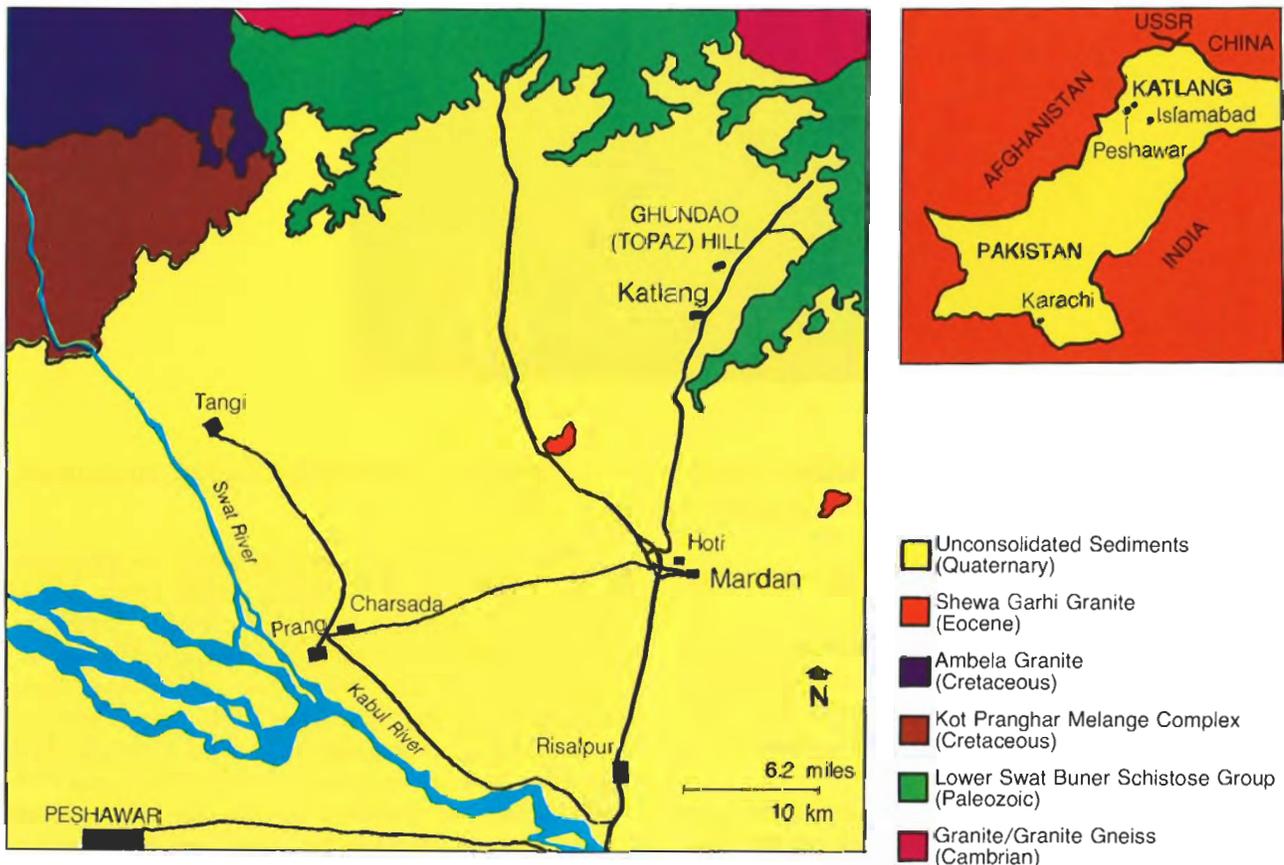
Figure 3. The view from the Ghundao hill across the plain of Katlang toward the southeastern foothills of the Hindu Kush range shows how flat the plain from which the two hillocks rise actually is.

Figure 4. An open cut in the flank of Topaz Hill reveals the vertical stacking of the strata.
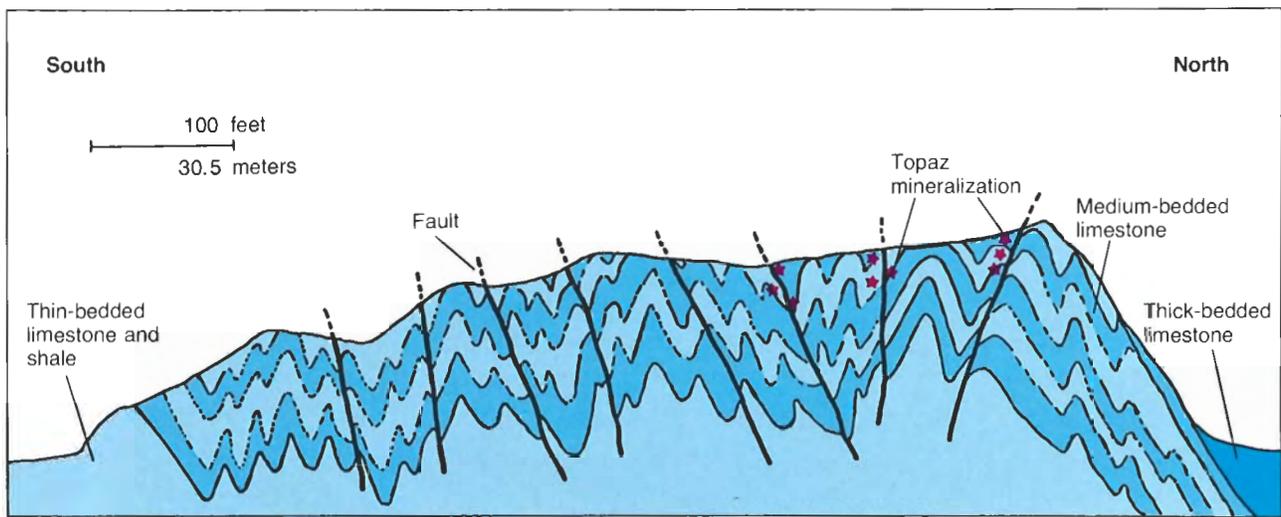
Figure 5. This diagramatic geological section across the Ghundao hill shows the three major lithologic units and the extensive folding and faulting. After A.H. Kazmi. Artwork by Cecile Miranda.

A "pinch and swell" structure is common along the topaz-bearing calcite veins, although some are quite narrow (type 1) and others are much larger and more extensive (type 2). Topaz also occurs in calcite that forms small lenticular tension gashes in limestone at the crests of the folds or drag folds (again, see figure 6).

Jan (1979) concluded that the topaz may have formed by hydrothermal/pneumatolytic activity, followed by tectonic movements which fractured the crystals and resulted in their incorporation

into later-formed vein calcite. Although Jan mentions that the mineralizing solutions for the Katlang topaz may have been genetically related to the Swat granite gneisses, the authors believe that the Katlang topaz is late syntectonic, and was formed largely through pneumatolytic processes linked with the final stages of consolidation of the much younger (Eocene) granitic intrusions of Shewa, which are in close proximity to the topaz deposits (again, see figure 2). Some supporting evidence is provided by the fact that trace-element analyses of
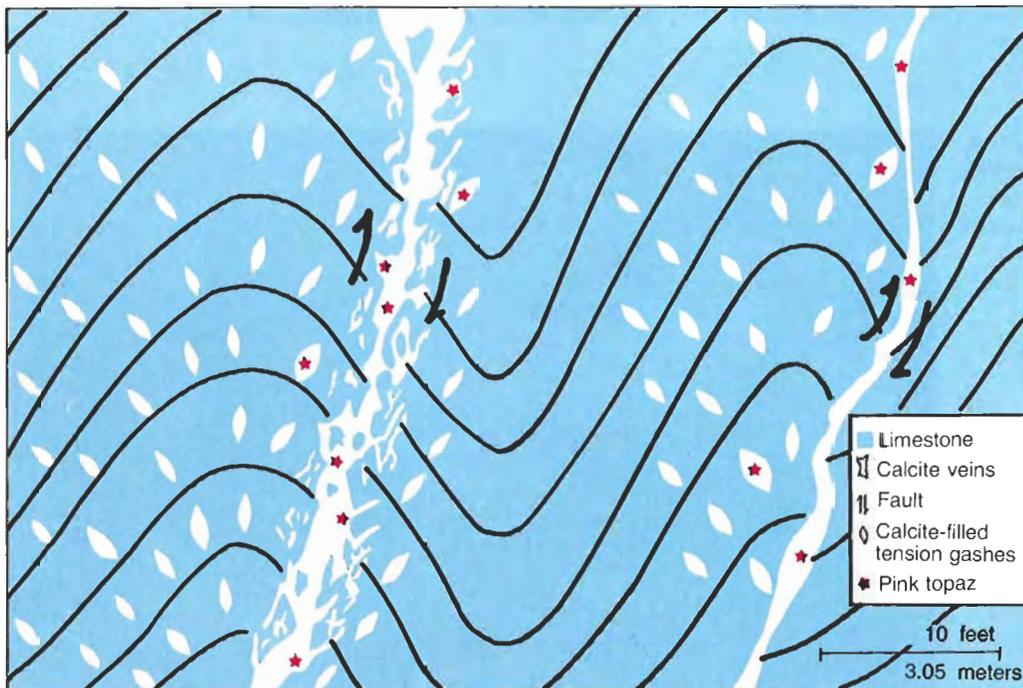
Figure 6. This diagram illustrates the structure and mineralization of the topaz deposit at Ghundao. Note especially the topaz-bearing calcite veins and tension gashes. After A. H. Kazmi. Artwork by Cecile Miranda.

Limestone
Calcite veins
Fault
Calcite-filled tension gashes
Pink topaz

Warsak and Shewa granites (from the Peshawar basin) by Kempe (1983) show up to 10 ppm chromium. This may explain the presence of Cr_2O_3 in the Katlang topaz (see below). Study of these granites by Chaudhry and Shams (1983) has revealed that these rocks developed in an environment that would have been ideal for the formation of the type of mineral deposits that we see today at Katlang.

Figure 7. Although the pink topaz from Ghundao usually occurs embedded in the host calcite, it is also found as fine, well-formed crystals protruding from the host calcite into a vug or as loose crystals.

Figure 8. Miners collect the loose rocks at the bottom of one of the large open cuts that has been blasted into the side of the Ghundao hill. One miner uses a pick to remove pieces of calcite from the wall of the cut.

MINING AND PRODUCTION

Topaz was first discovered at Ghundao in the fall of 1972 by local residents who dug the crystals secretly and then brought them to the market in Peshawar. When the government became aware of this illegal digging, the West Pakistan Industrial Development Corporation (WPIDC) was asked to undertake detailed studies of the topaz-bearing hillock. The Mineral Development Cell of the WPIDC in Peshawar first studied the Ghundao hill in January 1973 (Afridi et al., 1973). Prospecting rights were held by the WPIDC and later by its successor, the Pakistan Mineral Development Corporation (PMDC), but no systematic mining was conducted until the deposits were taken over by the Gemstone Corporation of Pakistan (GEMCP) in 1979. Local residents, however, reportedly con-

tinued unauthorized mining during this period, until the GEMCP began geologic exploration and systematic mining of the deposits in 1981. This work was carried out under the guidance and supervision of one of the authors, Dr. Kazmi.

Presently, all mining in the area is under the control of the GEMCP. All workings are open cuts consisting of trench-like incisions (figure 8) blasted into the calcite veins that are known to bear topaz. Hand tools as well as pneumatic drills are used to dislodge fragments of calcite that remain attached to the open-cut walls. To minimize damage to the crystals during mining, great care is taken in deciding where to drill, in using low-strength explosive charges, and in controlling

Figure 9. On a heap of blasted pieces of rock, miners break promising pieces in search of topaz crystals.

the blasting. Promising lumps of rock are then carefully broken up with hammers to free the enclosed topaz crystals (figure 9).

By February 1983 (when the senior author visited Ghundao in the company of Dr. Kazmi), three open cuts had been driven deep into the hillside; the largest of these cuts almost reached the summit. At the time, approximately 15 miners were working the deposit. The daily production of topaz was so small that all of it could be carried

easily by hand to the small depot in Ghundao Village. Only a very small percentage of the crystals are clean enough to be cut as gems.

The total production of gem-quality pink topaz recorded up to November 1984 is 72,076 ct. Annual production currently ranges between 20,000 and 30,000 ct; collectors' specimens are also available. The largest cut pink topaz from this source recorded to date is 37.76 ct (illustrated in Spengler, 1985, p. 669).

Figure 10. These three crystals represent the main colors—colorless, pink, and brownish—of the topaz found at Ghundao. The sizes of the three crystals are somewhat representative of the proportion in which these colors occur at Ghundao (the largest crystal is approximately 10.25 mm). Like most of the topaz found at this locality, these crystals are highly fractured and broken.

Figure 11. These three faceted pink topazes from Ghundao illustrate the most prized color found at the locality (from left to right: 5.68 ct, 18.41 ct, 9.38 ct).

CRYSTALLOGRAPHY

Well-developed euhedral crystals of topaz are rare at this locality; the majority are broken and highly fractured (see figure 10). Individual crystals seldom attain a length of 3 cm and are usually stubby to tabular in habit; that is, they are flattened along the a-axis due to the pronounced development of the prism {110}. Well-crystallized specimens display the four bipyramids {011}, {012}, {111}, and {112} and two to three prisms of {110}, {120}, and {010}. Both {110} and {120} are nearly always well formed and are commonly striated. The basal pinacoid {001} is rarely present; when it is present, it is usually etched. Most crystals are heavily included.

Unit-cell parameters were obtained from X-ray powder diffraction data, indexed by comparison with the data listed by the JCPDS file No. 12-765 and using a least-squares refinement program (Applemen and Evans, 1973) with reagent grade NaCl as an internal standard. The unit-cell parameters determined are: $\underline{a}$ = 8.3841 ± 0.0013; $\underline{b}$ = 8.8335 ± 0.0009; $\underline{c}$ = 4.6617 ± 0.0006 Å; V = 3.45 ± 0.1 Å³.

VISUAL APPEARANCE

The topaz crystals found at Ghundao range from colorless through very pale beige to light brown, to very pale to deep pink (again, see figure 10). Only

the pink gems find ready buyers in the gem market; unfortunately, these represent a small proportion of the total production. This deposit near Katlang is the only known *in-situ* occurrence of pink topaz. Although some pink crystals were once found in the gravels in the Sanarka River (also called the Kamenko River; see Kornetova, 1950) in the Ural Mountains of the USSR, the *in-situ* deposits yielding them have never been found. All other pink topazes — especially those from Brazil — owe their color to heat treatment.

The pink hue of the Pakistan material is so distinctive that the color-trained eye can distinguish it without much difficulty from the "burned" specimens mentioned above. The prized shade of Katlang pink topaz is faintly violet in tone, and the best examples can be described as cyclamen pink (figure 11). This shade is comparable to color tones 10:2:2 with corresponding values X_c44.4; Y_c34.6; and Z_c37.5 of DIN Color Chart 6164.

The pink topazes from Katlang take an excellent polish and therefore reflect a lively surface brilliance (i.e., luster). They are slippery to the touch, as is usual with faceted topazes.

PHYSICAL PROPERTIES

To establish the physical constants, five faceted gems (2.5–18.4 ct) and seven cleavage fragments were tested using standard gemological instru-

TABLE 1. Gemological properties of topaz from Katlang, Pakistan.[a]

Property	Pink	Colorless	Brownish
Refractive indices	$n\alpha = 1.629$–1.631 (1.630) $n\beta = 1.631$–1.634 (1.632) $n\gamma = 1.638$–1.642 (1.640)	$n\alpha = 1.610$–1.612 (1.611) $n\beta = 1.612$–1.615 (1.614) $n\gamma = 1.620$–1.623 (1.622)	$n\alpha = 1.608$–1.611 (1.610) $n\beta = 1.611$–1.614 (1.613) $n\gamma = 1.617$–1.621 (1.619)
Birefringence Axial angle	$+0.009$–0.011 (0.010) $2V = 53°00'$	$+0.010$–0.011 (0.010) $2V = 53°04'$	$+0.009$–0.010 (0.009) $2V = 56°10'$
Pleochroism	$n\gamma$ = yellow $n\beta$ = purple (mostly pale) $n\gamma$ = dense mauve to violet	none	Very weak; colorless, yellowish, brownish
Absorption	Extremely weak line at 682 nm (indicates coloration by Cr^{3+})	none	none
Luminescence	Very weak; dark red to long-wave ultraviolet radiation. Distinct to brilliant milky green sheen (amplified in fractures) to short-wave ultraviolet radiation	none	none
Density	3.51–3.53 g/cm³ (3.52)	3.55 g/cm³	3.56 g/cm³

[a]The extreme values of constants are given, with mean values in parentheses. Twelve pink stones and three each of the colorless and brownish topazes were examined.

ments (table 1). The data obtained concur very closely with the published statements of Bank (1976a and b), Jan (1979), and Petrov (1977).

In comparison to the other color varieties found at Ghundao, the pink stones are outstanding not only for their high refractive indices, but also for their somewhat low density, as Bank remarked (1976a and b).

INCLUSIONS

Fissures constitute the bulk of the inclusions in the faceted pink topazes, while mineral inclusions apparently are quite rare. These fissures often appear as cleavage cracks running parallel to the basal plane, either gas or liquid filled or as attractively patterned healing fissures (figure 12). The most interesting patterns are made by various two-phase — liquid and gas — inclusions, in which the liquid phase is dominant. The peculiar shapes of these inclusions did not allow for quantitative analysis, but observations with the microscope indicated that they consist of aqueous solutions of medium to low salinity, since daughter crystals were not observed. When the liquid phase moistens the walls of the fissures in little drops or in elongated tubes in parallel alignment, the regular, planar dispersion makes it easy to recognize the host gem because the pattern is similar to that of innumerable topazes from widely separated

Figure 12. Discrete two-phase inclusions in parallel arrangement are commonly seen in pink topaz from the Ghundao hill, near Katlang, Pakistan. Magnified 50×.

Figure 13. These parallel rows of two-phase inclusions are a diagnostic internal feature of topaz. Magnified 16×.
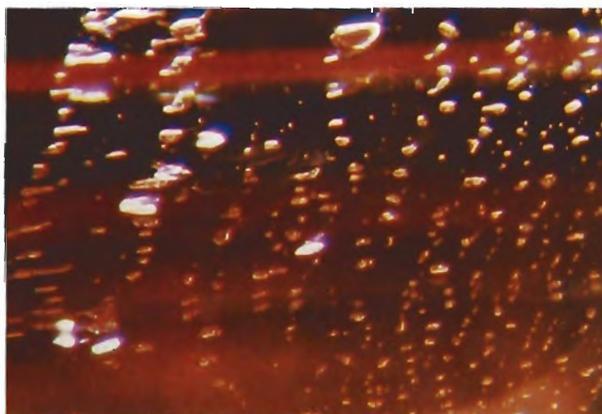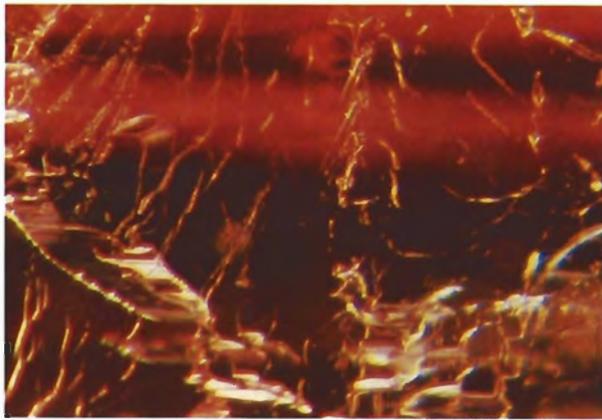
Figure 14. These fine fibers of two-phase inclusions seen in pink topaz from Ghundao are reminiscent of the trichites normally found in tourmaline. Magnified 20×.

Figure 15. These curious swirl marks and growth features observed in Ghundao topaz appear to be connected to cleavage cracks. Such cracks in parallel alignment are an indication that these topazes should be treated with care. Magnified 30×.

sources (figure 13). However, when the liquid inclusions are irregularly dispersed and entwined like tangled threads, they look exactly like the well-known trichites in tourmaline (figure 14). Also noteworthy in this material are random swirls which seem to be connected with the parallel cleavage fissures (figure 15). Cleavages and their accompanying swirl marks also occur in otherwise internally flawless pink topazes.

CHEMISTRY

The composition of topaz is fairly constant except for variation in hydroxyl content. Several microprobe analyses were carried out on each of three different samples, which represented three different shades of cyclamen pink. Wet chemical analyses were subsequently performed, using a specific ion electrode for determining the amount of fluorine (table 2). Particular care was taken to avoid fluorine loss in the process of fusing the sample with alkaline carbonates. Because of problems encountered in performing the thermogravimetric determination of H_2O present in the sample, total H_2O was estimated after heating at a constant temperature of 850°C for 24 hours. The analyzed topazes reveal a low Fe content and minor amounts of Cr, V, and Ca, while Mg and Mn are present in some of the samples but not in others. The analyses also indicate that the pink topaz from this source is poor in fluorine and rich in hydroxyl (considering that topaz may accommodate as much as 30 wt.% F). The systematic variation of unit-cell dimensions with respect to F and OH concentrations (Rosenberg, 1967; Chaudhry and Howie, 1970; Ribbe and Rosenberg, 1971; Bambauer et al., 1971) allow us to estimate a fluorine content of $15.6–16.3 \pm 0.5$ wt.%.

The correlation between physical properties and the weight percentage of fluorine was studied by Ribbe and Roşenberg (1971), Bambauer et al. (1971), and others. The substitution of the fluorine ion by the larger hydroxyl group leads to an increase in the refractive indices. At the same time, there is a lessening of the optic axial angle $2V\gamma$ and of the density. The behavior of the pink topazes from Katlang is consistent with these observations.

Chemical analyses were not carried out on the colorless or brown Katlang topazes. However, it

TABLE 2. Wet chemical analysis of pink topaz from Pakistan.

Oxide	Wt. %	Numbers of ions on the basis of 24 (O, OH, F)		
SiO_2	32.60	Si	3.988	4.000
TiO_2	—	Al	0.012	
Al_2O_3	56.83	Al	8.183	
Cr_2O_3	0.01	Cr	0.002	
V_2O_5	0.01	V	0.002	
FeO^a	0.08	Fe	0.008	8.214
MnO	—	Mn	—	
MgO	0.07	Mg	0.012	
CaO	0.05	Ca	0.007	
F	15.78	F	6.105	7.411
H_2O^{+b}	1.60	OH	1.306	
H_2O^{-b}	0.30			
	107.33			
O ≡ F	6.64			
Total	100.69			

[a]Total iron as FeO.
[b]Determined by thermogravimetry.

Figure 16. These three sets of stones illustrate the effects of heat treatment and irradiation on the color of topaz from Katlang, Pakistan. The top row = sample 1; the middle row = sample 2; the bottom row = sample 3.

can be deduced from the physical properties (table 1) — i.e., their lower refractive indices and higher specific gravities compared to the pink variety — that they are richer in fluorine. Indeed, the median values for fluorine may be assessed at about 21 ± 1 wt.%.

TREATMENT AND COLOR

The attractive pink color of topaz is caused by trace amounts of the Cr^{3+} ion; other topaz colors are due to color centers (Nassau, 1984). In accord, microprobe analyses of the Katlang pink topazes showed chromium-oxide contents of 0.01 to 0.03 wt.% that correlate with the intensity of color. No color change was observed in specimens that had been exposed to the hot summer sun of Peshawar (38°–48°C) for 65 days (Jan, 1979).

Given the occurrence of other color varieties of topaz from Katlang (light pink, colorless, or brownish tones), in significantly greater quantities, the question arose as to whether these other topazes would lend themselves to color alteration or improvement by heat treatment and/or irradiation. Dr. Kurt Nassau was so kind as to carry out various experiments in color alteration on pink, colorless,

and brownish specimens which the senior author had obtained in Pakistan. All irradiation experiments were conducted using 20 Mrad gamma rays from a cobalt-60 source; all heat treatments lasted 15 hours. The results are shown in figure 16.

Sample 1. Reddish brown; lost its orange component after 15 hours heated at 500°C, acquiring a pale pink hue. When it was subsequently irradiated, turned orange-brown; did not change color when heated to 250° or 300°C; heating to 350°C caused a change back to pink (figure 16, top row).

Conclusion: The pink color is due to Cr; it is probably stable at any temperature. The orange-brown color is induced by Cr plus a color center produced by irradiation; it is probably not affected by daylight, but will turn pink if subsequently heated to 350°C for 15 hours.

Sample 2. Very pale tan; turned virtually colorless when heated to 500°C; then turned dark orange-brown and pale tan in zones when subsequently irradiated (figure 16, middle row); subsequent heatings through 80°, 100°, 120°, 140°, up to 250°C caused slow decolorization to colorless.

Conclusion: This material contains color cen-

ters that cause intensification of hue upon irradiation, but it subsequently bleaches when heated between 120° and 250°C for 15 hours; while not tested, the irradiated material is almost certain to bleach in daylight.

Sample 3. Colorless; upon irradiation turned dark orange-brown, partly patchy, partly zoned; reverted to colorless when heated for 15 hours to 500°C. Further irradiation and reheating produced the same results, although one cleavage piece showed a slight trace of tan, but another showed a very faint blue (figure 16, bottom row).
Conclusion: Same as for sample 2 above.

The results of these experiments by Dr. K. Nassau are similar to those he reported earlier for topazes (Nassau, 1974, 1975, 1980) exposed to gamma-ray irradiation and subsequent high-temperature heating. Further experiments on the Katlang topazes are planned.

PROSPECTS FOR THE FUTURE

In recent months, the Gemstone Corporation of Pakistan (GEMCP) has extended exploration activities to other hills in the vicinity of Ghundao and has succeeded in locating occurrences of pink topaz in the Shakar Tangi and Rama areas, situated northeast of Ghundao and about 7 km south-southeast of Katlang. At present, detailed exploration of these areas is in progress. There seem to be fair prospects for locating additional deposits.

Pink topaz has never been and is still not an abundant gemstone. Hence, it is welcome news that cuttable pink topaz of natural color is being found at various localities in Pakistan.

Since GEMCP has also been successful in discovering new aquamarine deposits in other parts of Kohistan, the gem world may expect Pakistan to produce more gemstones and additional gemstone varieties, becoming an important supplier to the gem market in the future.

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CARBON DIOXIDE FLUID INCLUSIONS AS PROOF OF NATURAL-COLORED CORUNDUM

By John I. Koivula

The question of how to identify natural-colored from heat-treated corundum has long puzzled the gemological community. One important clue is now provided by carbon dioxide fluid inclusions. Because such inclusions cannot survive heat treatment, their existence intact and unruptured in rubies and sapphires is conclusive proof that no heat treatment has occurred.

ABOUT THE AUTHOR

Mr. Koivula is senior gemologist in the Research Department at the Gemological Institute of America, Santa Monica, California.

The photomicrographs in figures 2, 3, and 4 were taken by the author.

Until the mid-1970s, when the practice of high-temperature treatment of corundum became widespread, liquid and gaseous carbon dioxide (CO_2) fluid inclusions were commonly observed in Sri Lankan rubies and sapphires. In fact, the author has studied well over a hundred pieces of geuda (untreated) corundum with these inclusions. Traditionally, these inclusions have been useful in establishing the natural origin of their host (Gübelin and Koivula, 1986). With the prevalence of heat treatment, however, they have taken on additional significance: Because carbon dioxide fluid inclusions cannot survive the temperatures required to alter color in corundum, their presence provides conclusive proof that the color also is natural.

HISTORICAL BACKGROUND

Sir David Brewster, a Scottish physicist, first discovered CO_2 fluid inclusions while examining sapphires and other single-crystal gem materials with the microscope. The year was 1823. Although he did not identify the liquid as carbon dioxide, he made note of his discovery and reported on this "remarkable new fluid found in the cavities of rocks" (Brewster, 1823). He observed that this strange new fluid was often found in the presence of water, although the two were immiscible (would not mix). The liquid had a refractive index less than that of water and a coefficient of thermal expansion approximately 30 times that shown by water. The fluid was also nonwetting and would ball up like elemental mercury rather than flow over and coat the interior walls of a negative crystal cavity.

Since Brewster's discovery, the study of CO_2 fluid inclusions has continued. With infrared absorption spectrometry (passing an infrared beam though a thin parallel-windowed plate of a gem), inclusion investigators have identified five separate forms of closely related carbon-oxygen compounds which may occur in fluid inclusions (Roedder, 1972). Three of these are found in solution with

Figure 1. The 1.84-ct Sri Lankan blue sapphire used in the experiment. Photo © Tino Hammid.

water: H_2CO_3, HCO_3^{-1} and CO_3^{-2}. The remaining two, liquid and gaseous CO_2, are the ones of primary interest to gemologists concerned with the identification of heat-treated rubies and sapphires.

THE EXPLOSIVE NATURE OF CO_2

As indicated by the following statement taken from a letter written by Sir David Brewster to Sir Walter Scott in 1835, Brewster had, through continued experimentation, become aware of the explosive potential of CO_2 fluid inclusions when heated:

> When the gem which contains the highly expansive fluid is strong, and the cavity not near the surface, heat may be applied to it without danger, but in the course of my experiments on this subject, the mineral has often burst with a tremendous explosion, and in one case wounded me on the brow.

It is this explosive potential of CO_2 fluid inclusions (Koivula, 1980, 1980–1981) that makes their presence excellent positive proof that the host rubies and sapphires have not undergone heat treatment.

Although Brewster was not referring to temperatures anywhere near as high as those required to effect a color change in corundum, it is nonetheless surprising how little heat is required to actually explode (shatter) a gem containing one or more of these fluid inclusions. Brewster's statement regarding the application of heat "without danger" when the inclusion is "not near the surface" holds true for some gem corundums heated to temperatures of only 250°C to 400°C (depending on the size of the host gem, and the size, shape, and position of the CO_2 fluid inclusion within the gem). It is not true, as discovered experimentally by the author, for gems heated above 400°C. Because of this "explosive fatality," heat treaters of Sri Lankan rubies and sapphires commonly trim away areas of the rough that contain inclusions, or partially saw, or even drill, into the inclusions.

If the CO_2 inclusions are completely removed, then the gem has an excellent chance of surviving the 1500°C-plus temperatures required to alter

color in corundum. If they are not removed, the inclusion will explode and the gem will be badly damaged or completely destroyed. In either case, these inclusions will no longer exist.

EXPERIMENTAL CONSIDERATIONS

Liquid carbon dioxide has a critical temperature of 31.2°C (88.2°F). Above this temperature inclusions containing the liquid form of CO_2 homogenize into a uniform high-pressure fluid; as the temperature is increased above the critical point, pressure also rises drastically.

When we consider that crystals containing CO_2 inclusions form under great pressure at considerable depth within the earth, it becomes apparent that if such crystals are now at the earth's surface, then the compensating pressure of the rock that once surrounded them is removed. Yet the inclusions are still at their original high pressure of formation. So at room temperature we now have corundum crystals containing fluid inclusions with high outward pressure (1000 psi or more) that have only external atmospheric pressure (instead of tons of rock) to compensate.

If we further aggravate this volatile situation by faceting, preforming, or trimming the stone and bring the inclusions closer to the surface (i.e., by cutting away layers of protective crystalline corundum that lend structural integrity to the crystal) we have dramatically increased the chances for a pressure burst. It is easy to see, then, why stones containing CO_2 inclusions do not survive the application of heat energy.

EMPIRICAL PROOF

To dramatically prove this point, the author selected a 1.84-ct untreated blue Sri Lankan sapphire with a tiny, intact carbon dioxide fluid inclusion just beneath the table surface (figure 1).

When the host sapphire was held below the critical temperature of 31.2°C (88.2°F), both the liquid and gaseous CO_2 phases were visible within the negative crystal (figure 2). Just a slight warming above the critical temperature by the heat generated from the microscope lamp caused the meniscus around the bubble to disappear (figure 3).

In the name of science, this gem was placed on a ceramic tile in an electric muffle furnace and the temperature was gradually increased. A popping sound was heard when the temperature gauge on the furnace indicated just 270°C. At this point, the furnace was turned off and allowed to cool.

The stone was inspected. The CO_2 fluid inclusion had exploded, blown a shard out of the table, and left behind a crater (figure 4).

CONCLUSION

Many gem dealers today feel compelled to heat treat virtually every piece of corundum. Fine gems in no real need of treatment are subjected to the furnace with the hope that a few extra dollars can be cooked from them. Even gems that originally entered the market years before heat treatment became popular are being burned for "improvement." And little by little, inclusions that once gave natural, unadulterated gems uniqueness are disappearing. The heat treater's furnace is acting as

Figure 2. Negative crystal filled with liquid and gaseous carbon dioxide as observed below the critical temperature. Dark-field illumination, magnified 50×.

Figure 3. The same CO_2-filled negative crystal as in figure 2 but just above the critical temperature (31.2°C) for carbon dioxide. Dark-field illumination, magnified 50×.
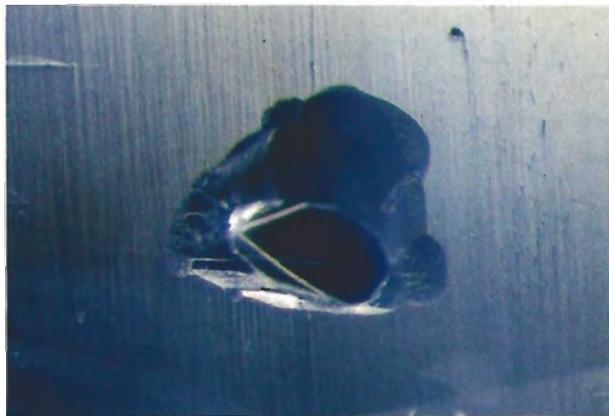
Figure 4. The same negative crystal as shown in figures 2 and 3 but after exploding. The gem was heated to only 270°C. Dark-field and shadowed oblique illumination, magnified 50×.

a gem-blender, slowly homogenizing the corundum population and making the relatively common appear rare to the uneducated.

As a consequence, very few CO_2 fluid inclusions in corundum have been seen in the GIA Gem Trade Laboratory during the last few years (R.

Crowningshield, pers. comm.). Mr. Crowningshield's observation concerning the Gem Trade Laboratory is an important one. The more prevalent heat treatment has become, the fewer of these inclusions are seen. Carbon dioxide fluid inclusions will not survive heat treatment. Therefore, an unruptured carbon dioxide fluid inclusion in a ruby or sapphire is absolute proof that the gem is natural and has not been heat treated.

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CONTRIBUTIONS TO A HISTORY OF GEMOLOGY: SPECIFIC GRAVITY— ORIGINS AND DEVELOPMENT OF THE HYDROSTATIC METHOD

By John Sinkankas

The development of the hydrostatic method of specific gravity determination as applied to gems is traced from Archimedes's discovery to the present, with brief historical remarks supplied on other methods. This is the first in a series of articles on the history of gemology that will appear periodically in Gems & Gemology.

ABOUT THE AUTHOR

Dr. Sinkankas is the author of numerous books and articles on lapidary work, mineralogy, occurrences of gemstones, and prospecting and collecting. With his wife, Marjorie, he operates Peri Lithon Books, in San Diego, CA, a mail-order antiquarian book business devoted to the earth sciences and related fields.

The first useful method of comparing the densities of substances as an aid to identification is attributed by Vitruvius (ca. 13 B.C.) to Archimedes, the famous Greek scientist (ca. 287—212 B.C.). As the story goes, Archimedes was asked by King Hieron II of Syracuse to determine if a newly delivered crown was pure gold as claimed by its maker. Archimedes received the inspiration for his now-famous displacement method of determining comparative densities when he stepped into a brimming bathtub and noted the overflow caused by the added volume of his body. Inspiration struck—Eureka!—the water displaced must be equal to the volume of any material inserted into it, and hence it must follow that for substances of equal weight, a "lighter" or less dense substance would displace more water than a "heavier" or denser material. A comparative volumetric displacement test of the crown and a mass of pure gold equal to it in weight showed that the crown displaced more water, hence it had to be "lighter," hence it had to be adulterated. This fundamental principle first enunciated by Archimedes is basically the one that we still follow in all measurements of specific gravity involving immersions in fluid. Incidentally, the scoundrelly goldsmith was executed.

Although little progress was made in the hydrostatic measurement of specific gravity during more than 10 centuries following Archimedes's discovery, the increased interest in gemstones from the late 17th century on led to fairly rapid developments both of the method and of specific values from that time. Today, the hydrostatic technique for measuring specific gravity is a standard test in gemstone identification (see box). The following discussion traces the origins and development of this very basic gemological tool.

EARLY DENSITY TESTS OF PRECIOUS METALS

Differences in weight among objects of equal size were appreciated in Roman times according to Ball (1950), who

THE HYDROSTATIC METHOD OF DETERMINING SPECIFIC GRAVITY

The Archimedes principle states that an object immersed in water displaces a volume of water equal to its own. Thus, when Archimedes stepped into his bath, the water level rose. In addition, however, the water (or any liquid, for that matter) exerts a buoyant force upwards on the immersed object, against the downward force of gravity, and the object appears to have lost weight in comparison with its weight in air. This loss of weight is the same as the weight of an equal volume of water (the amount displaced, in fact).

The hydrostatic method of determining specific gravity depends on these simple laws of physics. First, one weighs the gemstone in the normal manner on an accurate balance. Since specific gravity is a ratio, any unit of measure (carats, grams, etc.) will do. The balance is then set up with a special apparatus such as that shown in figure 1. The stone is placed in the wire basket suspended in the container of water and its new weight can then be measured.

The numeric value for specific gravity is the ratio of an object's weight in air to that of an equal volume of water, which can be found by the formula:

$$\frac{\text{wt. in air}}{(\text{wt. in air}) - (\text{wt. in water})}$$

The term *density* is often used interchangeably with *specific gravity* but, while the numeric values derived for each are nearly the same, the former is actually the mass per unit volume of a substance and is expressed in grams per cubic centimeter (g/cm^3). Specific gravity—a ratio—has no unit.

Figure 1. A contemporary balance used for the hydrostatic determination of specific gravity.

summarized the gemological content of Pliny's *Natural History* of 79 A.D. Ball noted early knowledge concerning the heaviness of placer gold and that the ancient miners took advantage of this property to separate the gold from lighter rock particles. Pliny himself was aware of differences in weight among lighter objects, such as precious stones, for as Ball states, "Pliny's first test for differentiating genuine precious stones from glass imitations is weight, for ordinarily the genuine stone is heavier than the false." Egyptian records indicate that even before Pliny's time the heaviness of gold was well known and used in concentration operations during gold mining (Forbes, 1950). Davies (1809) refers to the work *De Ponderibus et Mensuribus (Weighing and Mensuration)*, written approximately 45 A.D. by Quintus Remnius Palaemon, which showed how specific gravities of solids could be ascertained.

The use of precious metals as marks of wealth and, more importantly, as media of exchange in commerce, early established a need for standardizing the proportions of gold and silver (the principal alloying metal) in coins and in other applications. According to Smith and Forbes (1957), crude means of specific-gravity determination were developed as early as the sixth century when "a balance with a graduated beam and movable fulcrum was described in the poem *Carmen de Ponderibus (Poem on Weighing)* attributed to Priscian." They further note that as early as the 11th and 12th centuries a list of weights of metals relative to wax was compiled for the purpose of assisting a foundryman to determine how much metal to melt. "By the seventeenth century extensive tables of similar [specific gravity] data became common in mathematicians' works." A table devised particularly to help the assayer appeared in the 13th century, and by the close of the 16th century, not only were the principles understood but man's ingenuity was also being turned to the design and manufacture of more precise balances.

SEVENTEENTH- AND EIGHTEENTH-CENTURY EUROPE: DENSITY TESTING OF GEMSTONES BEGINS

A notable experimentalist was Francis Bacon (1561–1626), who drew up a table of densities, published some time after his death, which Davies (1809, p. 537) believed to be "the oldest table of specific gravities now extant." Davies also cited an even earlier contribution, that of Marinus Ghetaldus (1566–1626), who made his own hydrostatic experiments "with care and exactness," and in 1603 published a treatise on weighing. Ghetaldus is credited with determining the first specific gravity for any metal (Debus, 1968). Other early experimentalists include Johannes Baptista Villalpandus (1552–1608) and Marin Mersenne (1588–1648).

Possibly because the evaluation of specific gravity of gemstones was of little concern in the early 1600s, we find that Boetius de Boodt (1550–1634), who may justifiably be called the "Pliny of Gemology," says nothing more about differing gemstone densities than that they exist (1647). He gives no hint that any method of placing a numerical value on this property existed among gem dealers and jewelers of the time. It is, of course, possible that because gems are usually very small relative to other materials, existing apparatus could not be counted on to afford consistent, reliable results. In contrast, chemists and physicists of the same period were actively measuring densities, devising better methods and instrumentation, and defining the limitations of the hydrostatic method. For example, Robert Boyle (1627–1691), best known among gemologists for his *Essay about the Origine and Virtues of Gems* (1672), produced a treatise in 1666 titled *Hydrostatical Paradoxes Proved and Illustrated by Experiments* (Boyle, ed. by Shaw, 1725).

Boyle tested a variety of substances, including gem materials, with the balance shown in figure 2, but preceded his remarks with advice on how to go about obtaining the greatest accuracy. First, he describes the balance and its parts and accessories. He then states that he found horse hair to be the best suspension thread because "its weight usually differs so little from that of water, that the difference may be safely neglected." However, he advises that an equal quantity of hair, as was used to fasten the specimen for immersion weighing, be placed in the opposite pan to reduce error. Other instructions for specific-gravity weighings are
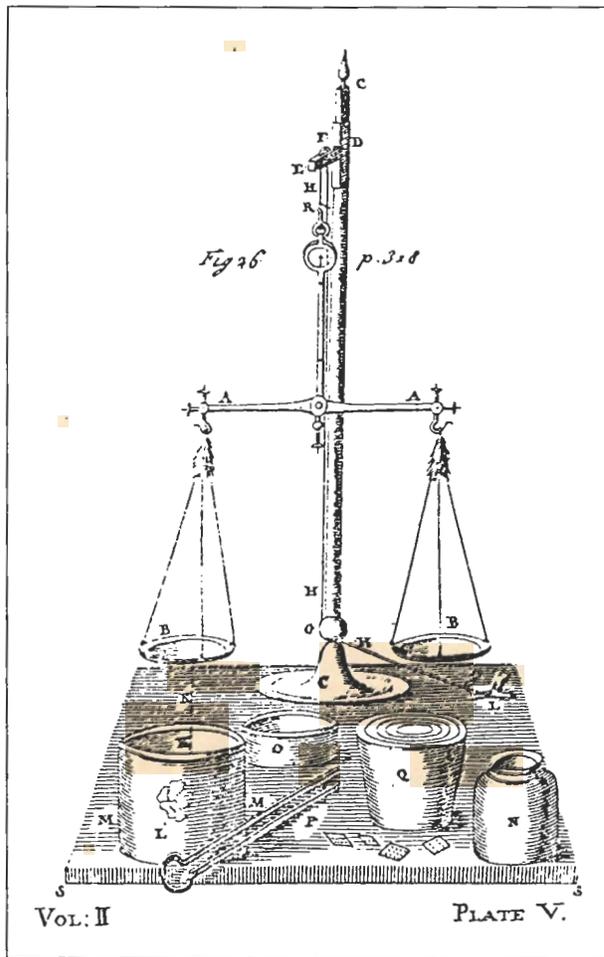
Figure 2. Plate V from the second volume of Robert Boyle's collected works (P. Shaw edition of 1725) showing his specific-gravity balance and associated accessories. The principal parts are the stand C-C and the rather elaborate means for raising and lowering the beam A-A and pans B-B with pulleys and weight (the small lion on the right, erroneously marked L). The specimen L (on the lower left) is shown suspended by horsehair K in the water bucket M-M. Grain weights are in container O, larger weights (nested) are in Q, jar N holds the water supply, and the forceps P are used to handle weights.

equally as informative, for example, avoiding bubbles, and the like, such that one cannot help but admire his thoroughness.

Boyle stressed the value of S.G. determinations in the detection of frauds and substitutes because they "may assist us to guess, with probability, whether a mineral body be of a stoney nature, or not." He was referring specifically to

speculations at the time as to the exact nature of coral, which some thought to be a petrification and others some sort of plant. Boyle tested a fine specimen of red coral and obtained an S.G. of 2.68; he noted that this value "exceeded that of crystal [quartz]," and concluded that "their opinion, who take it for a stone, seems most probable." The animal nature of coral was not established until about 1723 (by J. A. Peyssonel, 1694–1759; see Lacaze-Duthiers, 1864). In connection with coral, and to emphasize the usefulness of S.G. determinations, Boyle manufactured some realistic coral imitations and then showed how these were easily detected on the basis of S.G. "notwithstanding their fine colour, shape, and gloss." Other tests were made on preparations of "pastes or factitious gems," made with red lead (minium), which again were easily distinguished on the basis of their specific gravities.

With regard to pearls, which he also tested, Boyle makes the significant remark that specific-gravity weighings are nondestructive in nature, and "a pearl, for instance, is discoverable to be counterfeit, without the least prejudice to it." On one "monstrous" (206 grains) baroque pearl, he determined a specific gravity of 2.51. Because of his interest in disclosing the frauds then prevalent in medicine, Boyle included in his tests the enormously expensive bezoars and other calculi to show that these organic materials, whatever their medicinal values, could be readily distinguished from mineral concretions of like appearance. At the end of his discourse, Boyle provided the results of his tests in the form of tables which are reproduced here as figure 3; note that some gemstones are included.

Also during the first half of the 18th century, John Ellicott (?1706–1772), noted instrument maker and scientist, very precisely determined the specific gravity of a series of 14 large diamonds, four from Brazil and 10 from the "East Indies" (Borneo?). The stones included some that were in excess of 29 ct (Davies, 1809). It was the size of the stones that inspired Ellicott to undertake the determinations, because hitherto most test specimens had been only a few carats or less. Ellicott's values, 3.501–3.525, average 3.517, compare fa-

Figure 3. Robert Boyle's tables of specific-gravity values obtained through the use of the apparatus shown in figure 2 (from the P. Shaw edition of 1725).

The Hydroſtatical Balance.

	Weigh'd in Air.	In Water.	Proportion.	
Another —	345	197	2.33	
Another from *Jamaica* —	2011	1127	2.27	
Lead-ore —	686	590	7.14	
Another piece from *Cumberland*, rich	1872	1586½	.54	
Manganeſe, a piece —	321	230	3.53	
Marcaſite —	814	631	4.65	
Another from *Stalbridge* —	243	189	4.5	
Another more ſhining than ordinary	287	227	4.78	
Mineral, *Corniſh*, like a ſhining marcaſite —	145	129	9.6	
Ore of ſilver, choice from *Saxony* —	458	366	4.22	
Another piece —	1120	960	7.	
Oſteocolla —	195	108	2.24	
Rhinoceros's horn—	8563	4260	1.99	
Rock-cryſtal —	256	140	2.20	to 1
Slat, *Iriſh* —	779	467	2.49	
Sulphur vivum —	371	185	2	
German, very fine —	306	152	1.98	
Talc, a piece like *Lapis Amianthus*	596	334	2.28	
Talc { *Venetian* —	082	508	2.73	
{ of *Jamaica* —	1857	1238	3	
Tin-glaſs —	468	419	9.55	
Tin-ore, *New-Engliſh* —	812	613	4.8	
Tin-ore, black, rich—	1293	984	4.18	
Another piece, choice —	2893	2314	5	
Tutty, a ſingle piece —	104	83	5	
Vitriol, *Engl.* a very fine piece—	1093	512	1.88	
Vitrum Antimonii —	357½	282½	4.76	
Unicorn's horn, a piece—	407	195	1.91	

* Later trials have furniſh'd us with the following table of the ſpecific gravities of ſolids and fluids.

A TABLE of the ſpecific Gravities of ſeveral ſolid and fluid Bodies.

Fine gold,	19,640	Caſt braſs	8,000
Standard-gold	18,888	Steel, ſoft	7,738
Quick-ſilver	14,000	the ſame hard	7,704
Lead	11,325	piece ſpring temper	7,809
Fine Silver	11,091	Iron	7,645
Standard-ſilver	10,535	Tin	7,320
Biſmuth	9,700	Glaſs of antimony	5,280
Copper	9,000	A pſeudo topaz	4,270

The Hydroſtatical Balance.

A diamond	3,400	Serum of human blood	1,190
Clear cryſtal glaſs	3,150	Pitch	1,150
Iſland cryſtal	2,720	Spirit of ſalt	1,130
Fine marble	2,700	Spirit of urine	1,120
Rock-cryſtal	2,650	Human blood	1,040
Common green glaſs	2,620	Amber	1,040
Stone of a mean gravity	2,500	Milk	1,030
Sal gemma	2,143	Urine	1,030
Brick	2,000	Dry box-wood	1,030
Nitre,	1,900	Sea-water	1,030
Alabaſter	1,875	Common water	1,000
Dry ivory	1,825	Camphire	0,996
Brimſtone	1,800	Bees-wax	0,955
Dantzick vitriol	1,715	Linſeed oil	0,932
Alum	1,714	Dry oak—	0,925
Borax	1,714	Oil olive	0,913
Calculus humanus	1,700	Spirit of turpentine	0,874
Oil of vitriol	1,700	Rectified ſpirit of wine	0,866
Oil of tartar	1,550	Dry aſh	0,800
Bezoar	1,500	Dry maple	0,755
Honey	1,450	Dry elm	0,600
Gum arabic	1,375	Dry fir	0,550
Spirit of nitre	1,315	Cork	0,240
Aqua fortis	1,300	Air	0,001

Figure 4. Title page of Brisson's 1787 work on specific gravity.

to specific gravities according to season, summer to winter, which serve as a crude set of temperature corrections.

In 1798, Charles Francis Greville (1749–1809) published an extensive description of the corundums of Asia, which also appeared in abridged form (Davies, 1809, Vol. 18, pp. 356–378). He provided S.G. tables for a number of varieties of corundum, as reported by earlier researchers, as well as values for topaz and diamond.

Among the most important specific gravities incorporated in Davies's tables are those of P. van Musschenbroek (1692–1761), the celebrated Dutch scientist, which were first published in his *Elementa Physicae* (1734) and republished, enlarged, in his *Essai de Physique* (1739). These values were consulted by M. J. Brisson (1723–1806), the famous French physicist, during his compilation of *Pesanteur Spécifique des Corps* (*Specific Gravities of Bodies*). Published in 1787, this is clearly the most accurate and complete of all specific-gravity compilations of that period (figure 4). A German translation by J. G. L. Blumhof, with some rearrangement and augmentation, was published in Leipzig in 1795. Both works are rare, which may account for their neglect by most gemological historians; only B. W. Anderson (1938) notes Brisson's original treatise and provides a thoroughly detailed and admirable analysis. Brisson explains his methods, his apparatus, his standard use of rainwater as an immersion fluid, and the adoption of a standard temperature for measurements. As a result of his care, his values are in most instances remarkably close to those considered acceptable today. Brisson recognized that specific-gravity values tend to be constant for minerals and urged that these values be used in conjunction with obvious external features—especially crystal forms (of which he provided two engraved plates), and also color, hardness, and the phenomenon of double refraction—to identify gemstones in particular, thus setting forth the first scientific proposal for gemstone identification. His scheme precedes even that used by Haüy in his epochal gemological treatise (1817), which will be described below. Brisson was remarkably thorough in obtaining specimens to test, including gemstones; scarcely any known at the time failed to catch his attention. By exercising his prestige and position, he obtained the loan of the Regent diamond from the French Crown Treasury and was the first to establish its specific gravity.

vorably with today's generally accepted range of 3.514–3.518 (Bruton, 1978).

Great interest was aroused throughout Europe by the density information that the hydrostatic method could provide for many substances, as shown in the lengthy article and extensive tables of Richard Davies, M.D. (d. 1768), originally published in the *Philosophical Transactions of the Royal Society of London* (Vol. 45, No. 488, 1748, pp. 416–489) and republished in abridged form (Davies, 1809). Davies provided an excellent historical summary, including a survey of investigators and their methods and findings, beginning with Archimedes. He then incorporated the findings of Ghetaldus, Villalpandus, Mersenne, Boyle and others into 11 tables, each with numerous entries and citing sources for same; three of these tables (1, 3, and 4) contain data on gem materials. The 11th table provides adjustments to be applied

By the end of the 18th century, the usefulness of the hydrostatic method was everywhere acknowledged and specific-gravity values had become routine data in numerous chemical and physical treatises. Among gemological textbooks, for example, which also incorporated such data, that of C. Prosper Brard (1788–1838), *Traité des Pierres Précieuses* (1808), provided a list of gemstone specific gravities, in descending order, from zircon to amber, and a list of weights per cubic foot of various ornamental and building stones. Shortly afterward, in 1813, J. B. Pujoulx (1762–1821) published an economic mineralogy which stressed the importance of correlating property values and features in gem identification, and described the structure and use of the Nicholson hydrometer for taking specific gravities.

THE NINETEENTH CENTURY: SPECIFIC GRAVITY ASSUMES A KEY ROLE IN GEM IDENTIFICATION

In 1817, a large and detailed discussion of specific gravity and its importance in mineralogical identification appeared in the *Propadeutik der Mineralogie* of C. C. Leonhard, J. H. Kopp, and C. L. Gaertner, which also provided a history of previous investigations as well as a large table of specific-gravity values ranging from several substances less dense than water to gold. Another important table provided temperature corrections for weighings in water. This year also marked the appearance of R. J. Haüy's landmark work, *Traité des Caractères Physiques des Pierres Précieuses* (*Treatise on the Physical Characteristics of Precious Stones*).

While the fundamental concept of correlating several properties or features to achieve identification had already been clearly enunciated by Brisson, with whose work Haüy was familiar, it was left to the latter to write the first usable textbook, *per se*, of gem identification in which the reader is told what all the properties are, why they are characteristic, and how they may be measured, tested, or observed. This general discussion is followed by 11 tables that are surely the first of their kind as applied to gemstones and the model for many others published since. The first argument is color, hence the tables are headed colorless, red, blue, green, etc., with a "red-brown" table for zircons, another for gems displaying reflecting phenomena such as asterism and adularescence, and a final table for opaque gems of blue-green color, that is,

real turquoise and "bone turquoise." Color as a first argument remains very much in use today, for example, in B. W. Anderson's *Gem Testing* (1980). Within each table, Haüy gives columns for light phenomena, specific gravity, hardness, single or double refraction, electrification by friction, same by heat, and magnetism (undoubtedly his inclusion of electrical/magnetic properties was inspired by his investigations of these phenomena at about the time that he became interested in gemstones). The importance of Haüy's treatise was immediately recognized and led to a German edition (1818) and an Italian edition (1819). In 1825, Haüy issued a pamphlet summary of the main work with a series of crystal drawings.

In 1832, two important gemological texts appeared with significant information on specific gravity: the first, a small "pocketbook" by J. R. Blum (1802–1883); the second, a much more detailed work by P. Boué. Blum provided an extensive table of color versus specific gravity that in part followed Haüy's scheme. Boué's work devoted more space to specific gravity and incorporated an engraved plate that depicted a balance with a sliding weight on the arm (figure 5), which design Boué claimed was invented by Brard, although the latter said nothing about it in his 1808 book. An important novelty of Boué's treatise is his inspection table for specific gravity (Vol. 2, plate 3).

The first book after Brisson (1787) to devote itself solely to the specific gravity of mineral substances was M. Websky's 1868 work, which coupled specific gravities with increasing hardness in a series of ranges from S.G. 0.4–0.7 to S.G. 12–25. While gemstone species are included, they are not specifically designated nor are they treated separately. Subsequent gemological treatises have included S.G. data. The most extensive S.G. table for minerals and gemstones currently available is in the *Gemstone and Mineral Data Book* (Sinkankas, 1972).

OTHER METHODS OF DETERMINING SPECIFIC GRAVITY

Although no attempt has been made in this contribution to discuss other methods of determining specific gravity, a few notes on them may be of interest to place the hydrostatic method in perspective. The pycnometer, or specific-gravity bottle, is sometimes used in gemological determinations. This special glass flask is first filled with water, then weighed; next the flask is emptied and
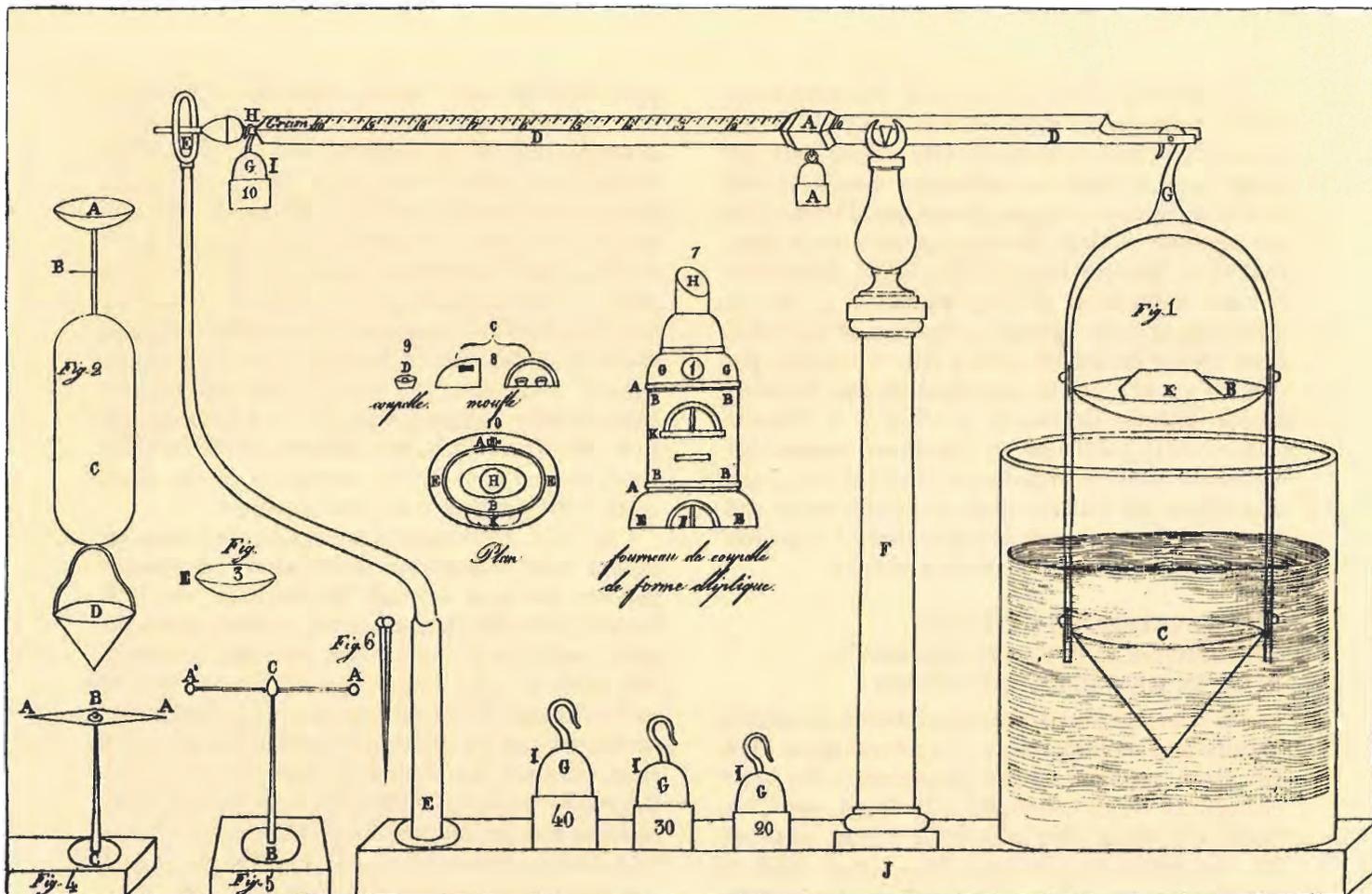
Figure 5. Plate 3 from Boué's treatise on jewelry showing a sliding weight beam balance ("Fig. 1") with pans for weighing in air and weighing in water. When the specimen K is placed in the upper pan, one of the weights marked G is selected to balance the beam, and the slider A is adjusted to give the final balance. When the specimen is placed in the lower pan C, the difference between the slider positions gives loss of weight in water.

the gem fragment or cut gem inserted; last, the bottle is refilled with water and weighed again. The displacement of water by the gem material measures gem volume and hence enables the specific gravity to be determined. There are various forms of pycnometer bottles, a common type being that shown in figure 6. According to Darmstaedter (1908), the first pycnometer can be traced to 1121 A.D. and a certain Arabian savant, named Alkhazini, who investigated the specific gravity of fluids. The modern form of the pycnometer was devised in 1699 by chemist Wilhelm Homberg (1652–1715).

The simple yet effective hydrometer invented by the ingenious English instrument maker, William Nicholson (1753–1815), around 1787 was greeted everywhere with enthusiasm due more to

its ease of operation than to any increase in accuracy. It also suffered from severe capacity restrictions which required, in the case of cut-gem weighings, that a series of instruments be manufactured to accommodate different sample weights. A typical Nicholson hydrometer is shown in figure 7. The crucial place on the instrument is the slender neck between the upper pan and the large hollow body, because it is along this neck, suitably graduated, that the difference is noted between a weighing with the gem in the upper pan (weight in air) and in the lower pan (weight in water). Ordinary glass hydrometers can be modified to become crude Nicholson instruments, if one chooses to experiment with this device.

Another S.G. instrument, again inspired more

by the need for quick determinations than for accuracy, is the Jolly balance shown in figure 8. It is named after its inventor, P. J. G. von Jolly (1809–1884), and depends for its operation on the extensibility of a tapered spring of many turns from which hangs a double-pan arrangement; the upper pan is for in-air weighings and the lower one, immersed in water, for in-water weighings. Differences in weight are indicated by a pointer attached to the spring which moves against the vertical scale on the same column that supports the spring. Even today, the Jolly balance is used much more frequently than either the beam balance or the Nicholson hydrometer; the latter is actually now an antique of considerable collection value.

The influence of liquids of densities higher (or lower) than water on the flotation of solids must surely have been apparent to man at some very distant age in the past, but only in relatively recent times was it deemed feasible to use heavy liquids as indicators of the specific gravity of the solids immersed in them. While a simple "sink or float" test was indicative, it was also found that certain liquids could be diluted to provide an entire range of known densities, so that a precise determination on a given sample became possible. A good

Figure 6. A pycnometer, or stoppered glass bottle, for determining specific gravity. From Groth (1887).
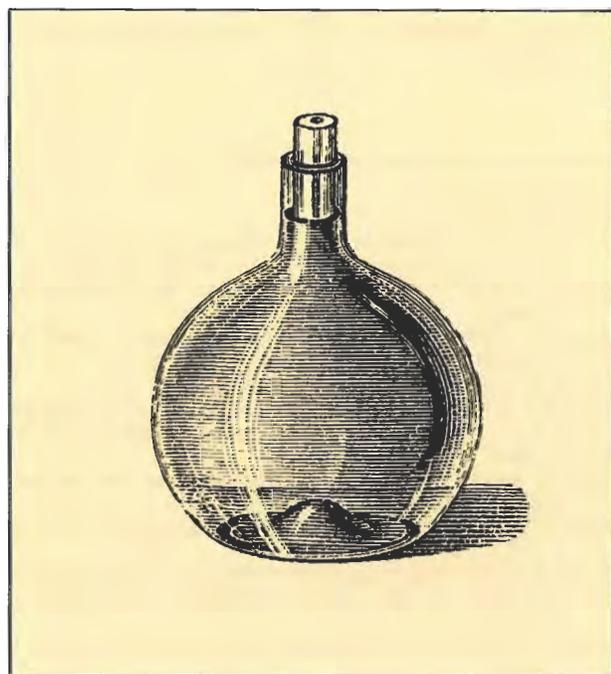
summary of the problem, investigators, instrumentation, etc., appears in Thorpe (1913). Thorpe claims that the first use of heavy liquids for S.G. determination can be dated to 1862, but the first liquid generally adopted for the purpose is

Figure 7. Nicholson's hydrometer. Upper pan F-K is for "in-air" weighing, readings are taken from graduated stem b, O-S is the boyancy float, and E-G, the lower pan, is for "in-water" weighing. Not shown: glass cylinder in which apparatus floats in water. From Kobell (1864, p. 115).
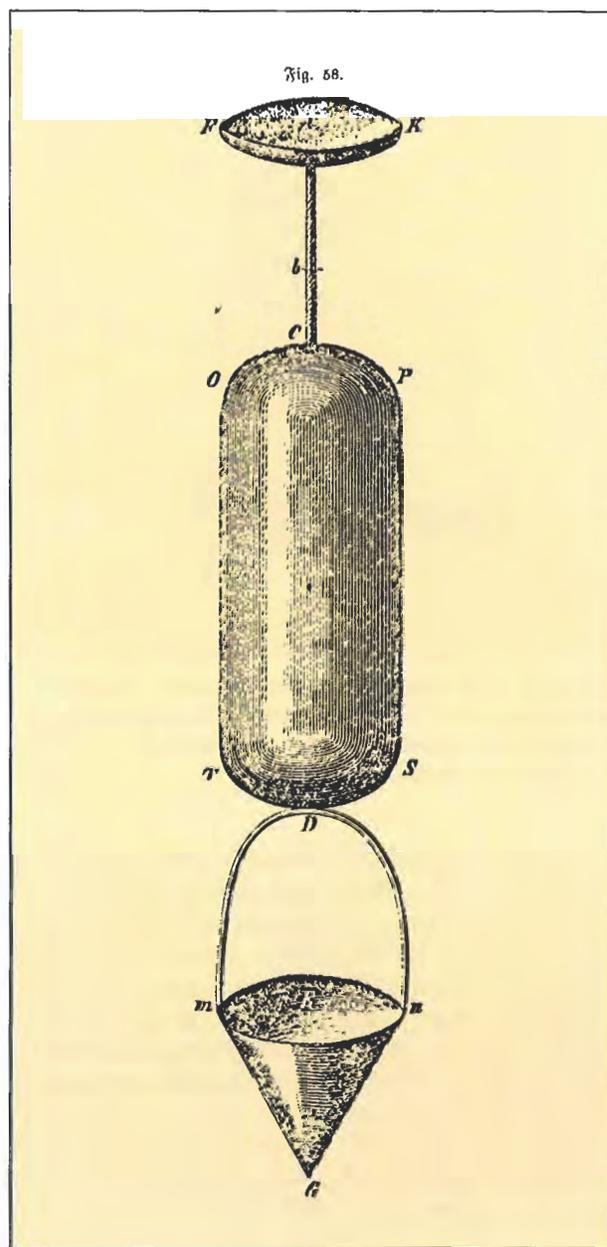
Figure 8. Jolly balance, still much used for rough determinations of specific gravity of large gems or mineral specimens. Courtesy of Eberbach Corporation, Ann Arbor, MI.
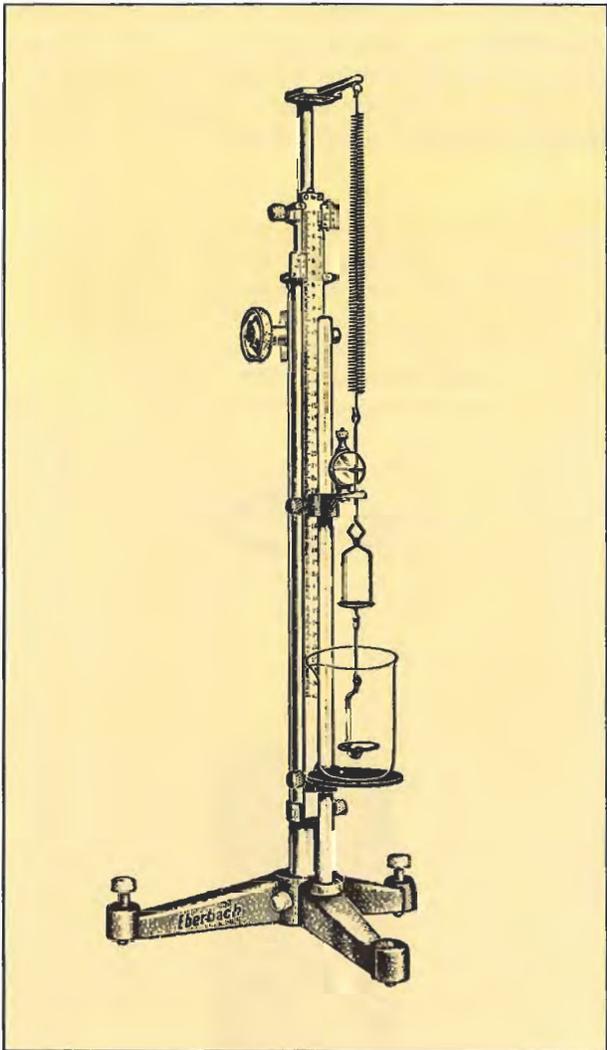
those mentioned above have been developed and are still used in relative safety for the immersion method of gem testing.

For a valuable review of the problems associated with suspension separation of minerals in heavy liquids, including a large number of abstracts of pertinent literature, see P. G. H. Boswell (1933) and also the large paper by J. D. Sullivan (1927). A fascinating account of weighing and the use of scales and weights throughout the ages is contained in B. Kisch (1965).

Lastly, it should be mentioned that various instruments have been devised to measure the volume of water displaced by a solid. A very obvious and simple method is to place a specimen in a graduated cylinder filled to a certain mark with water, and then to note the apparent increase in water volume which, of course, gives the volume of the immersed object.

CONCLUSION

The hydrostatic method of S.G. determination, now more than 2,000 years old, is still an excellent method for obtaining rapid results without the need for possibly dangerous test substances. However, its accuracy drops sharply when small specimens or cut gems are used, and for the latter immersion fluids may prove to be faster and more convenient. For extremely accurate determinations, many investigators still employ some form of pycnometer under carefully controlled conditions in conjunction with a very precise analytical balance.

Sonstadt's or Thoulet's solution, first proposed by Sonstadt in 1874. The usefulness and convenience of a number of heavy liquids is counterbalanced by their noxious or even actively poisonous properties. However, the discovery of methylene iodide, a relatively safe compound, and its use in petrography (Brauns, 1886) led also to its adoption for testing gems. The first gemological textbook to incorporate instructions on the use of heavy liquids was that of P. Groth (1887). Much more elaborate instructions then appeared in Max Bauer's classic text, *Edelsteinkunde* (1st edit., 1896). In the course of time, other liquids besides

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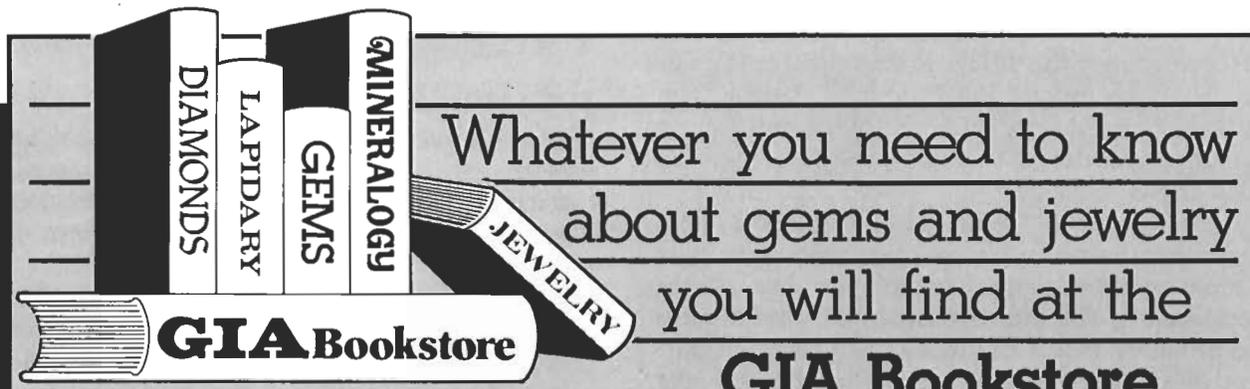
NOTES
· AND ·
NEW TECHNIQUES

COLOMBAGE-ARA SCHEELITE

By Mahinda Gunawardene

A new deposit of scheelite was discovered in 1983 near Ratnapura, Sri Lanka. This article analyzes the gemological properties of this rare gem mineral, and compares them with those recorded for scheelites from Mexico and the United States.

In 1983, a new occurrence of gem scheelite was discovered near the village of Colombage-Ara, not far from the city of Ratnapura, Sri Lanka. The author obtained a parcel of faceted stones from a Ratnapura dealer who had represented them as rock crystal quartz.

The scheelites examined by the author were reportedly found in a small pegmatite vein near Colombage-Ara, approximately 80 km southsoutheast of the city of Ratnapura. Preliminary examination with a 10× lens and a diffraction grating hand spectroscope helped to identify the stones. Since the refractometer failed to provide a shadow-edge on the scale, the stones were first thought to be zircon, especially as a 10× lens exhibited double images of the rear facet edges. However, the spectroscope revealed a rare-earth spectrum, with lines centered around 584 nm, instead of the absorptions typical for zircon. This confirmed the colorless samples to be the first gem scheelites discovered in Sri Lanka.

Scheelite is colorless in its purest state, but the allochromatic gem can occur in a wide variety of colors, including orange, yellow, green, purple, brown, red, and many shades of gray. Few references to this $CaWO_4$ mineral are found in the gemological literature (see, for example, Webster, 1976, and Arem, 1977), although it is a very attractive collector's stone (figure 1). The physical properties of scheelite, such as refractive index and specific gravity, are comparatively high, but the mineral is soft (4.5–5 on the Mohs scale). Cuttable gem material has been found in the United States in California, Arizona, Utah, and Nevada, as well as in Mexico, Czechoslovakia, Italy, Switzerland, Finland, France, England, Korea, and Australia.

LOCATION AND OCCURRENCE

The village of Colombage-Ara lies on the southwestern edge of the Udawalawe reservoir, approximately 5 km northeast of the main road between Ratnapura and Embilipitiya, in southern Sri Lanka.

Scheelite in rocks of Precambrian age has been reported in Colorado and Wyoming by Tweto (1960) and Argall (1943), and is disseminated in regionally metamorphosed rocks, mainly in cal-

Figure 1. These three scheelites were among the first 55 gem scheelites found in Colombage-Ara, Sri Lanka. The large one in the upper portion of the photo weighs 12.20 ct and the other two, 6.35 and 7.42 ct, respectively.

cosilicate gneiss. Similar geologic conditions exist in Sri Lanka in Precambrian rocks of the Highland series (Munasinghe and Dissanayake, 1981). The district surrounding the towns of Colombage-Ara and Ratnapura is located in the southern part of the metamorphic rock assemblage.

Approximately 20 kg (44 lbs.) of scheelite have been found at this locality to date. Although most of the crystals range from 0.30 to 5.00 ct, stones as large as 25 ct have been recovered.

GEMOLOGICAL PROPERTIES

Table 1 gives the gemological properties of 10 scheelites from Sri Lanka, one from California, and one from Mexico that were examined for this study.

Visual Appearance. Most of the scheelites from Colombage-Ara are colorless. However, a yellowish hue is visible in a few samples, and grayish white stones have (though rarely) been seen. The gem scheelites are clean with good transparency. A few, especially those that are grayish white, are semi-transparent to translucent.

Refractive Index. Shadow-edge observations on a Riplus refractometer indicated that the ranges of refractive indices for Sri Lankan scheelites are 1.920–1.922 and 1.930–1.935. The approximate birefringences calculated range from 0.012 to 0.015.

Specific Gravity. Specific gravity was determined on a Mettler electronic carat scale with a hydrostatic attachment. The Colombage-Ara scheelites were found to have specific gravities between 5.94 and 6.30; the upper limit is considerably higher than the upper limits for scheelites from other localities (Webster, 1976).

Reaction to Ultraviolet Radiation. All of the Sri Lankan scheelites tested fluoresced a clear whitish or chalky blue when exposed to short-wave ultraviolet radiation. The California specimen fluoresced a very strong blue. A yellowish fluorescence at one end of the Mexican scheelite masked the intensity of the typical whitish blue fluorescence. Cannon and Grimaldi (1942) proved that the yellow fluorescence seen in scheelite is often caused by the presence of powellite ($CaMoO_4$) molecules.

Spectroscopic Analysis. The visible-light absorption spectra of scheelites from Sri Lanka, Mexico,

TABLE 1. The physical properties and reactions to ultraviolet radiation of natural scheelites from Sri Lanka, the United States, and Mexico.

| Gem locality (no. of stones)	Color	Refractive index	Specific gravity	Short-wave ultraviolet	Long-wave ultraviolet
Sri Lanka (8)	Colorless	1.920–1.922 and 1.930–1.935	5.94–6.30	Distinct whitish blue	Dull oily yellow
Sri Lanka (1)	V. lt. yellow	1.921 and 1.933	6.21	Distinct whitish blue	Dull oily yellow
Sri Lanka (1)	Grayish white	1.920 and 1.935	6.16	Distinct chalky blue	Dull oily yellow
United States (1) (Kern County, California)	Colorless	1.918 and 1.936	6.15	Very strong blue	Dull oily yellow
Mexico (1) (Milopilos, Sonora)	Canary yellow	1.930	6.11	Distinct whitish blue with yellow rims	Indistinct
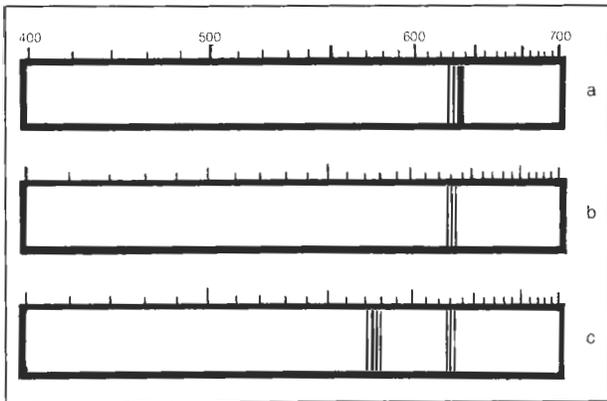
Figure 2. The absorption spectra as seen with a prism-type hand-held spectroscope in scheelites from (a) Sri Lanka, (b) California, and (c) Mexico.

Figure 3. The spectrum of a Sri Lankan scheelite as recorded on a Pye-Unicam SP8-100 UV-VIS spectrophotometer.

and the United States vary considerably. The absorption spectra of some of the stones tested, as seen through a prism-type spectroscope, are shown in figure 2. The spectrum of a Sri Lankan scheelite as recorded on a Pye-Unicam SP8-100 UV-VIS spectrophotometer is shown in figure 3.

Microscopy. The photomicrograph shown in figure 4, taken while the stone was immersed in methylene iodide, clearly reveals the angular zoning frequently seen in Sri Lankan scheelites. Wavy kaleidoscopic colors were evident when the stone was observed with polarized light (figure 5). This phenomenon may have been due to internal strain in the structure of the Sri Lankan material. During this study, 55 scheelites were examined with the

microscope; no characteristic mineral inclusions were discovered, although many forms of fingerprint-like liquid inclusions were often visible (figure 6).

California scheelite typically contains distinct two-phase inclusions. The yellow scheelite from Sonora, Mexico, contained fine fingerprint-like liquid inclusions as well as healed "fingerprints."

CHEMICAL ANALYSIS

Chemical data for the 10 Sri Lankan scheelites were obtained through energy-dispersive X-ray fluorescence (EDXRF), which revealed the presence of tungsten and calcium (see figure 7). Silica

Figure 4. The angular zoning seen here in a stone immersed in methylene iodide is frequently observed in scheelite from Sri Lanka. Transmitted light, magnified 40×.
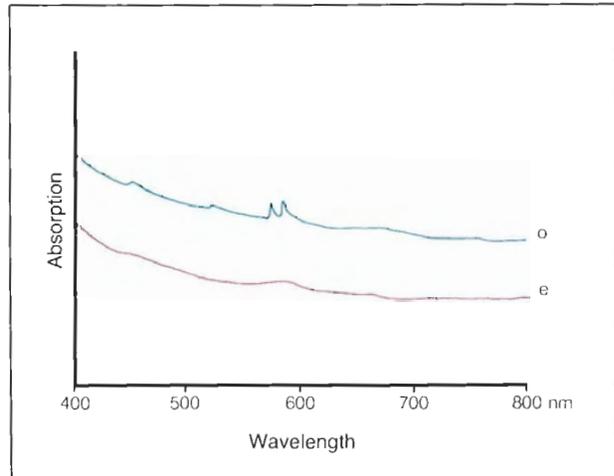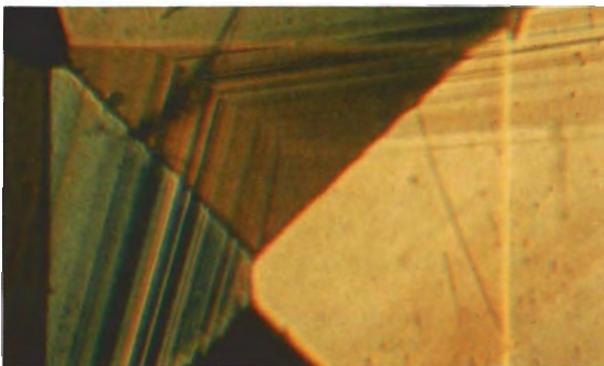
Figure 5. This colorless scheelite from Sri Lanka, observed with crossed polarizers, displays the wavy kaleidoscopic effect often seen in this material. Magnified 50×.
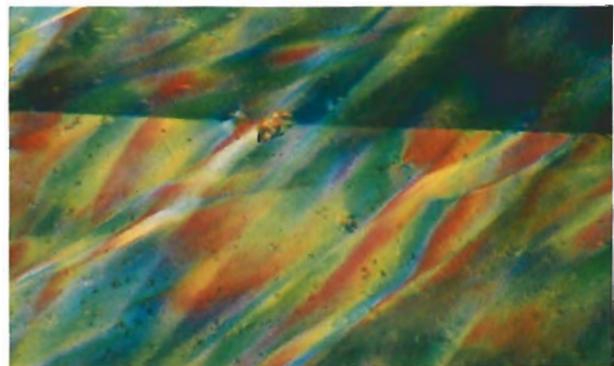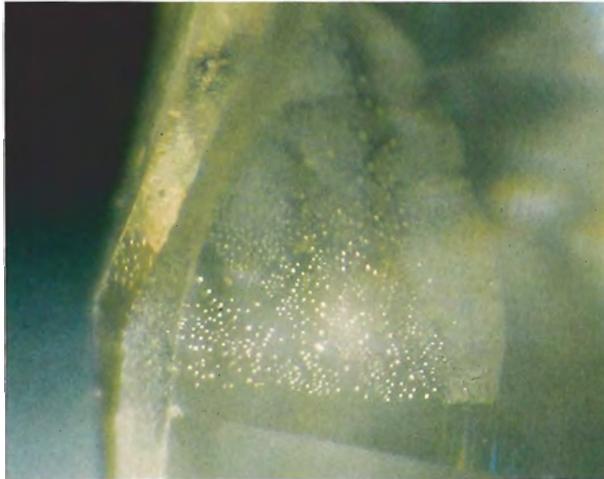
Figure 6. Fingerprint-like liquid feathers are often seen in Colombage-Ara scheelite from Sri Lanka. Dark-field illumination, magnified 32×.

Figure 7. Energy-dispersive X-ray fluorescence spectrum of a Sri Lankan scheelite. The major elemental peaks, calcium (Ca) and tungsten (W), have been labeled.

was detected in most of the samples studied. A few of the Sri Lankan scheelites also contained iron, copper, and sulfur. Notably, the light yellow scheelites contained iron, which probably contributes to their coloration. Under normal operating conditions, Sri Lankan scheelite tends to split under the electron beam of the microprobe. However, patient and careful use of the microprobe provided major element percentages of CaO (20.22 wt.%) and WO_3 (77.78 wt.%), but minor elements (the remaining 2 wt.%) were not recorded.

SUMMARY AND CONCLUSION

The first scheelites reported from Sri Lanka have been found in a small pegmatite vein near the town of Colombage-Ara. Although relatively few stones have been found to date, the material is attractive and some fairly large pieces (up to 25 ct) have been mined.

The Colombage-Ara scheelites differ from stones from California and Mexico in specific gravity, spectrum, and inclusions. Although this find is gemologically interesting, the Precambrian Sri Lankan scheelite deposits have not proved to be economically important. The small-scale mining that produced the stones found to date has now come to a virtual halt.

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Gem Trade LAB NOTES

Fused AMBER

The Fall 1983 Gem Trade Lab Notes column reported on a necklace of beads composed of sizable chunks of amber embedded in plastic. Figure 1 shows a similar necklace that was recently submitted to the New York laboratory. However, the beads in this necklace proved to be made from chunks of amber that were somehow fused together without the use of any identifiable cement or other binder. Many of the beads exhibited black, irregular inclusions at the contact surfaces where the fragments were fused together (figure 2).

These beads were apparently manufactured by a process different from that used to produce the pressed amber that we usually see, a process by which pieces of amber are reduced to tiny fragments and then pressed through a sieve-like apparatus. This results in a fairly clear product, but one that has a "cream-of-wheat" texture when viewed with magnification. In addition, tiny bumps corresponding to the individual fragments are visible on the surface of this material in reflected light. None of the beads in the necklace shown in figure 1 had either of these characteristics. *RC*

Figure 1. The beads in this necklace (31 × 26 × 24 mm) appear to be composed of chunks of amber that have been fused together.

DIAMOND

Fanciful Cuts Created by Laser Sawing

Until just a few years ago, diamonds were parted by one of two methods: cleaving or sawing. Both of these methods have specific limitations caused by the diamond's crystalline structure, which dictates in what directions the stones may be cleaved or sawed. The somewhat recent introduction of lasers into diamond cutting has provided an effective alternative. Without applying any pressure on the diamond being fashioned, the laser can part the stone regardless of its crystalline structure, sometimes much faster and more economically than by traditional methods. Even problematic diamonds, such as those with knots or disoriented internal grains, can be laser sawn in virtually any direction. In addition, the laser technician can cut diamond rough into predetermined designs without regard to orientation.

Figure 2. Black inclusions of an unknown nature occur at the contact surfaces of the fused fragments in the beads shown in figure 1. Magnified 10×.
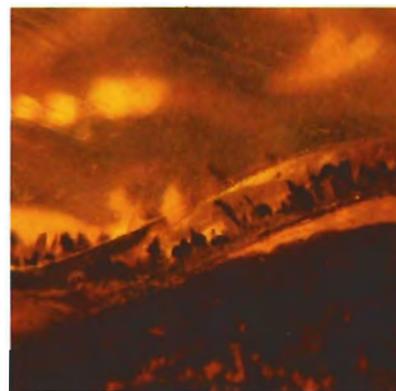
Over the past few years, diamonds have appeared in many ornate shapes, such as butterflies, fish, horse heads, trees, and flowers (the Spring 1986 Gem Trade Lab Notes shows a complete alphabet of faceted diamonds cut by laser). Generally, these fancifully cut diamonds are faceted on both crown and pavilion surfaces.

The Los Angeles laboratory recently had the opportunity to examine several interesting fancy-cut diamonds somewhat different from those seen previously, including a sail boat (12 mm long × 2 mm thick) and a tennis racket matched up with a baguette diamond for the handle (figure 3). Both were cut from thin macles, thereby producing relatively large stones from difficult to cut pieces of rough. For each item, the large parallel faces of the macle were first polished flat and the outline of the shape cut with a laser. The grooves were then cut into the back of the piece, and facets were placed around the edges on both the top and the bottom. These diamonds are somewhat reminiscent of the "profile cut" diamonds introduced in 1961.   RK

Natural-Color Light Green Diamonds

Although the presence of small green or brown irradiation stains on the surface of light green diamonds (usually in or near naturals) does not automatically prove that the color is natural, it is a strong indication. We know of no such stains being produced artificially. It is important to note, however, that while these irradiation stains are most probably of natural origin, they do not prove that the "body color" of the diamond is entirely of natural origin. Near-colorless or faint green diamonds with
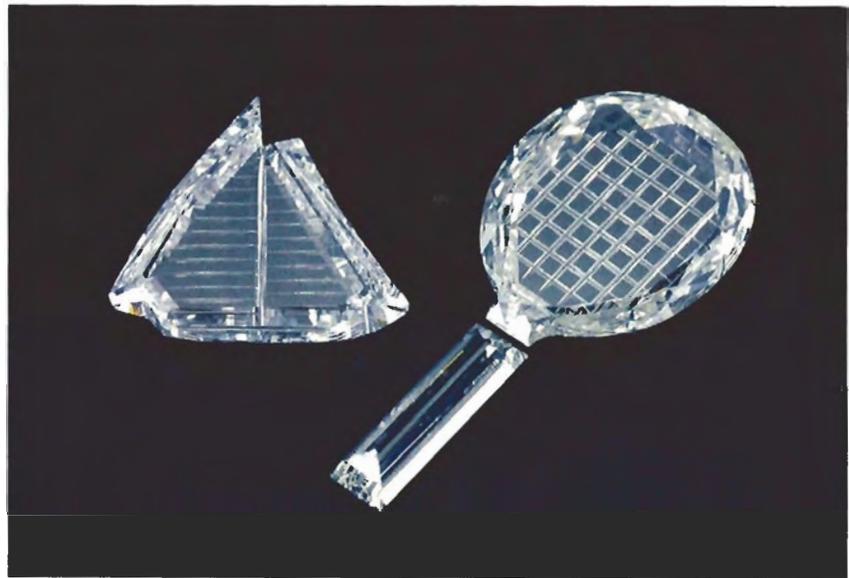
Figure 3. With the technology provided by laser sawing, fanciful cuts such as this 12-mm sailboat and tennis racket can be obtained from otherwise difficult to cut pieces of rough.

such stains could be artificially irradiated to darken the color or produce a light to dark green color.

Sometimes the heat of polishing will alter the green "skin" color to brown. This evidently occurred on the stone shown in figure 4, where a tiny brown natural irradiation stain may be seen at the culet. The stone was graded "very light green," with a statement to the effect that the presence of an irradiation spot indicates natural color.

Nearly all diamonds cut from the green "speculative" rough sold by the Diamond Trading Company are considered speculative because they usually do not remain green after being cut; rather, they end up being in the near-colorless "G–H" range. The thin green "skin" effectively masks the true body color. Very rarely, one of these stones turns out to be faint to light green even if all surface evidence of the green skin is removed. Since the color is due to irradiation and, in most cases, no tests exist to distinguish between natural and man-induced irradiation, stones of this color but without a green- or brown-stained natural are saddled with a "color origin unde-

termined" report. On occasion, the laboratory has advised cutters to leave a little of the colored surface on the finished stone if it is one of the rare pieces of green rough that retains some of the color after cutting.

One example of green surface irradiation staining that left no doubt as to the natural origin of the surface color is shown in figure 5. The 2.35-ct rough crystal was very kindly loaned to us for study by a New York diamond dealer. It is difficult to imagine what conditions within the

Figure 4. Irradiation stains on green diamond rough are sometimes altered to brown, as seen here, by the heat of polishing. Magnified 20×.

earth could have caused this dendritic surface pattern. The rough would probably cut a near-colorless stone, although it is hoped that it will not be cut, since in its present state it is a true phenomenon of nature.   *RC*

Unusual Inclusion in Diamond

The same dealer provided us with another "mind blower" in the form of a sawed diamond crystal fragment. Looking through the stone toward the sawed area, one can see what appears to be a large green crystal inclusion that was obviously the reason for dividing the diamond at that point. However, upon turning the piece over, one sees that the "included crystal" is really a negative crystal with a green lining (figure 6). To add even more to the uniqueness of this specimen, inside the green-lined negative crystal is a tiny green diamond crystal that is completely loose within the cavity.   *RC*

Figure 5. This unusual green dendritic irradiation stain was observed on the surface of a 2.35-ct diamond crystal. Magnified 10×.

Figure 6. A loose green diamond crystal is trapped inside a green irradiation-stained cavity in this sawed diamond section. Magnified 15×.
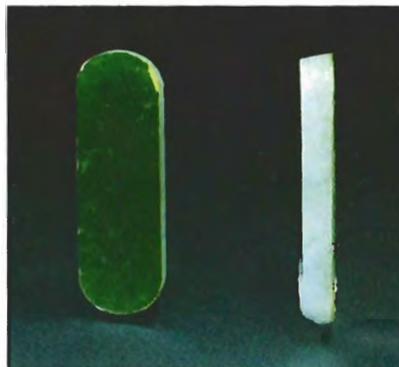
Figure 7. This 20 × 6 × 2.5 mm assembled tablet consists of a thin (0.1 mm) layer of green jadeite on top of a thicker (2.2 –2.3 mm) layer of white jadeite, as evident in this double-exposure photo.

Jadeite JADE Doublet

Figure 7 shows an oval tablet (20 × 6 × 2.5 mm) that the Los Angeles lab received for identification. Simple observation revealed that the tablet was assembled. The piece consisted of two parts, one extremely thin (only 0.1 mm) green layer at the top and another much thicker (2.2 –2.3 mm) white layer at the bottom. Using high magnification, we noted that the layers had been joined by a slightly yellowish cement that contained numerous small gas bubbles (figure 8). The thin top layer was a mottled dark green with numerous small near-colorless veins (figure 9). Visually, this part of the assemblage somewhat resembled green chloromelanite. The white bottom portion showed a definite crystalline structure. We were able to obtain indistinct R.I. readings (ranging from 1.64 to 1.74) on the green portion, which seemed unusual. When examined with a spectroscope in both reflected and transmitted light, the green layer revealed distinct lines in the red portion of the spectrum, suggesting that it was colored by chromium. Although the tests indicated that the top was probably natural-color jadeite jade, we could not positively identify both layers with ordinary
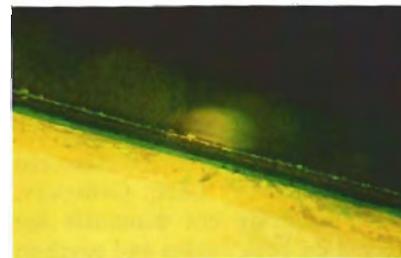
Figure 8. At 63 × magnification, the yellowish cement that joins the two jadeite layers shown in figure 7 is visible.
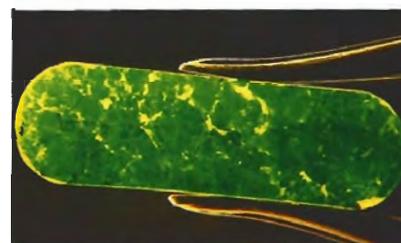
Figure 9. The top portion of the assembled jadeite piece is a mottled green with numerous small near-colorless veins. Magnified 10×.

gemological testing methods. Therefore, we tested both the green and the white portions on the infrared spectrometer. The infrared spectra of both portions matched the spectrum of jadeite jade. We also scraped a tiny amount of powder from each layer for X-ray diffraction analysis. The diffraction patterns obtained for both layers matched that of jadeite jade, strongly indicating that both parts of the assembled stone were jadeite jade. However, at the present time we have no explanation for the apparent variation in the refractive indices of the green portion. Further analysis would be desirable.   *KH*

Dyed LAPIS LAZULI, Difficult to Detect

The Los Angeles laboratory was recently asked to determine whether or not the lapis lazuli necklace illustrated in figure 10 had been dyed. Ev-

Figure 10. The dye in these 15-mm lapis lazuli beads could not be detected on an acetone-soaked swab, but did show when the beads were carefully tested with hydrochloric acid.

idence of dye is most frequently encountered as a concentration of blue or purple in the fractured and porous areas. This necklace had an unusually large number of distinctly purple areas, which were easily seen with the unaided eye. However, when the beads were rubbed (first lightly and then vigorously) in an inconspicuous area with an acetone-soaked cotton swab, no dye appeared on the swab. Since lapis lazuli is sometimes coated with wax to hide dye, conceal a poor polish, or prevent dye from staining clothing or stone papers (see the Summer 1981 and Summer 1986 Gem Trade Lab Notes), we looked for a wax by careful microscopic examination and testing with a hot point. None was revealed.

Several years ago, the laboratory examined a dyed blue marble bead which when tested with acetone did not show any evidence of dye. However, when that marble bead was tested with a solution of 10% hydrochloric acid, a very dark blue stain appeared on the cotton swab (see the Fall 1982 Gem Trade Lab Notes). We decided to test the lapis necklace shown in figure 10 with this method.

Using a cotton swab soaked with a 10% solution of hydrochloric acid, we obtained a light bluish purple stain. Testing of only the purple areas yielded more of a stain than did other areas of the beads. Therefore, if no evidence of dye is obtained with acetone, one should also try the dilute HCl solution before concluding that there is no evidence of dye. As always when handling acids, use extreme care with HCl.   *RK*

PEARLS

Black Cultured Pearls

When natural-color black cultured pearls from Tahiti and, more rarely, from the Philippines and Okinawa, first appeared in the trade, the GIA Gem Trade Laboratory tested them with long-wave ultraviolet radiation. By comparing the fluorescence color with that of a polished shell from Tahiti, we became familiar with the characteristic indistinct red-brown glow of the natural-color black cultured pearls. We were also impressed with the distinct appearance of these cultured pearls in the radiographs. We rarely have any difficulty recog-

nizing them as cultured since there is almost always a clear-cut difference between the nacre and the nucleus. In fact, they are often divided by a black ring that is caused by the transparency of the conchiolin layer surrounding the nucleus (figure 11).

In the past year or so, we have seen an increasing number of treated black cultured pearls. These treated black cultured pearls either fluoresce slightly greenish (rather than red-brown) to long-wave ultraviolet radiation, or are completely inert. Also, necklaces of these treated cultured pearls are usually uniform in fluorescence, in contrast to the differing tones of their naturally colored counterparts. The greatest difference between the two products is in their X-radiographs. Sometimes difficulties are presented in telling whether the treated pearls are cultured or natural, since the treatment effectively masks the contrast between the nacre and the nucleus (figure 12). In some necklaces, not even one black ring is visible around a nucleus. If a silver-based or other metallic dye is used, some of the pearls may show an opaque white reversal ring part way around the nucleus, since the metal deposit does not transmit X-rays.   *RC*

Figure 11. A black ring of conchiolin between the nacre and the nucleus on this X-radiograph identifies these natural-color black pearls as cultured.
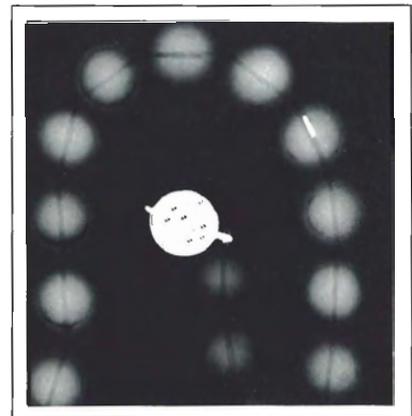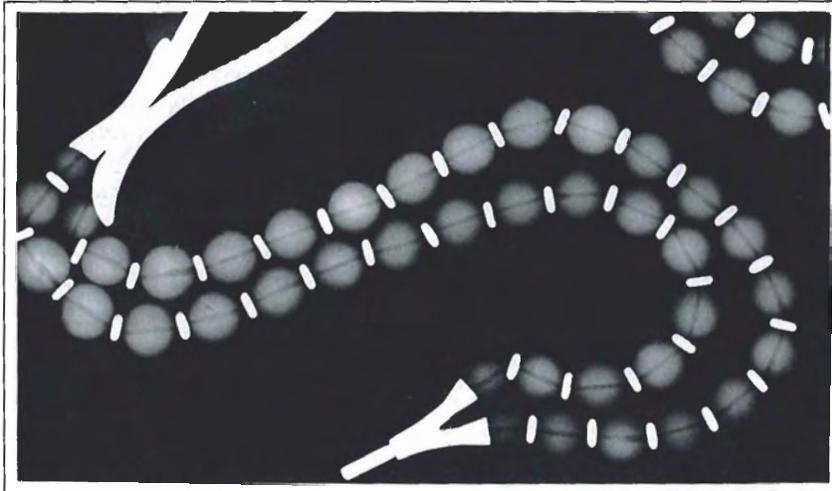
Figure 12. In these black cultured pearls, treatment has effectively masked the black ring around the nucleus on the X-radiograph.
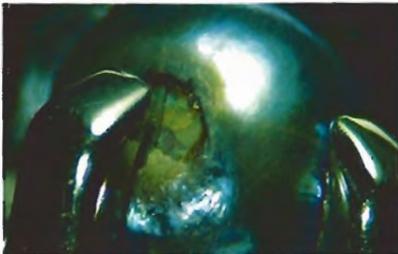
Figure 13. By examining the damaged area next to the prong on this 5-mm black pearl, the lab was able to determine that the color was natural.

A Black Natural Pearl with Unusual Fluorescence

A woman's ring set with one round undrilled pearl was sent to the Los Angeles laboratory for identification. The pearl was rather small (approximately 5 mm in diameter), but had a very attractive brownish black color with a fairly high luster. Even without magnification, a small damaged area was visible next to one prong (figure 13). Here the top layer was gone, exposing part of the conchiolin layer and the underlying nacreous layer, which appeared to be a deeper black and have a higher luster than the outer layer. We also noted that the outer layer was completely transparent. We concluded that the

color of this pearl was derived from the conchiolin layer rather than from any organic pigments in the outer layer. It was obvious, therefore, that the color was of natural origin and not the result of chemical treatment. The X-radiograph showed numerous concentric layers around a dark center, proving that the pearl was of natural origin. However, natural-color

black pearls usually show a reddish brown glow when exposed to long-wave U.V. radiation. Therefore, we were quite surprised to see that this pearl fluoresced a strong yellow. This was the first time that we have seen this remarkable color fluorescence in a natural-color black pearl.   *KH*

Blue to Gray Saltwater Cultured Pearls

Recently, three 10-mm round gray "pearls," two in earrings and the third in a brooch, were submitted to the New York laboratory (figure 14) along with several pieces that were found to contain natural pearls. These gray pearls had the appearance we have long associated with cultured pearls, whether natural color, dyed, or irradiated. However, we were surprised by the X-radiograph, which showed that each pearl had an opaque center within a shell of average-thickness nacre. The owner gave us permission to remove the pearl from the brooch, which enabled us to see by looking down the drill hole that the central material was white (figure 15) and had superficial properties much like those of the traditional French pearl cement, in-

Figure 14. All three of the 12-mm gray cultured pearls in this pair of earrings and matching brooch were found to have hollow centers filled with some foreign material.

cluding the tendency to be slightly soluble to our X-ray immersion fluid.

We are mystified as to how these pearls were formed. If they are indeed cultured, what was the nucleus and how was it removed? As the photograph indicates, the drill hole through which the nucleus would have had to have been removed is an opening only approximately four times the size of a normal drill hole. Possibly, the pearls were cultured around a plastic bead or some experimental material, which was later dissolved. The coincidence of having three nearly identical hollow natural pearls is too great to be believed.

Blue to gray saltwater cultured pearls may owe their color to one or more of five different factors: (1) precolored bead nuclei that show through a transparent, fairly thin, uncolored nacre may be used; (2) growth conditions may color the nacreous layer, at times so strongly that bleaching will not remove the color; (3) growth conditions may cause an abnormal deposit of dark conchiolin around the bead nucleus before growth of the nacre begins; (4) cultured pearls (usually drilled) may be dyed, with the dye commonly lodging in the zone around the nucleus and under the nacre; and (5) they may be irradiated, an operation that darkens the freshwater shell bead nucleus under the colorless nacre.

Figure 15. A white cement-like material can be seen in the drill hole of one of the cultured pearls shown in figure 14. Magnified 15×.

Figure 16. The yellowish green color of this 38.47-ct tourmaline is very unusual.

As seen in figure 15, the nacre is blue-gray, which indicates that the color is either natural or due to dye, but it is definitely not caused by irradiation or by a dark layer of conchiolin. As Dr. Kurt Nassau observed a number of years ago, gamma irradiation of saltwater cultured pearls darkens only the freshwater bead nuclei, not the nacre. Evidently, natural saltwater pearls or shell will not be affected by irradiation, while freshwater shell will be colored, as noted by R. T. Liddicoat, Jr. (*Gems & Gemology*, Spring 1967).   RC

TOURMALINE, Unusual Yellowish Green

An interesting 38.47-ct yellowish green faceted tourmaline (figure 16) was submitted to the Los Angeles laboratory for identification. In addition to its intriguing vivid color, which until recently had not been seen in gem tourmalines, this stone gave a birefringence value of 0.028, which is well above the maximum typically noted for other gem tourmalines (0.020). However, the refractive index values of 1.621 and
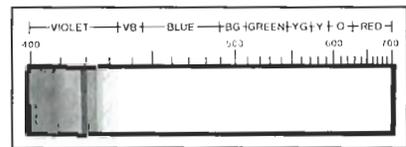
Figure 17. The absorption spectrum of the tourmaline shown in figure 16 is probably due to the unusually large amount of manganese in this stone.

1.649 and a specific gravity of 3.13 are still well within the range for the various species of tourmaline. The stone is inert to long- and short-wave ultraviolet radiation. Viewed with a GEM spectroscope unit, the stone displayed a cut-off at about 410 nm, a strong absorption band from approximately 418 to 420 nm, and a fainter narrow band at approximately 423.5 nm (figure 17). These bands are probably associated with manganese. The stone contained liquid- and gas-filled inclusions typical of many tourmalines (figure 18).

Chemical data from electron microprobe analysis of four separate spots on the stone revealed an unusually high level of manganese (9.2 wt.% MnO). Otherwise, the results
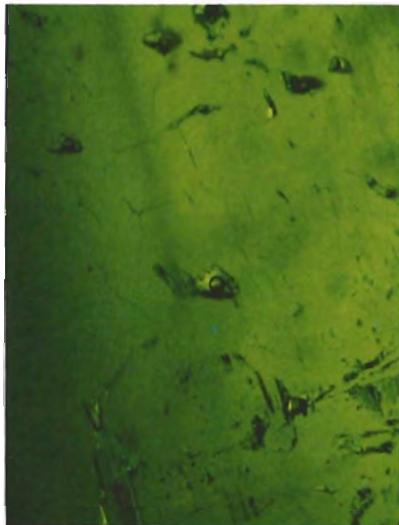
Figure 18. Two-phase, liquid and gas, inclusions similar to those found in many other tourmalines were observed in the stone shown in figure 17. Transmitted light, magnified 25×.

Figure 19. Reddish brown Zambian tourmalines (left) are often heated to produce a yellowish green color (right).

are consistent with published tourmaline analyses.

We do not know the exact origin of this particular gem tourmaline, but we have seen some material, vaguely reminiscent in color as well as in physical and optical properties, that originated from pegmatite localities along the Luangwa River Valley between Kafue and Chirundi, in Zambia. The partial resemblance to the faceted stone described here leads us to believe that it is of Zambian origin.

Although some gem tourmaline from Zambia is heat treated to change or improve the color (see figure 19), we are convinced that this stone was not heat treated because of the absence of any obvious damage to the numerous liquid-gas inclusions (again, see figure 18).

In most green tourmaline, the dominant coloring agent is thought to be iron. However, Schmetzer and Bank (Neues Jahrbuch für Mineralogie Monatshefte, 1984, pp. 61–69) suggested that the spectral features of the yellow to yellowish brown or greenish yellow Zambian

Figure 20. K. Schmetzer and H. Bank found an unusually high weight percentage of manganese in the greenish yellow Zambian tourmalines that they studied, which are similar in color to the stone shown here.

tourmalines that they studied (see figure 20) may have involved manganese. Tourmalines in general contain no more than a few weight percentages of MnO, but Schmetzer and Bank reported 6.37–6.80 wt.% MnO in the Zambian tourmalines they studied.

In 1929, Kunitz (Chemie der Erde, pp. 208–251) proposed the name "tsilaisite" for a hypothetical new end member of the tourmaline group, with an ideal chemical formula requiring about 20 wt.% MnO. However, "tsilaisite" is not yet officially recognized by mineralogists because no natural material has been

found that is at least half composed of the "tsilaisite" component, which would require more than 10.7 wt.% MnO. Pure "tsilaisite" has reportedly been produced in the laboratory, and provides measurable physical and optical properties. The stone we examined, with its high manganese content, exhibits properties even more like those of the man-made "tsilaisite" than does the material studied by Schmetzer and Bank, and is closer chemically to hypothetical "tsilaisite" than any other tourmaline reported thus far. If gem "tsilaisite" were at some point discovered, it would be distinguishable from gem elbaites by its higher refractive indices, birefringence, and specific gravity. A more detailed discussion of this stone is scheduled to appear in an upcoming issue of the American Mineralogist.   RK

Editorial Forum

DYED LAPIS LAZULI

I read with great interest the Gem Trade Laboratory's experiences with dyed lapis lazuli (Gem Trade Lab Notes, Spring 1986, p. 49). I too have had some experience with this material and would like to share the following with you.

For several years we have manufactured a reproduction of a necklace that the Metropolitan Museum of Art has in its collection. One of the components is a specially cut series of lapis beads. We knew that the material we received from oriental suppliers had been dyed, but unlike samples received from Europe, this dye did not respond to the usual acetone swab test. Indeed, these beads were soaked in acetone and no change was seen in the color of the bead or in the acetone solution itself.

Customer complaints about blue stains on clothing and skin prompted further tests. Although the dye was impervious to acetone, it readily dissolved in denatured alcohol (a major component in most colognes and perfumes).

We now "wash" all lapis coming into our studio. Concentrations of the dye tend to accumulate in and around the holes of the beads. The color removed does not seem to change the overall appearance of the bead, and this washing process has eliminated customer complaints.

> Frederick Elessar Borgardt
> Manager, Reproduction Studio
> Metropolitan Museum of Art, NY

"WHEN I USE A WORD . . ."
THE "SYNTHETIC" CONTROVERSY

In his letter to *Gems & Gemology* (Summer 1986, p. 107), Dr. W. W. Hanneman objects to the use of the word *synthetic* as an abbreviation for *synthetic gemstone*. He also uses the term *synthetic* as synonymous with any man-made substance, despite a long gemological (and gemmological) tradition of using such a designation only for the man-made equivalents of a natural material. Some gem synthesizers have also recently stated their desire to replace *synthetic* with *cultured*.

One needs to recall a passage from Lewis Carroll's *Through the Looking Glass:*

> "When *I* use a word," Humpty Dumpty said . . . "it means just what I choose it to mean — neither more nor less."
> "The question is," said Alice, "whether you *can* make words mean so many different things."
> "The question is," said Humpty Dumpty, "which is to be master — that's all."

Dictionaries do not control the use of words. A dictionary definition is no more than a report on how a word has been used in the past and is currently being used, usually with a considerable time delay. Specialized technological terms may not reach even major dictionaries for decades.

Words frequently have several distinct meanings, some general and some used only by certain specialists. For example, the term *dichroism* is well known to every gemologist as a change in color with orientation, particularly in polarized light. Yet chemists use the same word to describe a change in color, e.g., of an organic dye solution, with either concentration or thickness — a completely different meaning. The term *impulse* has a specific quantitative meaning in mechanics, quite distinct from the nontechnical meaning. The term *cultured* is applied to microorganisms, to education and, in a specialist's sense, to pearls. And so on. Such unexpected specialized meanings are included in some dictionaries but not in others.

The adjectival use of *synthetic* as in synthetic gemstone material, etc. (and its occasional abbreviation as a noun form) has been employed widely in gemology with the consistent meaning of man-made equivalent of the natural (see, for example, the gemology texts by Anderson, Liddicoat, Nassau, and Webster, among others). Synthetics are thus contrasted to imitations, pastes, fakes, simulants, and so on. While this may seem confusing to the novice, any specialist knowledgeable in this field readily understands the intended meaning, without any danger of confusion. There does not seem to be any urgent need for a change.

> Kurt Nassau, Ph.D.
> Bernardsville, NJ

PHOTOATLAS OF INCLUSIONS IN GEMSTONES

By Edward J. Gübelin and John I. Koivula, 532 pp., illus., publ. by ABC Edition, Zurich, Switzerland, 1986. US$175.00*

Surely the name most often associated with the use of inclusions for gem identification, and as a guide to the paragenesis of gems and gem materials, is that of Edward J. Gübelin. Working with him on the preparation of this monumental photoatlas is John I. Koivula, a remarkably gifted gem inclusion specialist and award-winning photomicrographer. The combined efforts of these two authors and scientists has resulted in a book that is sure to become a classic in the gemological literature.

Both authors have impressive gemological backgrounds. Dr. Gübelin, of Meggen, Switzerland, was the first person to introduce a systematic classification of gemstone inclusions. During the course of his career, he has published more than 150 papers and five books on gemology, and has designed instruments and accessories to improve microscopy. As a specialist in gemstone microscopy, Mr. Koivula has developed several new illumination techniques, including pinpoint illumination and shadowing. His photomicrograph of a gemstone inclusion captured first place in the 1984 Nikon International Small World Competition. In addition to his editorial responsibilities with *Gems & Gemology*, he has published more than 50 articles in various gemological publications and contributed to several books.

The new *Photoatlas* has more than five times as many color plates as Dr. Gübelin's 1974 classic, *Internal World of Gemstones*. There are some other interesting departures from *Internal World* as well. The *Photoatlas* is divided into six parts. The introduction discusses the importance and beauty of inclusions, as well as the procedures of microscopy and photomicrography. Part two is a pleasant surprise since, in addition to the information on the genesis of

mineral inclusions in gems, it also contains three essays: one by Dr. Edwin Roedder on the origin of fluid inclusions, the second by Dr. Henry Meyer on the genesis of diamond and its inclusions, and a third by Professor Dr. H. A. Stalder on the formation of quartz and its inclusions. Part three covers specific mineral, fluid, and glass (remnants of silicate melts that never crystallized) inclusions as well as multiple inclusion "scenes." Part four discusses various minerals and their inclusions, and part five presents inclusions found in manmade materials. The final section summarizes the work.

The authors are not given to verbosity, but Dr. Gübelin can be positively lyrical in English, which is not his native language. However, the 1440 magnificent photomicrographs speak for themselves. Beautifully reproduced and accompanied by interesting, concise captions, they provide the most thorough coverage of the subject ever accomplished.

Perhaps to prove a reviewer's objectivity, I am constrained to find something to criticize. It is exceedingly difficult in this instance, but on page 76 there are two photos of a three-phase inclusion in which a cube of halite is photographed in different positions in a liquid- and gas-filled cavity. The caption reads, in part: "Note how the gas bubbles stand out from its background in strong relief thanks to its much higher refractive index." This must, indeed, be a rare gas.

This book is not only beautiful (it contains roughly 13,000 square inches of color photographs), but it also provides a wealth of valuable information on a subject of vital importance to gemologists. If one can conceive of a book with a

$175.00 price tag as a great bargain, this is it.

<div style="text-align:right">RICHARD T. LIDDICOAT, JR.
Chairman of the Board
GIA — Santa Monica</div>

PEARLS: NATURAL, CULTURED AND IMITATION

By Alexander E. Farn, 150 pp., illus., publ. by Butterworth & Co., London, 1986. US$29.95*

This book is part of the new Butterworth Gem Books series, which is aimed at providing in-depth information on particular gems rather than surveying many or all types of gem materials under one cover. The idea has merit, but its execution in this book is lacking in several important ways.

At first glance, the book has all the ingredients for a first-class work. The author, a former director of the London Chamber of Commerce Laboratory, has had gem-testing experience that comes to only a few. The subject matter is of great interest because of the current popularity of cultured pearls, and because new books about pearls are few and far between — the last great one was *The Book of the Pearl*, by Kunz and Stevenson, published in 1908.

Even today, pearls are much misunderstood, and up-to-date information and research are sadly lacking. Much of our recent information about natural and cultured pearls has come from pearl growers, processors, and dealers, which is a clear case of the fox guarding the hens. For example, the Japanese cultured-pearl industry, until very recently, has been reluctant to admit that today, about 80% of its saltwater cultured pearls are harvested after one or at most two growing seasons (approximately eight to 20 months), rather than the three- to four-year period commonly accepted as fact. Similarly, the Japanese have been loath to explain the extent of the processing and treat-

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ments to which most cultured pearls are subjected. The need for fresh information about pearls is clear.

This book endeavors to cover most aspects of pearls, cultured pearls, and imitation pearls, and includes a brief gemological description, a chapter on the origin of pearls, a very brief historical perspective, an anatomy of the pearl oyster, a discussion of the sources of natural pearls, a chapter on cultured pearls, the techniques of pearl identification, a discussion of imitation pearls, natural-pearl pricing methods, and a final chapter entitled "A Pearl Pot-pourri," which includes small tidbits of "pearlobilia" that wouldn't fit anywhere else. Included also are a short glossary, a reading list, references, and an index.

The author effectively works to clarify and distinguish the differences between the various types of pearls and cultured pearls. Although the point has been made many times before, he emphasizes the fact that the term *pearl* should only be applied to natural pearls, of either saltwater or freshwater origin, and that cultured pearls should always be designated as such. This is an important distinction not always made in commerce.

The second chapter, on the origin of pearls, takes the reader back to the earliest ideas about pearl formation (e.g., myth of dew-formed pearls), and then carefully traces the evolution of modern thought on pearls which arrives at the conclusion, scientifically derived, that

most pearls are induced by parasitic infestation of the mollusk and rarely, if ever, by a grain of sand. While this idea is probably correct when applied to the saltwater pearl, certainly as opposed to the grain-of-sand myth, it should be noted that pearls, especially freshwater pearls, are often nucleated by *calcareous* objects, in the form of shell bits or shell-bearing parasitic mollusks.

The author also does a good job of presenting the techniques used in pearl identification, and proceeds from the simplest to the more advanced. His information is good, although a general reader might have difficulty following his explanation of the fine points and nuances of modern methods of pearl testing. A table showing the strengths and weaknesses of each method, vis-à-vis the various types of pearls and cultured pearls, would have been helpful. The table showing the number of pearls and cultured pearls tested at the London Laboratory from 1926 to 1984 is new information and very interesting. Notably, the author points out the difficulty in using available techniques to test some of the newer cultured pearls, especially mantle-tissue nucleated cultured pearls produced in saltwater, and calls for ongoing research in this field.

The book could have been much better in its overall execution; I came away with the impression that it was rather hurriedly put together. It suffers from a so-so editing job: the author's writing style, erudite in

tone, is often rambling and hard to follow. The editor should have helped to organize and present the information more effectively, so that the book would lend itself to reference.

Although the book has a good number of photographs, maps, line drawings, and tables, many of these are not especially well done, and do not add much. The photos of radiographs, intended to show the features which identify pearls and cultured pearls, are in most instances not sharp enough to reveal these characteristics.

Finally, while the author does achieve his stated objectives of distinguishing between the various types of pearls and cultured pearls and of explaining the history and technique of the pearl-identification practices used at the London Laboratory, he falls short of the broader goal of providing a useful source of information for both the public and the jewelry trade. His obvious forte is pearl identification, especially of oriental pearls, but the information he provides about cultured pearls in general and freshwater pearls in particular, both natural and cultured, is often out of date or incorrect. Although the book is truly a noble effort by a respected author, at a time when our knowledge about pearls and cultured pearls is still plagued by myths, half-truths, and noninformation, the work does little to break new ground.

JAMES L. SWEANEY, G.G
Mardon Jewelers
Riverside, CA

MORE ON "SYNTHETIC"

I would like to comment on the letter from W. W. Hanneman in your Summer 1986 issue.

Synthetic is acceptable on two grounds: (1) often in the usage of the English language, the noun is inferred, and the adjective only expressed; (2) I know of no dictionary that covers the specialized usage in every field of science, arts, sports, etc. *A synthetic* is a term perfectly understood by all gemologists, and widely defined in all gemological literature.

And, if Dr. Hanneman is going to be pedantic, the terms *borate* and *silicate* indicate a chemical formula, not a "defined crystal structure." The possible crystal structure may be inferred from the formula, but equally, many substances with a chemical formula can also exist in an amorphous form. Australia's best-known precious stone — opal — has the formula $SiO_2 \cdot nH_2O$ and is amorphous; chalcedony, with the same formula, is not.

W. H. Hicks, FGAA
Editor, *Australian Gemmologist*
South Yarra, Victoria, Australia

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Bowesite—a new lapidary material from Australia. S. M. B. Kelly, *Australian Gemmologist*, Vol. 16, No. 1, 1986, pp. 5–8.

The author reports on a new ornamental gemstone found near the town of Cracow in Queensland, Australia. Dubbed "bowesite," the material contains widely varying amounts of diopside, epidote, grossularite garnet, actinolite, andesine feldspar, quartz, sphene, calcite, and an iron oxide (probably magnetite).

The gemological properties of "bowesite" are as follows: color = green, from light to very dark (almost

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black), occasionally streaked or mottled with green and white; luster = vitreous on polished surfaces, dull to subvitreous on rough surfaces; diaphaneity = opaque; fracture = uneven to hackly; cleavage = none; refractive index = 1.57; specific gravity = 2.78–3.10, the higher values for darker-colored material; spectra, pleochroism, and fluorescence to ultraviolet radiation = none.

This material is currently being used for carving.

RCK

Emeralds. H. de Santana, *City & Country Home*, Vol. 5, No. 3, 1985 pp. 112–122.

Aimed primarily at more knowledgeable consumers, this article is meant to be a "primer" on emeralds. It flows through emerald folklore, history, and gemology, and concludes with a few cautionary tips on how and where to buy emeralds and what to look out for in emerald fakes, treatments, and synthetics.

Although most of the information should be familiar to the jeweler/gemologist, de Santana does present several interesting nuggets. For example, he reveals how the Spanish traded their glut of newly discovered Colombian emeralds to the Moghul princes of India, who were eventually robbed of their treasures by the Persians. In this way, many spectacular Colombian emeralds were incorporated into the crown jewels of Iran and the coffers of other Middle Eastern countries.

Color photos of magnificient emerald crystals and jewelry accompany the text.   *SAT*

Les gemmes en lumière (Gems in light). C. da Cunha and A. da Cunha, *Monde et Mineraux*, No. 73, 1986, pp. 27–29.

In this second in a series of articles that uses diverse specific examples to educate about gemology, the authors discuss three stones: a color-change sapphire, a sinhalite mistaken for a zircon, and, most interestingly, a blue sapphire from Ceylon that contains a new type of inclusion. When viewed with $40\times$ magnification, the inclusion resembles the pattern seen in nylon hosiery (with one run!). This striking new feature is illustrated by a color photograph. Although this is the only stone in which the authors have seen such a pattern, they speculate that this may be a characteristic inclusion of a natural stone.   *EF*

Irradiated gems: why the color comes and goes. K. Nassau, *Jewelers' Circular-Keystone*, Vol. 157, No. 7, 1986, pp. 294–299.

In this article, Dr. Nassau clarifies how the irradiation process relates to color changes in certain gemstones. The reason behind these color changes is color centers, a concept that Dr. Nassau simplifies well for the reader. Because color centers vary in strength from one material to another, irradiation-produced color is stable in some gemstones and not stable in others. The author then explains how different types of irradiation produce different results. The two major irradiation processes are discussed, with disadvantages and advantages of each process.

The first process uses either X-rays or gamma rays. Gamma-ray facilities produce uniform coloration without generating any significant heat or other hazard, such as radioactivity. X-rays behave much like gamma rays, but they produce color less uniformly and more slowly. The second major process involves high-energy electrons or neutrons. High-energy electrons are produced in linear accelerators by means of a process that consumes considerable electricity and can produce intense localized heating. Flowing cold water is needed to keep the gemstones from melting. Neutrons in a nuclear reactor produce uniform color without localized heating. Both electrons and neutrons can induce radioactivity, so gemstones may need to "cool off."

The author also explains how to tell whether a color produced by irradiation is stable or will fade. A section on the materials that are commonly irradiated is included, along with a convenient table summarizing the treatments and their stability. The article is well written and easy to understand.   *David C. LeRose*

Isomorpher Einbau von Eisen und Titan zur Erklärung der blauen Farbe von Rutil- und Spinell-haltigen seidig weifsen Korunden nach einer Wärm-ebehandlung (Solid solution of iron and titanium for explaining the blue colour of rutile- and spinel-containing silky-milky corundum after heat treatment.) H. Harder and A. Schneider, *Neues Jahrbuch für Mineralogie Monatshefte*, No. 5, 1986, pp. 209–218.

The treatment of gemstones, especially corundum, has become a growing concern to the trade in recent years. The authors report that heat treatment to produce blue sapphires is usually undertaken on nontransparent, heavily included grayish corundum from Sri Lanka. The blue color appears during heating, along with a striking improvement in transparency. However, clear sapphires seem to lose their color by the same process. This is related to dissolution of rutile needles in the corundum matrix at temperatures above 1550°C.

The origin of the blue color in natural sapphires has previously been attributed primarily to intervalence charge transfer between Fe^{2+} and Fe^{3+}, although we know that the blue in synthetic sapphires is due mainly to $Fe^{3+}-Ti^{4+}$ charge transfer. To understand the origin of the heat-induced color, the authors investigated iron-bearing inclusions in a sapphire from Sri Lanka with an electron microprobe. Rutile needles were observed which were found to contain up to 30% iron in both valence states. An Fe- and Mn-rich phase, probably spinel, was also found. The corundum contains 0.1% FeO and 0.005% TiO_2.

After a 30-minute treatment at 1600°C, the corundum was found to contain about the same percentage of iron oxide but 0.17% TiO_2, a 30-fold increase. Titanium in lower concentrations was found in the vicinity of former rutile inclusions. This clearly demonstrates that rutile inclusions are dissolved and titanium diffused away during the heating process. Iron appears to be mobile as well, but it reappears in the form of other types of inclusions (such as magnetite) on cooling, and does not remain diluted in the corundum host. The magnesium is not mobile.

Unfortunately, an optical absorption spectrum is not available. However, it is hypothesized that the increase in available diluted titanium after heat treatment is responsible for the blue coloration. Therefore, this is an example of a $Fe^{2+}-Ti^{4+}$ charge transfer.   *EF*

On the origin of blue sapphire from Elahera, Sri Lanka. G. Heilmann and U. Henn, *Australian Gemmologist*, Vol. 16, No. 1, 1986, pp. 2–4.

In this report on light blue sapphire found near Elahera in the Central Province of Sri Lanka, the authors describe the geology of Sri Lanka and the Elahera area specifically, and then present chemical data from electron microprobe analyses of the samples studied. These data show color-causing iron and titanium contents comparable to those of sapphires from other Sri Lankan sources.

Examination of the sapphires with a microscope

revealed the following: feathers consisting of elongated liquid-filled and two-phase inclusions, oriented rutile needles, rounded zircon crystals with pleochroic halos, prismatic apatite crystals, and platelets of biotite mica that show areas of severe corrosion. Based on the nature of the mica inclusions, the authors conclude that the sapphires originated from garnet-bearing gneisses that form the ridges bordering the gem pits.   *RCK*

Possibilities and limitations in radiographic determination of pearls. I. Lorenz and K. Schmetzer, *Journal of Gemmology*, Vol. 20, No. 2, 1986, pp. 114–123.

In the introduction, the authors briefly cover the investigations of other authors who have previously worked on the different methods of identification of pearls, fresh- or saltwater, natural or cultured. An outline of the experimental details used in this project is then given, including a list of the number of necklaces or individual pearls the authors tested and the testing parameters for each different method.

Results of the X-radiographs, X-ray diffraction (Laué) patterns, and X-ray luminescence are discussed and combined in capsule form in a table. However, there appears to be an error in the table, where the authors state that there is a radio-opaque bead in the center of bead-nucleated cultured pearls. Beads used for nuclei are usually made out of freshwater shell, which is translucent to X-rays, not opaque. While the beads are not as transparent to X-rays as conchiolin is, they are far from opaque, and are actually very slightly less transparent to X-rays than is saltwater nacre.

In their discussion of the various X-ray testing methods, the authors point out what they feel are the advantages and disadvantages of each test. They conclude by giving a schematic diagram which proposes a plan to determine the identity of a pearl of unknown origin.   *C. W. Fryer*

Rare among rare. J. C. Zeitner, *Lapidary Journal*, Vol. 39, No. 12, 1986, pp. 26–34.

This article capsulizes the properties, history, and some interesting facts about the more unusual gems of Asia. The author has classified these gems as rare using as her criterion the fact that only a few specimens are known (such as painite), or that the material is a rare variety of a more common species (such as imperial jadeite). Not only does the author discuss gems that have been used for centuries (despite their rarity), such as cat's-eye chrysoberyl and "padparadscha" sapphire, but she also describes the more recent discoveries of painite and taaffeite. Included in the article is a spectacular multistar variety of quartz found in Sri Lanka — as many as 16 stars have been observed on one gem. Another stone discovered in Sri Lanka, cat's-eye zircon, has an unusual chatoyant eye caused not by rutile but by tightly packed bands of mineral flakes, which are visible under magnifi-

cation. Other gems mentioned in this article include kornerupine, sinhalite, manganotantalite, alexandrite, sapphirine, demantoid, cassiterite, iolite, and triphane spodumene.   *David C. LeRose*

DIAMONDS

Famous diamonds of the world (XXIV): the "Nassak" diamond. I. Balfour, *Indiaqua*, Vol. 42, No. 3, 1985, pp. 133–135.

According to Balfour, a 90-ct stone known as the Nassak originally graced a statue of the god Shiva that stood in a Hindu temple in the town of Nasik, India. When the British defeated the last Indian Peshwa in 1818, the stone came into the possession of the Marquess of Hastings, who in turn presented it to the East India Company. They handed the precious stone over to the firm of Rundell and Bridge, who had the awkwardly cut stone recut for greater brilliance with only a 10% weight loss.

In 1831, Emanual Brothers bought the Nassak for only £7,200 (the low figure has been attributed to the depressed financial conditions during that period). In 1837, the Nassak was sold at auction (along with the Arcot and King George diamonds) to the first Marquess of Westminster, and it remained in the family until 1926 when it was sold to Georges Mauboussin, a Paris jeweler. Subsequently, the Nassak was purchased by Harry Winston, Inc., of New York, who had it recut to its present 43.38 ct. The stone went through the hands of three more owners until 1977, when it was sold to the King of Saudi Arabia.   *SAT*

Latter-day origin of diamonds of eclogitic paragenesis. S. H. Richardson, *Nature*, Vol. 322, No. 6080, 1986, pp. 623–626.

Mineral inclusions of syngenetic origin in diamonds (inclusions that formed contemporaneously with the diamond) provide a means of determining the conditions of diamond formation. The mineral inclusions in diamond fall into two groups: (1) a group consisting of olivine, orthopyroxene, and chrome pyrope, referred to as the "peridotitic" paragenesis; and (2) a group containing pyrope-almandine and omphacitic clinopyroxene, known as the "eclogitic" paragenesis. Inclusions of both groups can be age dated by any of several isotope dating methods. Using samarium-neodymium isotope ratios, diamonds of the peridotitic paragenesis from the Kimberley and Finsch kimberlites in southern Africa were dated at approximately 3.3 billion years. In contrast, diamonds of the eclogitic paragenesis, which predominate at the Premier kimberlite in southern Africa and the Argyle lamproite in northwestern Australia, have much younger ages of 1.1–1.2 billion years. Thus, the diamonds in the latter group represent a second, genetically distinct origin as compared to the much more ancient group of diamonds with "peridotitic" inclusions. The origin of diamonds in the second group is related in

time and space to periods of kimberlite or lamproite magmatism. *JES*

The rarest gem. D. Kaye, *Town & Country*, Vol. 140, No. 5073, 1986, pp. 134–139, and 177.

Fancy colored diamonds, which are among the rarest of all gemstones, have never before enjoyed such popularity and awareness as they do today. In the case of natural-color diamonds, the increased awareness of their breathtaking beauty and rarity has created unprecedented demand and unparalleled prices.

The author presents a lively story of today's colored diamond market, reflecting on the experiences and personal opinions of several dealers and collectors who specialize in these spectacular gems.

A brief explanation of the chemical make-up of diamonds acquaints the reader with the cause of color in these stones. The artificial coloring of diamonds by atomic bombardment is also mentioned. A brief account of yellow, pink, blue, and brown diamonds familiarizes the reader with historical notes, mining locations, and descriptive terms associated with these color varieties.

A discussion based on several interviews with dealers and gemologists regarding the judgment of color in these gems concludes that color discrimination is a difficult process that requires years of experience to develop. Current grading practices are also discussed, and their strengths and weaknesses identified.

Despite a few minor errors and omissions, the article is very interesting reading. It is well illustrated with 20 color photographs of colored diamonds set in a spectacular array of jewelry pieces. *SCH*

Rise in output: mining the same but officially reporting more. J. Roux, *Jewellery News Asia*, No. 19, 1986, pp. 39–47.

It is difficult at best to compile figures for world production of diamond rough. In some countries these statistics are unobtainable, and in others the activities of illicit miners and smugglers make accuracy impossible. Nevertheless, using statistics from the United States Bureau of Mines and the *Mining Annual Review*, Mr. Roux presents as detailed an analysis of the current diamond production as possible.

The report, broken down by continent, country, and, where applicable, individual mines, lists the output of diamond rough for 1983 and 1984, and the reasons for increases or decreases in each case. For example, in Botswana, a better grade of ore (where grade equals the number of carats obtained from 100 tons of ore) is responsible for the increase in production from the Jwaneng mine. In Angola, the war between the UNITA rebels and the existing Angolan government plus the high incidence of diamond smuggling are responsible for the drop in production.

Essentially, production increased in Botswana, the Central African Republic, Guinea, and Zaire; it de-creased in Australia, Angola, South Africa, Liberia, and Namibia. Production figures for South America, the People's Republic of China, the USSR, and a few other countries are only estimates due to the difficulties in obtaining reliable information.

The author's comprehensive style, augmented by graphs, makes this a fine overview of an important subject. *EBM*

GEM LOCALITIES

A bibliography of general mineral locality publications for the United States and Canada. R. D. Titamgim, *Rocks & Minerals*, Vol. 61, No. 4, 1986, pp. 203–209.

The gem and mineral collector can make his field trips much more rewarding by finding reference to locations that have already produced the minerals that interest him. Here Titamgim discusses how to research localities through the literature. An annotated bibliography of publications that describe gem and mineral localities in the United States and Canada (listed by state or province in addition to general references) is the focal point of the article. Many of these publications in turn include bibliographies that will provide additional sources of information. *Barton C. Curren*

Locating gem deposits by computer. M. O'Donoghue, *Journal of Gemmology*, Vol. 20, No. 2, 1986, pp. 87–90.

O'Donoghue presents an excellent introduction on how computer-searchable databases can aid the gemologist in locating gem-locality information. He begins with a review of the printed sources of information on gem deposits, commenting briefly on geologic maps. Then he turns his attention to strategies for computer searches in two earth science bibliographic databases: *GEOREF* and *GEOARCHIVE*.

Performing computer searches is like mastering a new language, with a new vocabulary to learn and new rules to follow. O'Donoghue points out some of the most essential of these rules, including spelling, truncation, and Boolean logic, as he discusses specific gem localities such as the ruby mines in Mogok, Burma. By carefully studying this article, the reader can learn some of the difficulties encountered in doing computer searches.

O'Donoghue concludes his article with two of the most challenging variables, geographical coordinates and chemical data. It is important to emphasize a caution the author touches on early in the article: Databases can be expensive to use. To avoid unnecessary costs, one must be well prepared before beginning a computer search. A good way to begin is to ask a librarian trained in database searching for assistance. *DMD*

Peridotites from the Island of Zabargad (St. John), Red Sea: petrology and geochemistry. E. Bonatti, G. Ottonello, P. R. Hamlyn, *Journal of Geophysical Research*, Vol. 91, No. B1, 1986, pp. 559–631.

The small island of Zabargad, in the Red Sea, has long been known as a source of gem-quality olivine, or peridot, which occurs in mantle-derived rock known as peridotite. Despite the historic notoriety of this island, there have been few detailed studies of its geology. This article presents results of a recent detailed study of the Zabargad peridotites that was undertaken to document their geologic features and establish their origin.

Bodies of peridotites crop out at several locations on the island. The peridotites can be divided into three groups: (1) a spinel lherzolite containing olivine, orthopyroxene, clinopyroxene, and spinel; (2) amphibole peridotites, with some magnesiohornblende in addition to the group of minerals mentioned above; and (3) plagioclase peridotites that contain plagioclase along with the other four minerals. Detailed mineralogic and geochemical data are presented for each rock type. All three rock types were derived from peridotitic melts that originated in the upper mantle at depths of approximately 30 km. The melts were probably emplaced from the upper mantle into the crust during the development of the Red Sea rift zone, in post-Mesozoic time.

Gem-quality olivine crystals are usually found in sizes up to 1 cm, although larger pieces have been mined. They are principally found in one area on the south side of the island, near a major fault along which a zone of alteration of the peridotite has developed. These gemmy crystals appear not to have been formed by the same process of melt crystallization that resulted in the formation of olivine and other minerals of the peridotite. Rather, the gem olivines probably crystallized as a result of the reaction of a volatile-rich hydrothermal fluid and the already crystallized peridotite. These reactions are thought to have taken place at temperatures in excess of 500°C but at relatively low pressure. *JES*

INSTRUMENTS AND TECHNIQUES

New developments in spectroscopic methods for detecting artificially coloured diamonds. G. S. Woods and A. T. Collins, *Journal of Gemmology*, Vol. 20, No. 2, 1986, pp. 75–82.

In this article on the separation of natural from treated (i.e., irradiated and heated) yellow diamonds, the authors describe the importance of sophisticated equipment. They focus on the UV-spectrophotometer (which provides a graph of the spectra), coupled with a cryogenic unit to cool the diamond and sharpen absorption bands, as well as an infrared spectrometer. We now know that the 595-nm absorption line ("5920"), once thought to be characteristic of treated stones, is destroyed when the diamond is heated at about 1000°C; as a consequence, some treated yellow stones do not show this band.

Woods and Collins present the various causes of the yellow color in diamonds, as they describe the effect of radiation damage and annealing. New criteria for the identification of treated yellow diamonds are proposed on the basis of sharp infrared absorption bands that appear after a diamond has been both irradiated and annealed: the H_{1b} and H_{1c} lines (at 2024 and 1935 nm, respectively). These lines may be eliminated by heating the stone to 1400°C, but the result is a very unattractive green color and graphitization of the inclusions.

In general, a treated stone should exhibit either the 595-nm line or the H_{1b} and H_{1c} lines. The presence and intensity of other bands (H_3, H_4, 1450 cm^{-1}) may help confirm the diagnosis. With such criteria, no treated yellow diamond should be mistaken as naturally colored. However, a yellow diamond that the late Basil Anderson had purchased before 1950, and which he was certain was natural, exhibits the features of an irradiated and annealed stone. Consequently, the authors conclude that a natural color yellow diamond could very rarely be classified as treated. *EF*

JEWELRY ARTS

Goldsmithing for profit. A. Revere, *Jewelers' Circular-Keystone*, Vol. 156, No. 13, 1985, pp. 120–124.

The title of this article is somewhat misleading, since it does not reveal money-making techniques for established goldsmiths. It does, however, contain step-by-step instructions for making two pieces of jewelry as outlined by Alan Revere, instructor at the Revere Academy of Jewelry Arts in San Francisco, California.

The first project instructs beginning goldsmiths on how to make a pearl ring, covering the basics of sawing and filing, as well as measuring, soldering, and finishing. The second project, a cylinder box clasp, requires a more advanced expertise in these techniques. Both projects are accompanied by helpful photos and notes. *SAT*

Indian antiquity. P. Francis, Jr., *Lapidary Journal*, Vol. 39, No. 12, 1986, pp. 45–55.

Although this article contains a plethora of information about Indian amethyst and citrine (including folklore, geology, trade between India and Rome, and heat treatment), it is primarily focused on the ancient lapidary centers of Kotalingala and Arikamedu. Much of the information is based on recent archaeological excavations of the sites.

Kotalingala, located on the Godavari River in central India, thrived from the fifth to the first century B.C. Although Kotalingala was a major regional trade city and was known for its amethyst and agate beads, it does not appear that the beads produced there were traded out of the country. The lapidaries in this city made only relatively simple round, cylindrical, or barrel-shaped beads. Careful excavation of a Kotalingala lapidary shop revealed that it was a small operation that required only

four basic tools, and probably employed only one or two workers. Since very little citrine has been recovered from this site, experts believe that Kotalingala lapidaries did not know how to heat treat amethyst to create citrine.

In contrast, the slightly more recent city of Arikamedu, located on India's southeast coast, was much more involved in foreign trade, especially with the Romans. This city boasted several different lapidary shops, which produced a dazzling array of both glass and stone beads. The Arikamedu lapidaries were far more advanced technologically than those of Kotalingala, as revealed by their extremely fine, uniformly shaped beads, pierced with diamond-tipped drills. The great number of citrine fragments recovered from the Arikamedu lapidary shops indicates that these lapidaries may have been skilled at creating citrine from amethyst.

SAT

JEWELRY RETAILING

The refashioning of Zale. S. Jensen, D. Federman, and J. Thompson, *Modern Jeweler*, Vol. 85, No. 7, 1986, pp. 100–123.

Zale Corporation has undergone enormous changes during the past two years, and three *Modern Jeweler* editors spent a week interviewing company officials and former employees to find out why. This special report delves into Zale's new corporate strategy, their new breed of executives, and the upscale Bailey Banks & Biddle division. Also included are interviews with Zale Chairman Donald Zale and President Bruce Lipshy, and a synopsis of Peoples Jewelers' attempt to overthrow the megaretailer. Although much of it is repetitious, this 23-page article does reveal the relentless, unified force behind "the golden arches of the jewelry industry."

In 1984, Zale's merchandising changed from bridal diamonds to a wider fashion image that includes gold, pearls, and colored stone jewelry. On the basis of what Zale claims to be voluminous market research, the company is now driven by marketing rather than manufacturing considerations. To a man (there appear to be no female top executives), the new generation at Zale's believes that today's target consumer is the fashion-conscious American working woman who now has the financial and emotional power to deck herself out. According to Zale's stats, these "jewelry junkies" are primarily interested in style, beauty, and price rather than consumer knowledge, and have little loyalty to any particular jewelry store. Interestingly, this philosophy conflicts with that voiced by seven women interviewed by S. Jensen in the May 1986 issue of *Modern Jeweler*, all of whom were unanimous in their quest for product knowledge and in their loyalty to a trusted, proven jeweler.

Ultimately, only time—and profits—will tell if Zale's "ready-aim-fire" mentality is really on target. *SAT*

Sophisticated ladies—what seven smart jewelry shoppers really think about you. S. Jensen, *Modern Jeweler*, Vol. 85, No. 5, 1986, pp. 37-43.

This article is an interview with a panel of seven women who frequently purchase fine jewelry from retail outlets. They express their likes, dislikes, and what, if possible, they would change in retail operations.

These women have a strong desire to be educated by their jeweler about the jewelry and gemstones they purchase. They are discouraged by quiet showrooms with high-pressure sales personnel, preferring to be greeted and left to browse and ask questions at their leisure. The panel expects certain services from their jeweler such as the cleaning and inspection of their jewelry. They expect problems to be brought to their attention before they turn their jewelry in for repair or cleaning. A store that employs an imaginative designer who can accurately sketch and describe the finished piece of jewelry is also important. They are not opposed to purchasing gold and silver from discount stores, but they prefer to purchase gemstones from their established jewelers. All are put off by advertising that insults their intelligence.

This article presents excellent insights into the desires and expectations of some important customers. Catering to the needs of these customers will lead to increased popularity and, more importantly, increased sales. *Barton C. Curen*

SYNTHETICS AND SIMULANTS

Natürliche kobaltblau Spinelle von Ratnapura, Sri Lanka (Natural cobalt blue spinel from Ratnapura, Sri Lanka). H. Harder, *Neues Jahrbuch für Mineralogie Monatshefte*, No. 3, 1986, pp. 97–100.

This article compares the chemical and gemological properties of a set of Verneuil synthetic colbalt-colored blue spinels with one natural cobalt-colored blue spinel. The color in the synthetic stones is caused by cobalt (up to 0.02%) or by a mixture of cobalt with chromium (0.003%), vanadium (0.001%), and titanium (0.013%). Verneuil synthetics almost always contain more aluminum than natural stones contain, and show no detectable gallium. Their refractive index range is higher (1.719–1.730) than that of natural spinel (1.715–1.720), as is the specific gravity (3.63–3.64 vs. 3.58–3.61). Irregular color zoning and strong ultraviolet fluorescence in the synthetic stones can be considered as complementary identification criteria.

Natural cobalt-colored blue spinel has been found in the Paradise mining area of Sabaragamuwa Province, in the Ratnapura District, Sri Lanka. The author examined a 1.22-ct rough crystal. It showed an absorption between 535 and 600 nm—like the Verneuil synthetics but weaker—and a strong red fluorescence near 720 nm; so, those optical criteria could not be used for identification. But some unspecified inclusions in a cleavage leave

no doubt about the natural origin of the stone. X-ray fluorescence revealed an extremely high cobalt concentration (0.09%) as well as 0.29% iron, and 0.01% gallium (which are almost always under the detection limits in synthetics) together with 0.025% chromium and 0.035% vanadium.

As a conclusion, the author recommends the use of refractive index and inclusions to distinguish between natural and synthetic spinels. Surprisingly, this study does not refer to any literature, even to the well-documented paper by J. E. Shigley and C. M. Stockton (*Gems & Gemology*, Spring 1984, pp. 34–41), which focused on the same subject. *EF*

On the problems of using the gallium content as a means of distinction between natural and synthetic gemstones. H. Schrader and U. Henn, *Journal of Gemmology*, Vol. 20, No. 2, 1986, pp. 108–113.
Recent investigations of trace elements in gemstones have led to claims that gallium content can be used as a means to distinguish natural from synthetic gemstones. The results obtained by the authors of this article through neutron activation analysis of natural and synthetic emeralds, corundums, and chrysoberyls reveal that the guidelines set by previous researchers are inadequate. The ranges of gallium content for natural and synthetic emeralds and corundums overlap considerably, while those of chrysoberyls are close enough to overlapping that they warrant extreme caution.

The authors also review the nondestructive techniques available for trace element determination as well as the advantages and drawbacks of each. It becomes readily apparent that such methods are far from becoming standard gemological techniques. The article concludes with a warning against reliance on gallium content for determination of origin and a proposal for further research in this area. *CMS*

Opticon! O, Opticon! B. Jones, *Rock and Gem*, Vol. 16, No. 7, 1986, pp. 60–61.
Opticon is the registered trademark for a prepolymer plastic resin produced by Hughes Associates of Excelsior, Minnesota. This resin is being promoted as filler for mineral specimens and gemstones that have cracks or cavities which extend to their surfaces. Opticon has a refractive index of 1.545, which is very close to that of quartz (1.544–1.553). Cracks or cavities within stones of a similar R. I. will virtually disappear when penetrated by this resin. Quartz gems, such as amethyst and citrine, members of the beryl group, such as aquamarine and emerald, as well as iolite and the feldspar group lend themselves very well to this treatment.

If a gem is suspected of being treated with Opticon, it can be tested with a hot point, which will melt the resin filler and have no effect on the gemstone itself. *Barton C. Curren*

Synthesis and characterization of tourmaline in the system $Na_2O-Al_2O_3-SiO_2-B_2O_3-H_2O$. P. E. Rosenberg, F. F. Foit, Jr., and V. Ekambaram, *American Mineralogist*, Vol. 71, No. 7/8, 1986, pp. 971–976.
A generalized ideal chemical formula for the tourmaline mineral group can be written $XY_3Z_6B_3Si_6(O, OH)_{30}(OH, F)$. In this formula, 'X', 'Y', and 'Z' represent sites of different size and geometry in the tourmaline crystal structure where various cations are located. In the case where $X = Na^+$ and $Z = Al^{3+}$, there are the four tourmalines: elbaite $(Y = Al^{3+} + Li^+)$, schorl $(Y = Fe^{2+})$, dravite $(Y = Mg^{2+})$, and buergerite $(Y = Fe^{3+})$. The authors of this article describe the laboratory synthesis of a similar Na-Al tourmaline whose composition approaches that of $(Y = Al^{3+})$. The tourmaline formed by melt crystallization in tiny, acicular crystals up to 200 micrometers in length. Refractive indices are epsilon = 1.639 and omega = 1.642. The chemical and physical properties of these crystals are similar to those of elbaite and dravite. The results reported in this article demonstrate the progress that has been made in the laboratory toward synthesizing minerals with complex chemistry. *JES*

Synthetic diamond as a pressure generator. A. Onodera, K. Furuno, and S. Yazu, *Science*, Vol. 232, No. 4756, 1986, pp. 1419–1420.
Synthetic diamonds have recently become available in suitable size (approxiately 1 ct) and quality for use as opposed anvils to generate high static pressure (up to 680 kilobars). These stones have been grown by Sumitomo Electric Industries in Japan. They are type Ib diamonds, containing singly substituting nitrogen, and therefore have a deep yellow color. The nitrogen concentration ranges from 30 to 60 ppm, as determined with the IR absorption at 1130 cm^{-1}. An X-ray topography study suggests that they have very few extended defects. The authors claim the following advantages for the use of synthetic diamonds in high-pressure experiments: (1) extended defects are fewer and can be controlled, (2) the concentration of nitrogen can be monitored to improve the strength, (3) the pressure-temperature conditions for preparing diamond crystals can be determined, and (4) suitable crystals can be obtained repeatedly. (However, the authors do not say that the growth experiment is reproducible).

Interestingly, the fracture mode of these synthetic diamonds is very different from that of natural diamonds. The cracks remain very shallow instead of leading to spalling or vertical fractures. The hardness, determined by indentation ("deformation" hardness), depends very little on the orientation, in contrast to natural diamond, which is anisotropic.

Although this article does not provide information on current production and price, it does give very interesting technical insights on the quality of Japanese synthetic diamonds. *EF*

GEM NEWS

John I. Koivula, *Editor*
Elise Misiorowski, *Contributing Editor*

COLORED STONES

Green-fluorescing emerald from Coscuez. An unusual emerald crystal from Coscuez, Colombia, was brought to us by Mr. Ron Ringsrud for examination. The report that follows was prepared by Dr. Emmanuel Fritsch, a GIA research scientist.

The crystal, about 1.5 cm long and 0.8 cm in diameter, weighs 7.94 ct. Its refractive indices (1.578 and 1.585) and specific gravity (2.72 by the hydrostatic method) are typical of material from Colombia (see *Gems & Gemology*, Summer 1986, pp. 67–79, for an in-depth article on Coscuez emeralds). The optical absorption spectrum is characteristic of that of emerald, with chromium lines around 680 nm visible with a hand spectroscope, although some features strongly suggest the presence of vanadium (Carol Stockton, pers. comm.). The specimen's external structure is the result of parallel intergrowth of a bundle of smaller (1–5 mm in diameter) crystals. Strong color zoning can be seen both parallel and perpendicular to the optic axis. The color decreases from one end (dark green) to the other (colorless) of the crystal; when viewed down the optic axis, the stone reveals a slightly yellowish green core about 5 mm in diameter surrounded by a darker rim of the same hue.

The most interesting phenomenon, though, is the weak green fluorescence of the emerald when exposed to long-wave ultraviolet radiation (also very weakly visible with short-wave U.V. radiation). Microscopy revealed that the fluorescence was not concentrated in cracks and so could not be related to the presence of oil. Moreover, the intensity of the fluorescence clearly correlates with the intensity of the green coloration. The emission spectrum resolved on an AMINCO SPF-500 fluorescence spectrometer revealed a band at 467 nm and a very broad band centered around 510 nm, probably responsible for the green hue. Further work would be required to determine the cause of the emission.

New source of gem garnets from Idaho. Mr. Leon M. Agee, of Walla Walla, Washington, recently identified and faceted a number of deep brownish red gem-quality garnets that had been found by Mr. Kim Boyd in Clearwater County, Idaho. A reader of Gem News, Mr. Agee sent one of the garnets to the editor to examine. Shown in figure 1, the round brilliant-cut garnet measures 13.17 × 8.20 mm and weighs 11.06 ct. The

Figure 1. This 11.06-ct almandine-spessartine garnet was recently found in Clearwater County, Idaho. Photo © Tino Hammid.

gemological properties of this material suggest that it should be classified as an almandine-spessartine garnet. When the stone was studied with the hand spectroscope, a strong 432.0-nm band that could be attributed to the manganese in spessartine was observed, together with absorption characteristics typical of almandine. The refractive index was over the limits (1.81) of the refractometer, and the hydrostatically determined specific gravity was approximately 4.13. Examination with the microscope revealed a partially healed fracture composed of numerous tiny two-phase fluid inclusions, suggesting a possible pegmatitic origin.

We do not know how much of this garnet is available, but we do know that the area is currently being prospected. It is interesting to note that Mr. Boyd found the garnets while he was placer mining for gold.

Pectolite. Dr. Emmanuel Fritsch also supplied the following information on blue pectolite to Gem News.

Pectolite, known under the trade name "Larimar," is commonly found at gem shows as attractive greenish blue cabochons with flower-like radiating patterns. "Larimar" is the juxtaposition of "Lari," the name of the daughter of the mine's developer, Miguel Mendez, and "mar," which means "sea" in Spanish (Dan MacAuley, pers. comm.) in reference to the stone's color. No information on the geologic setting of the mine is available. However, research is currently being conducted on the origin of the color. Work at GIA's Research Department demonstrates that the optical absorption spectrum of pectolite is very similar to that of turquoise, with a broad absorption band at about 650 nm, in the orangy red. This band is interpreted as being due to the copper ion Cu^{2+} in octahedral coordination. Further evidence of the presence of copper in this gem came from a study of the black metallic inclusions in a piece of pectolite donated to GIA by Helen Tillet, of St. Thomas, U.S. Virgin Islands. X-ray powder diffraction, performed by Chuck Fryer, identified these inclusions as chalcocite (Cu_2S).

Phosphorescent fake. Ms. Loreen Haas, of Crown Gems in Sherman Oaks, California, was kind enough to send Gem News three unusual colorless quartz crystals. The smallest of these, shown in figure 2, measured 18.1 × 10.1 × 7.3 mm, while the largest was recorded at 26.0 × 14.2 × 12.2 mm. All three of the crystals had been core-drilled from the base and their centers filled with a mixture of phosphorescent powder and epoxy resin. The bases had then been capped with yellow metal bell caps so that the crystals could be worn in an inverted position as pendants. Any light source could excite the powder filling to phosphoresce blue-green (figure 3), so that if the

crystals were brought into a dimly lit or dark room they would be observed to glow.

The crystals were originally purchased (for a rather large sum) as natural glow-in-the-dark quartz crystals. Apparently, some sort of occult power was attributed to them. When the purchaser brought them to Ms. Haas for study, she became suspicious and so contacted Gem News. This is a totally new treatment to us. Unfortunately, we were not able to determine how much of this material is being manufactured and sold at the present time.

Undesirable color change in blue zircon. Ms. Janice Mack Talcott, of Talcott Enterprises, Inc., in Olympia, Washington, phoned the Gem News editor to ask if he or his colleagues had ever heard of color instability in blue zircon. One of the company's clients had worn a fine blue zircon ring in a tanning booth for about 20 minutes. When she emerged, she noticed that the stone had turned a muddy grayish greenish brown, apparently as a result of the exposure to ultraviolet rays.

We had never heard of such a change and could find no mention of it in the available literature. Therefore, we decided to see if we could duplicate the color change and also whether the change could be reversed.

Two faceted blue zircons of the same dark color were selected. One was exposed to long-wave ultraviolet radiation for 20 minutes, while the other was kept as a color control. The color change was dramatic: from bright blue through a light grayish brown (figure 4) to a muddy grayish greenish brown.

To reverse the change, we placed the muddy grayish greenish brown zircon on the tip of an upright 80-watt quartz halogen–powered fiber-optic illuminator. After two hours of exposure to this incandescent light, the stone had completely returned to its original blue color.

Figure 2. This colorless quartz crystal (18.1 × 10.1 × 7.3 mm) was core-drilled and filled with phosphorescent powder and epoxy resin. The piece was then capped to form a pendant.

Figure 3. After it was exposed to light, the filled quartz crystal shown in figure 2 glowed blue-green when placed in a dimly lit room.
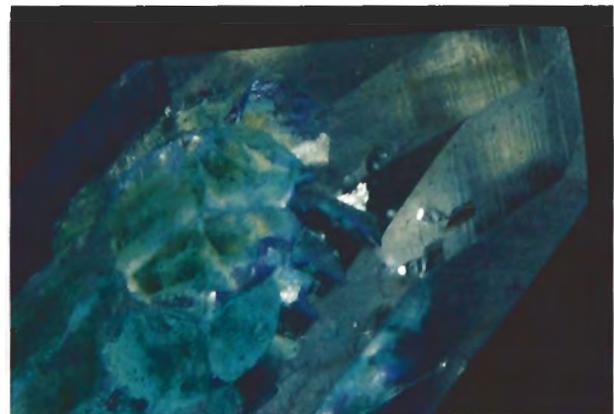
Figure 4. The grayish brown zircon on the right was the same color as the blue zircon on the left before it was exposed to long-wave ultraviolet radiation for 20 minutes. Note the radical color change. The most intense color obtained by this process—a muddy brown—was impossible to photograph because the lights required caused the stone to gradually revert back to its original color. Photo © Tino Hammid.

Exposure of the blue zircon to short-wave ultraviolet radiation also produced the same color change from blue to brown, and again the fiber-optic illuminator restored the original blue color.

Mr. Richard Hug of Cincinnati, Ohio, recently observed a similar color change in a blue zircon worn in a tanning booth. He reported that the zircon regained its original blue color after it had been placed on top of an ordinary light bulb for a couple of hours.

SYNTHETICS

Small, cuttable gem-quality synthetic diamonds: a reality. In the Spring 1985 Gem News column, we reported that Sumitomo Electric Industries and the National Institute for Research on Inorganic Materials, both in Japan, had succeeded in experimentally growing cuttable gem-quality synthetic diamond crystals as large as 1 cm and weighing up to 3.5 ct. We have now seen 10 pieces of synthetic diamond that were grown more recently by Sumitomo and are now being sold for industrial applications. These pieces are the property of Hughes Research Laboratory in Malibu, California, and were brought to the GIA Research Department for testing with the department's new infrared spectrometer. These fashioned pieces had been sawn, then laser cut, and then partly polished from the original crystals (which weighed up to 1.2 ct) into rectangular shapes weighing up to 0.40 ct and measuring approximately 4 × 4 × 2 mm.

Direct contact with Sumitomo's U.S. representative provided us with additional information on their product. On the basis of the infrared spectra, all of the synthetic diamond pieces are type Ib (dispersed nitrogen), which is intrinsically yellow and is often referred to in the trade as a "canary" color. This observation of diamond type immediately distinguishes the Sumitomo diamonds from the vast majority of natural yellow diamonds, which are type Ia. The synthetic diamonds are primarily being made for two industrial applications: heat sinks in electrical devices (Sumitomo's primary market for synthetic single-crystal diamonds), and industrial and surgical tools. The price range is $60 to $145 per rectangular piece for various sizes up to 0.40 ct. Sumitomo's representative also stated that they currently market the rectangular pieces only for scientific and industrial uses, and they do not intend to release any of the rough crystals. In addition, the company is currently experimenting with synthetic blue diamonds (type IIb) for use as semiconductors, and with synthetic colorless diamonds (type IIa) for industrial applications.

Because of the implications for the jewelry trade of this new technology, the GIA Research Department is currently documenting the gemological properties of the Sumitomo synthetic diamonds. The Sumitomo Company has been very cooperative in providing both samples of the synthetic diamonds and technical information. GIA Research purchased seven pieces of syn-

thetic diamond. Each had two large polished surfaces and various smaller crystal faces around the edges. They ranged from 0.11 to 0.37 ct. The largest piece measured 3.76 × 3.63 × 1.78 mm. This piece was subsequently cut for maximum weight retention in an attractive faceted stone. The resulting 0.16-ct square-step-cut stone measures approximately 3.48 × 3.33 × 1.73 mm, with a depth percentage of 52% and a weight retention of 44%. Considering the cost of the original piece of rough ($145) and the assumed cutting cost, the price per carat of this synthetic diamond would be equal to or exceed the price of a natural diamond of similar hue and clarity.

On the basis of a preliminary gemological examination, GIA Research has determined that the Sumitomo synthetic diamonds have some distinctive properties that aid in their identification. Because they are type Ib, they lack the sharp "Cape" lines in the absorption spectrum that are characteristic of type Ia diamonds. The Sumitomo synthetic diamonds are also unusual in their fluorescence behavior in that they are inert to long-wave ultraviolet radiation but fluoresce a greenish yellow to short-wave ultraviolet radiation. In color, the Sumitomo synthetic diamonds correspond to a fancy intense yellow. The pieces are often color zoned from deep yellow in the center to a narrow zone that is very pale yellow or colorless around the edges. The synthetic diamonds may display prominent internal grain lines and a "cruciform" strain pattern when observed between crossed polarizers. When the stones are viewed with the microscope, tiny metallic inclusions or white pinpoint inclusions may be observed. In addition, within the areas of deep yellow color, small colorless "vein-like" areas are visible. These features in combination are quite different from those found in natural diamonds of the same hue. The GIA Research Department is preparing a complete report on the Sumitomo synthetic diamonds for publication in *Gems & Gemology* in the near future. For further information, contact Dr. James Shigley, (213) 829-2991, extension 305.

ANNOUNCEMENTS

Fashion Institute of Technology presents "20th Century Design, International." This symposium will take place in New York on Saturday, November 15, 1986, and will feature world-renowned authorities on antique and 20th-century jewelry, including: Noelle De Gary, curator of the Musée des Arts Décoratifs; Fritz Falk, director of the Pforzheim Museum; Peter Hinks, of Sotheby Parke Bernet; and Graham Hughes, past director of Goldsmiths' Hall. For further information, contact the symposium coordinator, Jean Appleton, Jewelry Design Resource, (212) 760-7254.

Iberjoya will be held January 15–20 at the Ifema Exhibiton Center in Madrid. Contact: Institución Ferial de Madrid, Avenida de Portugal s/n, 28011 Madrid, Spain. Telex: 44025 IFEMA E.

Vicenzaoro 1 will be held January 15–22 at the Trade Fair Pavillions in Vicenza. Contact: Ente Fiera de Vicenza, Viale degli Scaligeri 34, 36100 Vicenza, Italy. Telex: 481542 FIER VII.

Jewelers International Showcase will be held January 17–19 at the Miami Beach Convention Center. Contact: Jewelers International Showcase Inc., 9835 Sunset Drive, Suite 208, Miami, FL 33173; (305) 279-0951.

BIJORHCA will be held January 30–February 3 at the Parc des Expositions, Villepinte, Paris. Contact: BIJORHCA, 26 Rue de Renard, 75004 Paris, France. Telex: 680377 BOCIF.

The 1987 Tucson Gem and Mineral Show will be held February 12–15 at the Tucson Community Center. The featured species for the show this year is quartz. For more information, contact the Tucson Gem and Mineral Society, P.O. Box 42543, Tucson, AZ 85733.

Also in Tucson, February 7–12, the American Gem Trade Association (AGTA) show will be held at the Doubletree Hotel. During that time, the winners of the Spectrum Award (a jewelry design contest specifically aimed at the effective use of colored stones) will be announced. The deadline for entries is November 4, 1986. For more information about the contest, contact the AGTA headquarters at the World Trade Center #181, P.O. Box 581043, Dallas, TX 75258, (214) 724-4367.

Numerous other shows are held at various hotels and motels in Tucson (e.g., the Holiday Inn Broadway, the Quality Inn, the Desert Inn, and the Santa Rita) during this same period.

INHORGENTA 87 will be held February 13–17 at the Trade Fair Centre in Munich, West Germany. Contact: Munchener Messe-und Ausstellungsgesellschaft mbH, Messegelande, Postfach 121009, D-8000 Munchen 12, West Germany. Telex: 5212086 AMEG D.

International Watch, Clock and Jewellery Fair will be held February 14–17 at the Centrepoint Exhibition, Centre Sydney. Contact: World Trade Promotions Pty. Ltd., 144 Riley Street, East Sydney, New South Wales, Australia. Telex: AA 176428 FSASYD.

Platinum Jewellery Fair 87 will be held February 16–17 at the Imperial Hotel, Tokyo, and on February 20 at the Hilton Hotel in Osaka. Contact: Platinum Guild International K.K., Imperial Tower 13A, 1-1-1 Uchisaiwai-cho, Chiyoda-ku, Tokyo 100, Japan. Telex: J29817 PGIKKJ.