

Gems & Gemology

VOLUME XXIV

SPRING 1988



The quarterly journal of the Gemological Institute of America

Gems & Gemology

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Gems & Gemology is published quarterly by the Gemological Institute of America, a nonprofit educational organization for the jewelry industry, 1660 Stewart St., Santa Monica, CA 90404.

Postmaster: Return undeliverable copies of *Gems & Gemology* to 1660 Stewart St., Santa Monica, CA 90404.

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Gems & Gemology

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ABOUT THE COVER: This 175-ct sapphire is exceptional for both its color and its size. The blue color is the result of $Fe^{2+} \rightarrow Ti^{2+}$ intervalence charge transfer, one of the color-causing mechanisms discussed in the second article of a three-part series on color in gemstones. In this issue, Drs. Fritsch and Rossman review causes of color that involve more than one atom, as well as those brought about by various defects. The sapphire pendant, set with 17 ct of diamonds and suspended from a necklace of 8–8.5 mm cultured pearls, is courtesy of Roger Farr—Park/Allbritton. Photo © Harold & Erica Van Pelt—Photographers, Los Angeles, CA.

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.

RETROSPECTIVE 1987

Undeniably, 1987 was yet another watershed year in gemology. In diamonds, a 0.95-ct fancy purplish red round brilliant-cut sold for \$880,000—a record per-carat price of \$926,000. In synthetic diamonds, not only did the first Sumitomo gem-quality synthetic diamonds appear on the gem market, but De Beers released information revealing just how far their experiments with gem-quality synthetic diamonds had progressed; one such crystal tipped the scale at over 11 ct. Perhaps the biggest news in colored stones last year was the discovery of a major find of superb alexandrites near the town of Hematita in Minas Gerais, Brazil; in less than three months in 1987, more than 50 kg of gem-quality alexandrites were taken from this small deposit before it was closed because of the violence that ensued. As for synthetic colored stones, producers continue to proliferate and even materials such as malachite are no longer beyond our technical capabilities. To help in the continuing battle to identify new synthetics and gem treatments as soon as they emerge on the market, sophisticated technology such as infrared spectroscopy is now being applied to a wide variety of gemological problems.

All of these topics, and many others, were covered in the 1987 volume of *Gems & Gemology*. And a detailed description of the remarkable Hematita alexandrite find is provided in this issue. We are pleased that *Gems & Gemology* continues to be, in the words of one of our readers, "absolutely essential to anyone in the business of jewelry." We would like to thank the members of our editorial review board, our very special section and technical editors, and the photographers and graphic artists who are responsible for building this reputation.

THE GEMS & GEMOLOGY MOST VALUABLE ARTICLE AWARD

We are also pleased to have this opportunity to recognize some of the many authors who, in 1987, helped make *Gems & Gemology* such a vital information source. The overwhelming choice of our readers for first place in the most valuable article award is "Gemstone Durability: Design to Display," by Deborah Martin. The response to this article was so strong that GIA has now released a laminated version of the chart of durability considerations for 31 gem species. Second place goes to the first in a three-part series that seeks to explain, in terms that the jeweler/gemologist can readily understand, the causes of color in gem materials: "An Update on Color in Gems. Part 1: Introduction and Colors Caused by Dispersed Metal Ions," by Emmanuel Fritsch and George Rossman. The current importance of yellow sapphire and the questions regarding its color stability were evident in the selection of the third-place article: "The Seven Types of Yellow Sapphire and Their Stability to Light," by Kurt Nassau and G. Kay Valente. Cash prizes of \$500, \$300, and \$100, respectively, will be shared by the authors of the first-, second-, and third-place articles. Brief biographies of the winning authors appear on the following page.

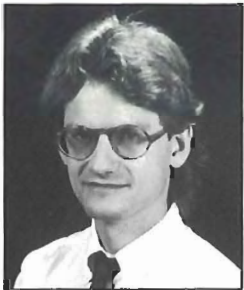
Alice S. Keller, Editor

THE WINNERS



DEBORAH DUPONT MARTIN

Ms. Martin began her jewelry career in retail sales and management, but quickly realized that her real interest was design and manufacturing. After several years as a bench jeweler, her love of gemstones brought her to the Gemological Institute of America, Santa Monica, where she received her Graduate Gemologist degree and subsequently taught in the Colored Stones/Gem Identification Department of the Resident Program. A native of Oklahoma, Ms. Martin is currently a staff gemologist with the GIA Gem Trade Laboratory, Inc., Los Angeles.



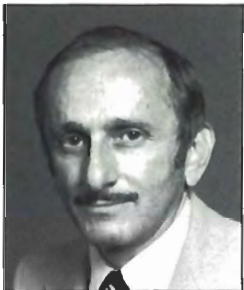
EMMANUEL FRITSCH

Dr. Fritsch studied engineering geology in Nancy, in eastern France, before moving to Paris, where he received his Ph.D. at the Sorbonne. He is currently a research scientist at GIA Santa Monica. A gemstone enthusiast for many years, Dr. Fritsch's research specialties are twinned crystals and the origin of color in gem materials.



GEORGE R. ROSSMAN

Dr. Rossman received his B.Sc. degree from Wisconsin State University, Eau Clair, and his Ph.D. (in chemistry) from the California Institute of Technology, Pasadena, where he is now professor of mineralogy. His current research studies involve the origin of color phenomena in minerals and the physical and chemical properties of minerals. He is also investigating how long-term natural background radiation can affect minerals.



KURT NASSAU

Dr. Nassau's work at the Materials Laboratory of AT&T Bell Laboratories includes active involvement in research on crystal growth and the chemistry of solid-state materials. Currently, Dr. Nassau is studying quenched and conventional glasses and crystals for electronic and fiber-optic applications as well as high-temperature superconductors. In addition to being a prolific writer (he has authored three books and over 330 articles as well as 15 patents), he belongs to several professional societies and serves on the board of governors of GIA. Born in Austria, Dr. Nassau received his B.Sc. from the University of Bristol, England, and his Ph.D. (in physical chemistry) from the University of Pittsburgh, Pennsylvania.



G. KAY VALENTE

Ms. Valente is currently vice-president of the American Gem Market System and directs their laboratory services. Ms. Valente has eight years of experience in color technology and its application to gems. A native of London, England, she received her education at the South West Essex Technical College.

AN UPDATE ON COLOR IN GEMS. PART 2: COLORS INVOLVING MULTIPLE ATOMS AND COLOR CENTERS

By Emmanuel Fritsch and George R. Rossman

This is the second part in a three-part series on the origin of color in gem materials. This article discusses colors produced by (1) processes that involve multiple atoms (e.g., blue sapphire, organic products), and (2) a variety of defect structures that are generally created by irradiation (natural or artificial), known collectively as "color centers" (e.g., green diamond).

In the first part of this series (Fritsch and Rossman, 1987), we reviewed how absorption of light by a dispersed metal ion such as chromium (Cr^{3+}) can produce color in a gem material such as ruby. However, color in gems is also commonly produced by a variety of processes that involve the combined presence of two or more ions (e.g., charge-transfer processes), or by irradiation sometimes combined with heating (the formation of a "color center"). In this article, we will describe and explain these mechanisms through a variety of examples, some of which are illustrated in figure 1. The reader who desires more information about the origin of color in gem materials will find the reviews by Nassau (1975), Loeffler and Burns (1976), Marfunin (1979), and Fritsch (1985) particularly helpful. It should be noted that in most cases, color-causing absorption bands are so broad that they cannot be well resolved with a hand spectroscope. If visible, they usually appear as a broad smudge or as a gradual darkening toward one end of the visible range.

PROCESSES INVOLVING MULTIPLE ATOMS

Charge Transfer: When an Electron Jumps from One Atom to Another. Color is caused by dispersed metal ions when electrons undergo transitions between atomic orbitals confined to a single ion (see part 1 of this series, Fritsch and Rossman, 1987). During this transition, the electrons never leave the central atom. There are, however, a number of different ways that electrons can jump from one atom to another. When this happens, spectacular colorations may result. One of these processes is called charge transfer because it can be described in simple terms as a mechanism that transfers a negative charge (i.e., an electron) from one atom to another.

When an Electron Visits Its Nearest Neighbor: Oxygen → Metal Charge Transfer. Heliodor, the golden variety of

ABOUT THE AUTHORS

Dr. Fritsch is research scientist at the Gemological Institute of America, Santa Monica, California. Dr. Rossman is professor of mineralogy at the California Institute of Technology, Pasadena, California.

Acknowledgments: E.F. wishes to thank Professor Georges Calas, of the University of Paris VII, for his help and encouragement in writing the original French version of this article. Special acknowledgment is given to Pat Gray for typing the manuscript and improving the translation. Particular appreciation is due to Laurel Bartlett and John Hummel for their constructive comments on this article. Jan Newell and Peter Johnston drew the line illustrations.

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Figure 1. Colors in gem materials can be caused by a number of different processes. This article concentrates on colors caused by processes involving multiple atoms and color centers. Examples of such colorations are illustrated here (see tables 1 and 2 for the specific origin of color for each stone). Clockwise, from top right: pink fluorite, violet scapolite, greenish yellow tourmaline, andalusite, amethyst, crocoite, citrine, and yellow fluorite, with blue kyanite in the center. Stones are from the GIA collection or courtesy of Pete Flusser, Overland Gems, Inc. Photo © Tino Hammid.

beryl (see figure 2), is colored by Fe^{3+} as it interacts with other atoms in the beryl structure. The transitions confined to the Fe^{3+} ion absorb in the blue and violet portion of the spectrum; they are very weak and make only a minor contribution to the color. The deep yellow of heliodor is caused mainly by an extremely strong absorption centered in the ultraviolet that extends into the blue end of the visible spectrum and absorbs violet and blue (Loeffler and Burns, 1976). This ultraviolet absorption is due not to Fe^{3+} alone but rather to an interaction between Fe^{3+} and its oxygen neighbors

in the beryl structure. The color results from light absorbed through the transfer of electrons from the oxygen ions to the iron ion. This color can also be induced artificially by the irradiation of blue beryl (see Fritsch and Rossman, 1987).

Usually oxygen \rightarrow metal charge-transfer absorptions are centered in the near ultraviolet and are broad enough to extend into the blue end of the visible spectrum, producing yellow to orange to brown colors. Their energy is fairly independent of the nature of the host mineral. The $\text{O}^{2-} \rightarrow \text{Fe}^{3+}$ absorption described above for beryl is found at

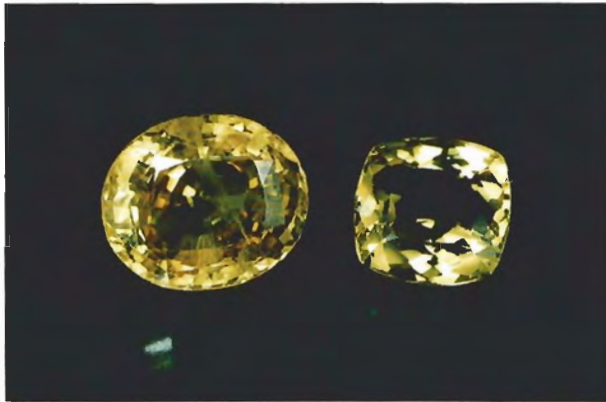


Figure 2. Some yellow sapphires (23.78 ct, left) and all golden beryls (heliodor, 9.94 ct, right) owe their color to $O^{2-} \rightarrow Fe^{3+}$ charge transfer. Photo by Shane McClure.

about the same energy – that is, the same region of the spectrum – in corundum (Tippins, 1970). Therefore, it contributes a similar strong yellow-orange color to sapphires, despite the fact that the details of the coordination environment are quite different for the isolated ion in these two minerals (in contrast, see Fritsch and Rossman, 1987, for the difference in color produced by chromium [Cr^{3+}] in beryl [emerald] and corundum [ruby]).

The center of the oxygen \rightarrow metal ion charge-transfer absorption band moves from the ultraviolet toward the visible region as the positive charge of the central metal ion increases. $O^{2-} \rightarrow Fe^{2+}$ charge transfer is centered well into the ultraviolet and has minimal effect on color, whereas $O^{2-} \rightarrow Fe^{3+}$ charge transfer is centered at the edge of the ultraviolet, and extends into the visible region, generally causing yellow to brown hues. Finally, $O^{2-} \rightarrow Fe^{4+}$ transitions absorb light in the middle of the visible region, giving amethyst, for example, its purple color (Cox, 1977).

Even ions that are not likely to generate color by themselves can do so with oxygen \rightarrow metal charge transfer. For instance, the chromate group ($Cr^{6+}O_4$) gives the mineral crocoite its bright orange-red color (see figure 1). The oxygen ions transfer some of their electrons to the chromium ion in such a way that transitions absorbing in the near ultraviolet and in part of the violet and blue are possible (Loeffler and Burns, 1976).

Transitions associated with a single metal ion have a much lower probability of occurring than do charge-transfer transitions. In the case of Fe^{3+} , the absorption resulting from one charge-transfer

transition is 100 to 1,000 times stronger than that resulting from an internal transition confined to the isolated ion (Mattson and Rossman, 1987a, 1987b). Consequently, charge-transfer colors are more intense than those caused by dispersed metal ions. Of course, the intensity of the color also depends on the extent to which the charge-transfer absorption occurs in the visible portion of the spectrum.

When an Electron Visits Its Next-Nearest Neighbor: Intervalence Charge Transfer. In some cases, an electron can travel further than one ion away, such that two metal ions separated by an oxygen atom can actually exchange electrons, too. This process can strongly influence the color of a gem. When such a transition takes place between two different oxidation states (e.g., Fe^{2+} and Fe^{3+}), it is called an intervalence charge-transfer (IVCT) transition.

Because of the natural abundance of iron, charge transfer is commonly observed between Fe^{2+} and Fe^{3+} . A popular gemstone colored by this type of IVCT is darker blue aquamarine, like the material from Coronel Murta (Brazil) and Tongafeno (Malagasy Republic). As we have seen already, the presence of Fe^{3+} induces the absorption of at least part of the violet, through $O^{2-} \rightarrow Fe^{3+}$ charge transfer. But when Fe^{2+} is also present in the adjacent site, the $Fe^{2+} \rightarrow Fe^{3+}$ IVCT strongly absorbs in the red end of the spectrum (Goldman et al., 1978). As the violet is already suppressed, this leaves a transmission window in the blue.

When there is much more Fe^{3+} than Fe^{2+} , the $O^{2-} \rightarrow Fe^{3+}$ charge transfer also absorbs part of the blue and results in a more greenish color. Heat treatment in a reducing atmosphere is used to change part of the Fe^{3+} to Fe^{2+} (Nassau, 1984). This moves the transmission window back into the blue, and produces a more saleable stone.

Intervalence charge transfers also occur between metal ions of different chemical elements. Such is the case for the $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer that gives sapphire its blue color (figure 3). The heat treatment of near-colorless "geuda" sapphires produces blue stones because naturally occurring inclusions of rutile and spinel in the corundum dissolve at high temperatures. Fe and Ti from the inclusions are released and, through random diffusion, form pairs of Fe^{2+} and Ti^{4+} ions which interact through $Fe^{2+} \rightarrow Ti^{4+}$ IVCT to yield the blue coloration (Harder and Schneider, 1986). The



Figure 3. The exceptional color of these sapphires is the result of $Fe^{2+} \rightarrow Ti^{4+}$ charge transfer. The largest stone weighs 48 ct. Photo courtesy of Sotheby's.

same charge transfer has been proposed as the origin of color in benitoite (Burns, 1970) and blue kyanite (Smith and Strens, 1976), although other band assignments are possible.

Charge transfer between Mn^{2+} and Ti^{4+} has been proposed to explain the greenish yellow color of some unusual Mn-rich tourmalines (Rossman and Mattson, 1986). This absorption, centered in the near ultraviolet, extends to about 500 nm, leaving a greenish yellow transmission.

An interesting feature of the intervalence charge transfer is its extreme directionality, which usually causes strong pleochroism. For example, the $Fe^{2+} \rightarrow Fe^{3+}$ IVCT coloration in aquamarine is best seen down the optic axis because of the orientation of the pairs of ions. This is why, to get the deepest possible color in aquamarine, the cutter often facets the table perpendicular to the optic axis. Even stronger pleochroism is observed in cordierite (iolite, figure 4), where the $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer takes place in a plane perpendicular to the c-axis (Faye et al., 1968; Smith and Strens, 1976). Another dramatic example of pleochroism associated with IVCT, lazulite, is explained in figure 5.

As one can appreciate from the former examples, charge-transfer processes generally create a strong pleochroism. To understand why the absorption is more intense in one direction than the other, it is necessary to know the exact location of the ions involved (see, e.g., figures 4 and 5). For many gem materials this is still under investigation.

Ion Pair Transitions. $Fe^{3+}-Fe^{3+}$ pair transitions are mentioned by Ferguson and Fielding (1971) to account for the color of some yellow sapphires. This type of cause of color has also been used to explain the hue of some red dravites (Mattson and Rossman, 1984), but the absorption is so efficient that any cut stone would be very dark. These absorptions are situated between 300 and 500 nm, where they absorb the blue end of the spectrum and generate yellow to red colors. In contrast to intervalence charge transfer, these are not single transitions involving only one electron: They arise from a transition that occurs simultaneously in both Fe^{3+} ions. In some cases, their energy is a sum of the energy of two isolated metal-ion transitions; this explains their relatively high-energy position (near-ultraviolet and blue end of the visible spectrum). It must be emphasized that such transitions are very strongly oriented along the $Fe^{3+}-O-Fe^{3+}$ bonds; as a result, they induce pleochroism. They are important in the heat treatment of sapphire. Whereas high-temperature treatment dissolves Fe and Ti to produce blue sapphire, treatment at less extreme temperatures can allow Fe^{3+} ions to diffuse together to form $Fe^{3+}-Fe^{3+}$ pairs which contribute to the color of some yellow sapphires.

Processes Not Involving Metal Ions. Although not commonly seen in gem materials, the colors of some minerals do not involve metal ions. A classic example is lazurite (the main component of lapis lazuli). This mineral contains sulphur atoms in its chemical formula. When the sulphur atoms are grouped in the form of the $(S_3)^-$ molecule, transitions among the atoms in this grouping produce the deep blue color (see Loeffler and Burns, 1976).

For organic gem materials, such as amber and pearls, delocalization of electrons is the most common cause of color (Nassau, 1975). Electrons can be delocalized (i.e., spread) over several atoms or over a whole molecule (a molecule is a group of atoms held together by chemical forces) through shared orbitals in which the electron travels. These

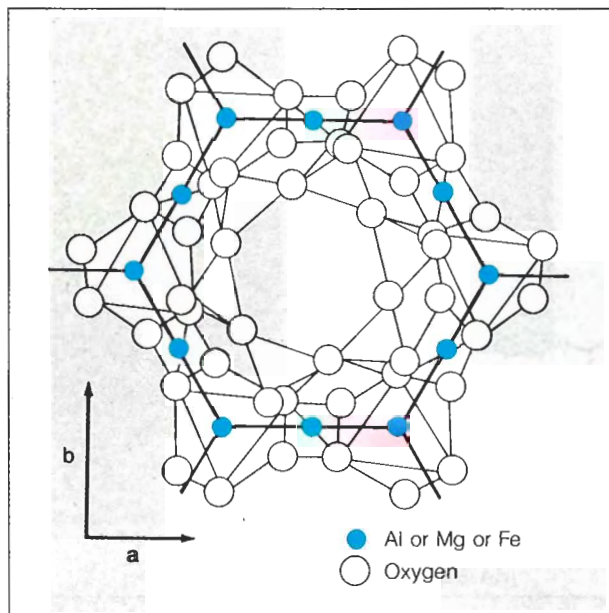
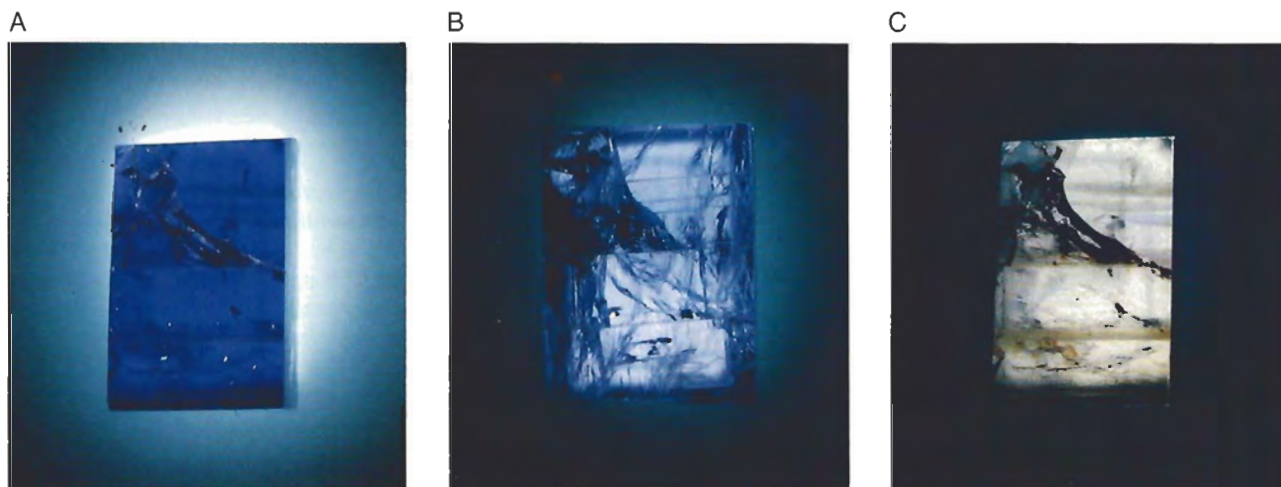


Figure 4. This diagram shows the structure of cordierite (iolite), viewed down the *c*-axis, as it relates to pleochroism. Iron ions substitute for Al or Mg atoms, so the intervalence charge transfer will occur in the three directions in which the Al and Mg atoms are aligned (heavy lines). One of those directions is strictly parallel to the *a*-axis, so light vibrating in this direction will be strongly absorbed, producing a very intense blue (A). Light vibrating in the other two directions will induce intervalence charge transfers at about 30° to the *b*-axis, thereby resulting in a lighter blue (B). There is no IVCT parallel to the *c*-axis (perpendicular to the plane of the figure), so no charge transfer for light vibrating in that direction is observed; the light yellow color is due to isolated Fe³⁺ (C). After Faye et al., 1968. The three different colors are easily seen on this specimen, photographed with light polarized parallel to the *a* (photo A), *b* (photo B) and *c* (photo C) axes, respectively. Photos by Shane McClure.



orbitals are called "molecular orbitals." Transitions can occur between molecular orbitals and absorb visible light, thereby causing color.

"Honey" to yellow tones of amber are the result of this delocalization (figure 6), as are the delicate pink to red colors of coral (figure 7) and some conch "pearls." The vast majority of the dyes used to enhance the color of gemstones also owe their effectiveness to molecular orbital transitions (Griffiths, 1981). Sometimes organic components give rise to a strong fluorescence, which provides a useful way of identifying foreign organic products such as some oil in emerald, dye in jadeite, and glues.

Various examples of charge-transfer colorations in gem materials are given in table 1. Again, one should remember that multiple coloring processes can occur simultaneously in a given gem material, and distinctly different processes can produce very similar colors. If the color of a particular stone is caused by dispersed metal ions, establishing the origin of color is usually a straightforward process. However, in cases where the origin of color involves charge transfer or, more generally, multiple atoms, it is often much more difficult to rigorously assess the cause of color, for a number of reasons explained by Mattson and Rossman (1987b).

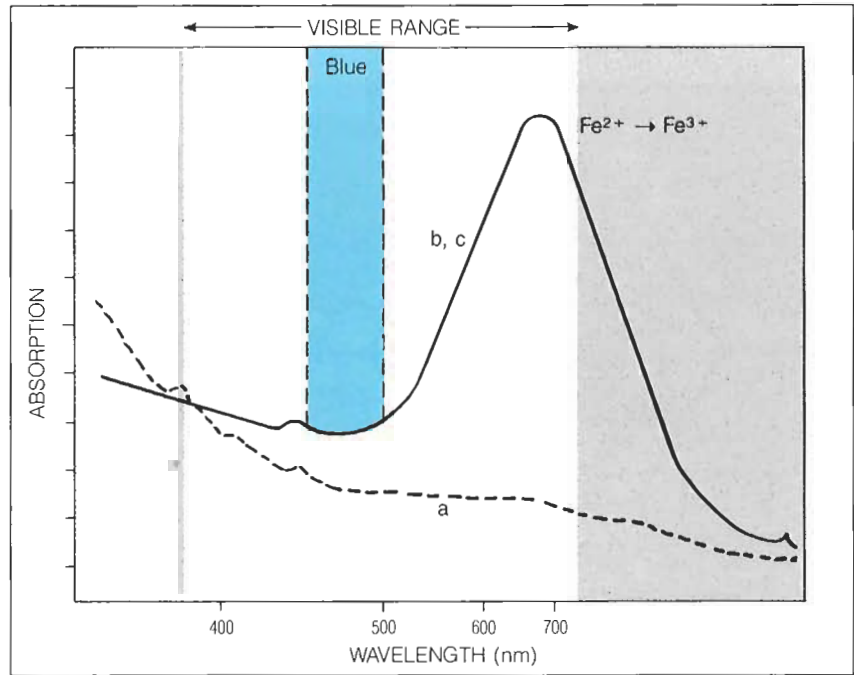
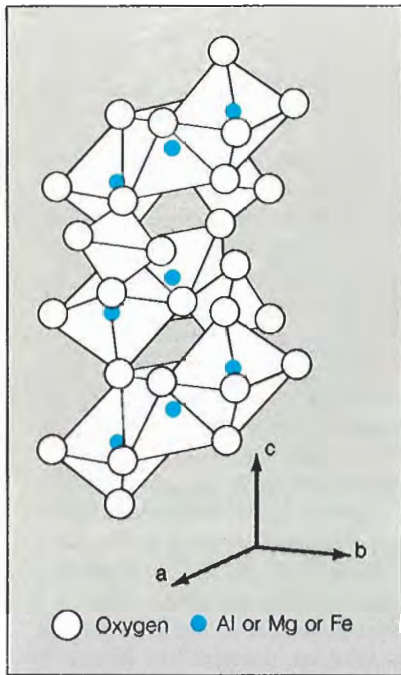


Figure 5. $Fe^{2+} \rightarrow Fe^{3+}$ charge transfer in lazulite: Iron ions can substitute for aluminum or magnesium atoms which are all situated in the b, c plane (left frame). As a result, the charge transfer will appear in the spectra obtained with light polarized parallel to the b and c directions (labeled b, c in the right frame), but no charge transfer will be observed in the a direction (labeled a). After Amthauer and Rossman, 1984. Strong blue to colorless pleochroism results, as illustrated by the 1.04-ct stone shown here. Photo by John Koivula.

COLOR CENTERS: HOW IMPERFECTIONS LEAD TO BEAUTIFUL COLORS

Many colors in gemstones are the result of exposure to high-energy radiation. This can happen in nature as a result of the widespread occurrence of low concentrations of naturally radioactive isotopes of U, Th, and K. It can also occur through artificial irradiation by means of a wide variety of laboratory and industrial technologies. Radiation can (1) change the oxidation state of metal ions and (2) interact with "defects" in the crystal. These defects may be, for example, missing atoms (vacancies) or additional atoms (interstitials). Also, electrons extracted by irradiation somewhere else in

the crystal can be put into preexisting growth or mechanical defects. This is sometimes poetically called "decorating a defect." These defects could, from the physical point of view, be considered "pseudo-atoms," inasmuch as they are usually the size of one or a few atoms. *Color center* is the generic term for a defect that causes light absorption (even if it is not in the visible range), particularly one that is affected by irradiation. Kittel (1980) gives a more systematic and theoretical approach to color centers, for those readers interested in greater detail.

The concept of color center is best explained through some typical examples. A vacancy type of color center means that an atom that is usually



Figure 6. Baltic amber, here carved in the form of Eros with a lion, is colored by electron delocalization over the large organic molecules that form amber. This 4.6-cm-long carving, which dates from the first century A.D., is from the De Bry Collection, Paris. Photo © Nelly Bariand.

Figure 7. The coral from which this 32.5-cm-wide piece was carved comes from the coral beds of Taiwan. The red hue is due to small amounts of an organic molecule from the carotenoid family. From the collection of Jack and Elaine Greenspan; photo © Harold & Erica Van Pelt.



TABLE 1. Color-producing processes involving multiple atoms and examples of the colors they cause in various gem materials.

Process	Color and gem material
Charge transfer	
<i>Oxygen→metal charge transfer</i>	
$O^{2-} \rightarrow Fe^{3+}$	Yellow to brown: beryl/heliodor (Wood and Nassau, 1968), corundum (Schmetzer et al., 1982), quartz/citrine, burned amethyst (Balitsky and Balitskaya, 1986), sinhalite (Farrell and Newnham, 1965)
$O^{2-} \rightarrow Fe^{4+}$	Purple: quartz/amethyst (Cox, 1977)
$O^{2-} \rightarrow Cr^{6+}$	Yellow to red: crocoite (Loeffler and Burns, 1976)
<i>Intervalence charge transfer</i>	
$Fe^{2+} - O - Fe^{3+}$	Violet: "lavender" jadeite (Rossman, 1974) Blue: beryl/aquamarine (Goldman et al., 1978), cordierite/iolite (Faye et al., 1968), lazulite (Amthauer and Rossman, 1984), amphibole/glaucophane (Smith and Strens, 1976), kyanite (Parkin et al., 1977), euclase (Mattson and Rossman, 1987b)
$Fe^{2+} - O - Ti^{4+}$	Blue: corundum (Smith and Strens, 1976), kyanite (Parkin et al., 1977) Brown: dravite (Smith, 1977), andalusite (Smith, 1977) Yellow to black: titanian andradite/melanite (not fully proved, Moore and White, 1971)
$Mn^{2+} - O - Ti^{4+}$	Greenish yellow: tourmaline (Rossman and Mattson, 1986)
Processes not involving metal ions	
S_3^-	Blue lazurite/lapis lazuli (see Loeffler and Burns, 1976)
Various organic compounds	Yellow to brown: amber and copal, tortoise shell (Nassau, 1975)
Porphyrins	Green and pink: oyster pearls (Fox et al., 1983)
Carotenoïds	Pink to red: conch "pearl," coral (Délé-Dubois and Merlin, 1981)
"Chromophores"	Any color: organic dyes (Griffiths, 1981)

present in a particular type of crystal has been removed by irradiation (see figure 8). This kind of defect is responsible for the color of most green diamonds, which have been exposed to radiation that is strong enough to remove carbon atoms from their original positions. This can happen either naturally or in the laboratory. A neutral carbon vacancy (i.e., without electrons in it), called the GRI center, is created and absorption occurs in the red and orange (Collins, 1982). This leaves a transmission window either in the blue (if there is no absorption in the violet-blue, as in nonconductive,

treated blue diamonds) or, more commonly, in the green.

In most cases, instead of dislocating an entire atom, irradiation expels an electron from its orbital. This is the explanation for the origin of color in two common varieties of quartz: smoky quartz and amethyst. In all smoky quartz crystals, aluminum (Al^{3+}) replaces a small part of the silicon (Si^{4+}). The presence of the aluminum impurity is not, in and of itself, enough to cause the color; the crystal has to be irradiated. Natural irradiation, over geologic time, can remove an electron from an oxygen atom adjacent to an aluminum ion (see figure 9), creating an intense absorption in the ultraviolet that extends into the visible range and induces the typical smoky color. Quartz will become completely black if the radiation is intense and the crystal contains enough aluminum. On heating, the smoky color leaves and the quartz returns to its original colorless state.

In amethyst, iron is the initial impurity. Fe^{3+} occupying the silicon site in quartz is changed by irradiation into Fe^{4+} , an uncommon valence state for iron (Cox, 1977). This oxidation state results from natural irradiation in the case of natural amethyst and from laboratory irradiation in the case of synthetic amethyst. The characteristic deep purple transmission results from absorption due to $O^{2+} \rightarrow Fe^{4+}$ charge transfer (see above), which is centered in the yellow-green.

Fe and Al are common impurities in quartz. Less common foreign molecules can also produce some spectacular colors in certain minerals. For example, the carbonate group (CO_3^{2-}) can be incorporated into the channels of the beryl structure during crystal growth. Under the influence of irradiation (usually natural but also possible in the laboratory if the precursor is there), this molecule loses an electron and becomes $(CO_3)^-$. The remaining extra electron on this molecule induces a broad absorption from the red to the green (see figure 10). This produces the attractive sapphire-blue color of the Maxixe-type beryl (Edgar and Vance, 1977). Interestingly, the sapphire-blue beryl originally found at the Maxixe mine in Minas Gerais, Brazil, is colored by a similar but different defect, the NO_3 group, which results from the irradiation of a nitrate impurity (NO_3^-) (Andersson, 1979). Unfortunately, like many other gemstones in which the color originates in color centers, Maxixe and Maxixe-type beryl fade when exposed to daylight.

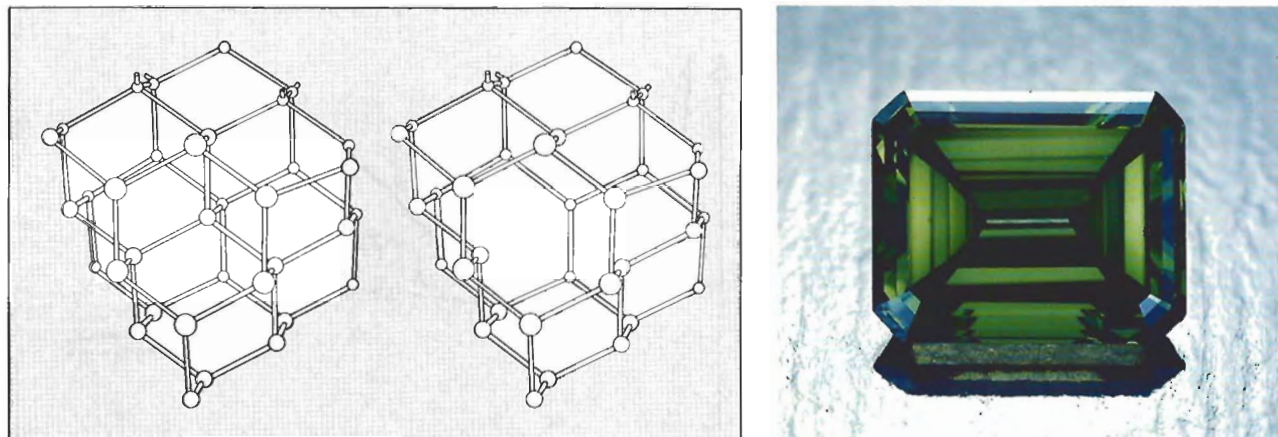
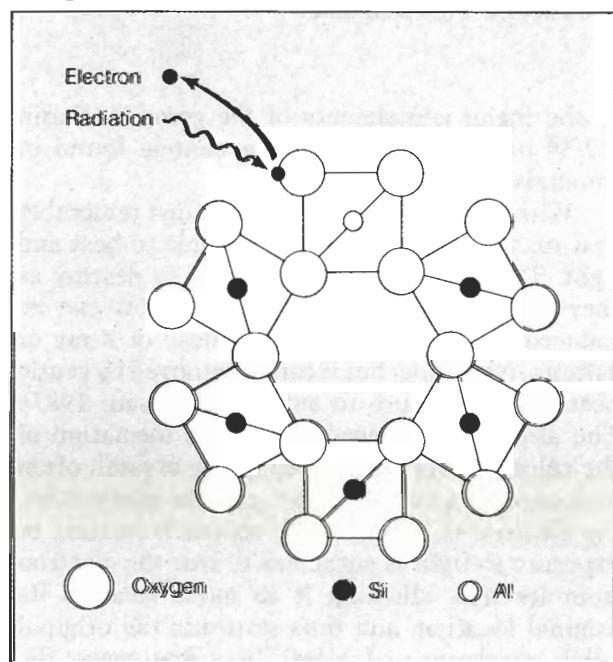


Figure 8. Strong radiation moves an atom away from its normal position (left) to produce a neutral carbon vacancy (right) in diamond. From Bursill and Glaisher, 1985. This very simple color center, called GR1 (general radiation 1) induces green color in diamond, as seen in the 0.40-ct treated green stone on the right. Diamond courtesy of Theodore and Irwin Moed, Inc.; photo © Tino Hammid.

One of the interesting features of the $(\text{CO}_3)^-$ defect in beryl is the very large breadth of its absorption range. In fact, in addition to the first sharp absorption, the $(\text{CO}_3)^-$ defect is represented

Figure 9. The color center responsible for the coloration of smoky quartz is more complex than that which colors green diamond. Irradiation removes an electron from an oxygen atom that is bonded to an aluminum atom, substituting for silicon.



by a group of bands that are spaced in a relatively regular way with decreasing intensity for shorter wavelengths (again, see figure 10). These are due to a strong coupling between the absorbing center and the vibrations of the molecule. Such an absorption system is called vibronic. The broad absorption feature is primarily responsible for the coloration; the absorption under the sharp peak absorbs so little light that it will hardly influence the color. Interestingly, this type of absorption system is responsible for most diamond colorations (Collins, 1982): yellow from the N2 and N3 centers (Cape lines), orange from the H3 center (503 nm and related bands), green from the GR1 center (again see figure 8), and other colors from combinations of these.

Color centers can be more complicated than just a vacancy or a foreign molecule, and often involve a defect in the crystal *plus* an impurity adjacent to it. Some fluorites (CaF_2) are light blue because they contain an yttrium (Y^{3+}) ion substituting for the calcium near a fluorine vacancy, which is populated by two electrons. This complex center absorbs in the violet and the yellow-green and so gives a blue hue (Bill and Calas, 1978).

Another example of a color center involving multiple components is the blue to green variety of microcline feldspar (amazonite). Hofmeister and Rossman (1985) attributed the color to Pb^{2+} in the crystal structure substituting for two potassium (K^+) ions. Under the action of natural irradiation, the lead is oxidized to Pb^{3+} . This oxidation only occurs if water molecules are bound to the struc-

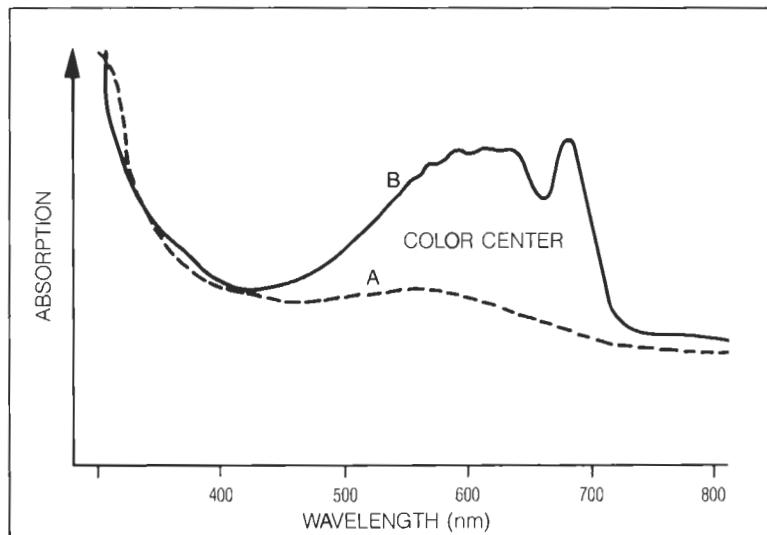
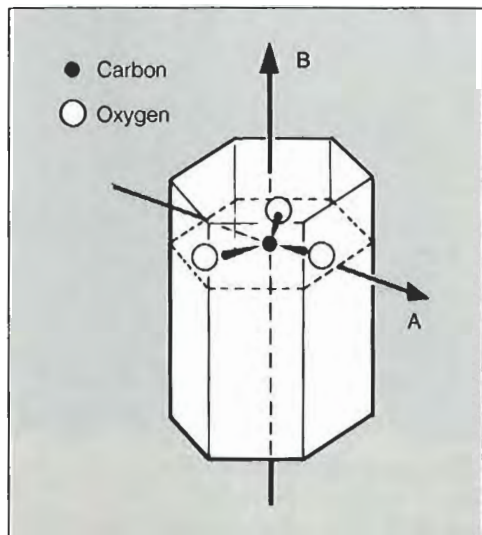


Figure 10. The absorption spectrum of a Maxixe-type beryl shows the characteristic strong pleochroism (A = polarized light, vibrating parallel to the optic axis; B = polarized light, vibrating perpendicular to the optic axis). The absorption of the red end of the spectrum is due to the $(\text{CO}_3)^-$ impurity in the channels of the beryl structure (after Nassau et al., 1976). The $(\text{CO}_3)^-$ molecule is planar and oriented perpendicular to the optic axis (left). The deepest color results when the table is cut perpendicular to the optic axis (as in the stone at the left). Photo © Tino Hammid.

ture in the vicinity of lead. This particular combination of impurities generates the blue to green color. This example also demonstrates the influence of water content on the susceptibility of a mineral to coloration by irradiation. In some cases, such as amazonite, water helps create color; in others, such as smoky quartz and amethyst, it prevents the coloration (Aines and Rossman, 1986).

Table 2 provides some idea of the wide variety of color centers in gem materials. Sophisticated techniques are usually required for their identification. The details of the color centers in even common stones, such as blue topaz (see figure 11), are still under debate (Schmetzer, 1987). Many of the color centers that result from irradiation require the presence of an impurity, but they also can be due solely to the effect of the irradiation on one

of the major components of the gem. Marfunin (1979) provides a list of color centers found in minerals and gem materials.

With regard to treatment, one must remember that many color centers are unstable to heat and light. They are sometimes as easy to destroy as they are to induce. For example, yellow can be induced in corundum by a low dose of X-ray or gamma irradiation, but it can be removed by gentle heating or exposure to sunlight (Nassau, 1987). The electrons displaced during the formation of the color centers are trapped in the crystal, often by a nearby cation (H^+ , Na^+ , etc.). In many cases, the electron is weakly held, so gentle heating or exposure to light is sufficient to free the electron from its trap, allowing it to move back to its original location, and thus restoring the original color (or absence of color). In a few cases, the

TABLE 2. Examples of gem materials colored by color centers, with an indication of the origin of color.^a

Gem material	Origin of color
Diamond	Green: neutral carbon vacancy/GR1 center (Collins, 1982) Yellow: aggregate of 3 nitrogen atoms/N3 center (Collins, 1982) Orange: vacancy trapped at nitrogen aggregates/H3 and H4 centers (Collins, 1982)
Quartz	Smoky: Al ³⁺ impurity + irradiation (see Partlow and Cohen, 1986) Yellow: Al ³⁺ -related color centers (Samoilovich et al., 1969) Purple: Fe ³⁺ impurity + irradiation → Fe ⁴⁺ (Balitsky and Balitskaya, 1986)
Corundum	Yellow: unstable color centers of unknown structure (Schiffman, 1981; Nassau, 1987)
Topaz	Blue: color centers of unknown structure (Schmetzer, 1986) Yellow: color center of unknown structure (Petrov, 1977) Reddish brown: "red" and "yellow" color centers of unknown structure (Petrov, 1977)
Tourmaline	Red: Mn ³⁺ due to irradiation (Manning, 1973)
Feldspar	Blue to green: color center involving Pb (Hofmeister and Rossman, 1985, 1986)
Scapolite	Violet: color centers related to radicals in the channels of the structure (Marfunin, 1979)
Beryl	Blue (Maxixe-type or Maxixe): CO ₃ ²⁻ or NO ₃ group due to irradiation (Andersson, 1979)
Spodumene	Green: unstable Mn ⁴⁺ due to irradiation (Cohen and Janezic, 1983) Yellow: color center of unknown structure (Rossman and Qiu, 1982)
Fluorite	Blue: Y ³⁺ + fluorine vacancy + 2 electrons Pink: YO ₂ center (Y ³⁺ + O ₂ ²⁻) Yellow: O ₂ ⁻ center = O ₂ substituting for fluorine (Bill and Calas, 1978)
Sodalite	Blue: interstitial oxygen ion O ⁻ near aluminum or silicon (Pizani et al., 1985) Pink: unstable electron substituting for Cl ⁻ in a tetrahedron of Na ⁺ ions (Pizani et al., 1985)

^aA given color in a specific gem material can be due to different causes. Consequently, not all yellow sapphires are, for example, colored by a color center (see table 1).

electron is tightly held, so the color is stable (e.g., red tourmaline).

In some instances, irradiation creates several centers at the same time. For example, in the commercial treatment of blue topaz, both blue and brown centers may be generated in the initial irradiation. Gentle heating is then used to remove the brown component (Nassau, 1985). Another possibility is that treatment does not create directly the desired color center, and that heating is



Figure 11. This 17-cm-high crystal of blue topaz from Virgem de Lapa and the 182-ct faceted topaz from Minas Gerais are both of natural color. The pear-shaped blue topaz in the pendant owes its color to artificial irradiation and subsequent annealing. The structure of the color centers in both natural and treated blue topaz is still under investigation. Stones and jewelry courtesy of The Collector, La Jolla and Fallbrook, CA; photo © Harold e) Erica Van Pelt.

required to bring the necessary ingredients together. Such is the case for many treated colored diamonds, in which vacancies move during annealing to meet one of the forms of nitrogen impurities (Collins, 1982).

CONCLUSION

We have now reviewed the three most common causes of color in gem materials: dispersed metal ions (Fritsch and Rossman, 1987), charge transfers and other processes that involve multiple ions, and color centers. The last article of this series will deal with types of coloration that are less often seen in gems, such as those that result from physical phenomena (as in opal) or from semiconductor-like properties (as in natural blue diamond).

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CHRYSOBERYL AND ALEXANDRITE FROM THE PEGMATITE DISTRICTS OF MINAS GERAIS, BRAZIL

By Keith Proctor

This fourth article in the author's series on the pegmatite districts of Minas Gerais, Brazil, focuses on chrysoberyl, particularly the rare but coveted varieties cat's-eye and alexandrite. Most of the cat's-eye chrysoberyls on the gem market today come from Brazil, primarily from the region around the Americana and Santana valleys. This article examines some of the more important mines in this region, with a detailed description of the Barro Preto deposit. Farther south, the Malacacheta area has produced a number of fine alexandrites during the last 13 years. Since October 1986, however, it has been overshadowed in both quality and quantity by the small Lavra de Hematita, which produced 50 kg of fine alexandrite in less than three months. These two occurrences are also described in detail.

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Acknowledgments: Special thanks to H. Kennedy, A. Tavares, and Dr. R. Nash, without whose help this article would not exist. The input of the following is greatly appreciated: K. Elawar, W. Brennan, S. Domingos, Dr. H. Bank, Dr. K. Schmetzer, Dr. F. Pough, Dr. E. Gübelin, S. Watt, C. Bank, Dr. J. Raggi, Dr. D. Schwartz, J. Drew, and O. Neto. Thanks also go to L. Moffett for typing the manuscript, to L. Rayburn for translations, and especially to Mauna Proctor for her help in translating, typing, and editing and for her constant support.

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The two commercially most important gem varieties of chrysoberyl—cat's-eye chrysoberyl and alexandrite—are among the world's rarest gemstones (figure 1). The state of Minas Gerais, Brazil, and the island of Sri Lanka are presently the world's two largest suppliers of chrysoberyl, cat's-eye chrysoberyl, and alexandrite, although Russia historically has produced some fine material. Since production from Sri Lanka has dropped off dramatically in recent years and the classic Uralian deposits are most likely exhausted, the major future production will probably come from Brazil.

Chrysoberyl, with a hardness of 8½, is the third hardest of the gemstones, following only diamond and corundum. Known in antiquity but not properly identified, chrysoberyl was found mixed with tourmaline and other gems in the gem gravels of Ceylon by at least the late 1600s. In Ceylon, the Singhalese natives considered chrysoberyl a superior kind of tourmaline (Ball, 1930). The name (*chryso-*, from Greek for yellow or golden, plus *beryl*) indicates that other, more sophisticated investigators considered chrysoberyl to be a variety of beryl (Sinkankas, 1964). It was finally chemically identified as a distinct species by Werner in 1789, and chrysoberyl with the chatoyant, or "cat's-eye" effect, was dubbed "cymophane" by Haüy in 1798 (Bauer, 1904; Bank, 1973).

Brazil was recognized early on as a major source, with the first mining exports (probably from the Araçuaí and Minas Novas districts) occurring by 1805. A huge—almost 8 kg—chrysoberyl was listed as one of the treasures of Rio de Janeiro in 1828 (Bauer, 1904; Ball, 1930). Brazilians have long coveted chrysoberyl, which they called "crisólita," and even named the city of Crisólita (probably another early source) after the gem. Today, Minas Gerais is the major source of chrysoberyl in Brazil. The Brazilian chrysoberyls range in color from yellow to yellowish green, olive green, gold, brown, and, rarely, "ruby" red (figure 2).



Figure 1. Minas Gerais is a major source of fine cat's-eye chrysoberyl and alexandrite. The "honey"-colored cat's-eye chrysoberyl shown here (5.47 ct) is from the Americana/Santana valley region; the alexandrite (3.03 ct), which appears red in incandescent light (here) and bluish green in fluorescent light, is from the newest deposit, Lavra de Hematita. Rings courtesy of Silverhorn, Santa Barbara, CA; photo © Tino Hammid.

The color-change variety of chrysoberyl, alexandrite, was discovered in the Ural Mountains of Russia in 1830; it was named after the heir-apparent to the Russian throne, the future Alexander II. The best Russian stones tend to be bluish green in daylight (or fluorescent light) and pink, reddish purple (raspberry), or, rarely, "ruby" red in incandescent light (Pough, 1976). Most of the Brazilian alexandrites discovered before October 1986 are also green in daylight but are more amethystine or pink in incandescent light (Kunz, 1913; Pough, 1973). However, the best gems from the newly discovered Lavra de Hematita (also known as Nova Era or Itabira) alexandrite deposit are predominantly bluish green to greenish blue (called *pavão* in Brazil) in daylight and pink, raspberry, "rhodolite," or "ruby" red in incandescent light (figure 3). The rarest of the rare alexandrites is fine cat's-eye alexandrite.

In the almost 200 years since chrysoberyl was first mined in Brazil, many tens of thousands of carats of chrysoberyl, cat's-eye chrysoberyl, and alexandrite have been taken from deposits in northeast Minas Gerais and the states of Bahia and Espirito Santo. At least 95% of the chrysoberyl and cat's-eye chrysoberyl found in Minas Gerais in recent years has come from the many deposits in the Santana and Americana valleys, near the city of Padre Paraíso in the Teófilo Otoni-Marambaia pegmatite districts (K. Elawar, H. Kennedy, A. Tavares, pers. comm., 1987; figure 4). The Barro Preto and Gil claims, as well as the Faísca and Cilindro deposits, are particularly notable. Virtually all of the finest alexandrite produced in the last 13 years has been mined from the pegmatite regions associated with the cities of Malacacheta and Itabira. In these two areas, the Córrego do Fogo and Hematita deposits are major producers for the



Figure 2. This 41-ct twinned crystal, found at Malacacheta in 1976, is a rare example of red chrysoberyl. Courtesy of Henry Kennedy, Teófilo Otoni, Brazil; photo © Fred L. Elsna.

world market. These deposits and the gems they produce are described below.

The reader is referred to part 1 of this series (Proctor, 1984) for a detailed description of the pegmatite deposits of Minas Gerais, the terminology used to describe these gem deposits, and the various mining methods used. To the author's knowledge, the various types of chrysoberyl are not being subjected to any form of color or phenomenon enhancement.

CHRYSOBERYL FROM THE AMERICANA AND SANTANA VALLEYS

As early as 1846, chrysoberyl was reported from Córrego de Santa Anna (probably the Santana valley), east of Araçuaí, by Van Helm Reischen. The earliest record of cat's-eye chrysoberyl in this region comes from Dr. Hermann Bank, whose father observed them when he visited the Americana valley on horseback in 1910. Not knowing what they were, the local cattle ranchers had been throwing the gems away (H. Bank, pers. comm., 1988).

In rare instances, fine alexandrites have been

found in the Americana valley. The earliest report is of a 10-ct gem that was cut in 1932; a notable find also occurred in 1975 (H. Bank, pers. comm., 1984). The Santana valley has produced only a few pale alexandrites with poor color change from near the junction of the Barro Preto and Gil creeks (H. Kennedy, pers. comm., 1987).

The following discussion provides what little information is available on the Faisca and Cilindro mines, in the Americana valley, and a detailed description of the mining operation at Barro Preto (with reference to the nearby operation at Gil), in the Santana valley.

Location and Access. These two valleys lie east of and roughly parallel to highway BR-116 (figure 4). The western valley is the watershed for the Santana River, which runs directly south from near Padre Paraíso; the parallel eastern valley is the watershed for the Americana River. The two valleys are separated by a ridge of hills, which is probably the original source of the chrysoberyls. Numerous streams that flow into these two rivers cut smaller valleys along both sides of this range of hills. It is within these smaller valleys that the chrysoberyls are found.

These chrysoberyl-bearing valleys may be reached by traveling north from Teófilo Otoni on BR-116 to km marker #175 (indicating the distance remaining to the Bahia border), 5 km north-east of Padre Paraíso. To reach the Gil and Barro Preto claims, one then takes a good dirt road east almost 10 km, toward the city of Águas Formosas. Just before reaching the hamlet of Ribeirão de Santana, take the road south into the Santana valley approximately 7 km to reach the Gil and Barro Preto creeks. To reach the Faisca and Cilindro *garimpos* (or workings, used to refer to a specific series of pits in the alluvium), instead of turning south at the 10 km junction one continues for an additional 18 km east and then turns south on another dirt road to the mining area, which lies along the Faisca and Topázio streams, two tributaries of the Americana River.

The Faisca and Cilindro Mines. Since 1939, Rudolf Ziemer and his family have mined relatively large quantities of chrysoberyl and cat's-eye chrysoberyl, and minor amounts of alexandrite as well as some topaz, from the Faisca mine (also known as the Ziemer mine) in the Americana valley. Ziemer's son (also named Rudolf) mechanized

their mining operation about 1975, resulting in a dramatic increase in production from what is probably the largest chrysoberyl operation in Brazil at the present time (A. Tavares, pers. comm., 1988). The Faísca mine lies directly over the mountain range that is opposite the Gil and Barro Preto concessions.

Owned by Hilton (Zequinha) Lopes, the Cilindro mine is adjacent to the Faísca mine. After the Faísca and the combined Gil and Barro Preto operations, it is probably the third largest producer in the area. Unfortunately, no production statistics are available for either the Faísca or the Cilindro mine. See figure 4 for additional significant workings in this area.

The Gil and Barro Preto Concessions. In 1960, a 785-gram crystal of gem-quality cat's-eye chrysoberyl was found in the Gil/Barro Preto region. In February of that year, Agenor Tavares obtained the crystal and, in 1967, acquired the mineral rights to these properties as a concession. He initiated a period of greater activity that resulted in the production of more than 500 grams of gem-quality chrysoberyl and cat's-eye chrysoberyl between 1968 and 1973 (the ratio of chrysoberyl to cat's-eye chrysoberyl found is roughly 4 to 1). However, relatively little came out in the course of the next five years (A. Tavares, pers. comm., 1987). For two years, 1979–1980, a Japanese company worked both Barro Preto and Gil with heavy machinery, but they found less than 6 kg of chrysoberyl and cat's-eye chrysoberyl combined. Currently, Henry Kennedy is the major lessee. His diggings cover a little less than a kilometer in each of the valleys, although most of his effort has been in Barro Preto. Production has increased steadily since he became involved in the early 1980s. Kennedy was instrumental in providing the geologic, mining, and production information given below. Also of great help was Dr. Rex Nash, a geologist in Minas Gerais who has studied the area extensively.

Geology and Occurrence. The Gil and Barro Preto claims are at an elevation of approximately 750 m. These "highlands" are basically granite and granitic gneiss with innumerable pegmatite intrusions.

Because of the number of pegmatites in this region and their highly decomposed state, the secondary deposits are rich in gem minerals. The Gil and Barro Preto valleys are typical of the region in that most of the chrysoberyls are found in



Figure 3. The finest alexandrites from the newly discovered Hematita mine range from bright pink to red in incandescent light. These stones (0.95 ct to 2.49 ct) are courtesy of Kremenz & Co., Newark, N.J. Photo © Tino Hammid.

colluvial-alluvial gem gravels (*cascalhos*) which lie beneath various layers of red soil and gray or black clay and/or sands of various colors (R. Nash, pers. comm., 1986). Accessory minerals found include schorl, beryl (heliodor and aquamarine), topaz, rhodolite garnet, andalusite, considerable quartz, and olivine (H. Kennedy, pers. comm., 1986).

In the Gil valley, most of the rough gem material is small and well rounded, which suggests that it was transported some distance from the original source. At Barro Preto, however, many of the rough broken pieces have terminated faces or sharp broken edges, which indicates that this area is probably closer to the original host rock. For the most part, the following geologic discussion is limited to the higher of the two valleys, Barro Preto, which has produced more large gems.

There are seven recognizable layers (which vary in thickness throughout the area) in most

parts of Barro Preto (H. Kennedy, pers. comm., 1988):

1. A red lateritic soil overburden.
2. An organically rich layer of black clay mixed with sand that is up to 1.25 m (4 ft.) thick (found only occasionally in the Gil valley; *barro preto* means black clay).
3. An upper *cascalho* layer of gem pebbles mixed with sand and rounded rocks that lies above the present creek level. This gravel layer is reddish brown from iron-oxide staining, and varies from

5 cm (at which point it contains no gems) to 1 m thick. A thicker layer with good-sized quartz gravel is a strong indicator that gem material is present. Approximately 15–20% of the gem chrysoberyls produced at Barro Preto, more than 90% of which have sharp broken edges or crystal faces, are found in this layer. This appears to be a colluvial layer that has weathered out of a nearby source and been eroded into this narrow valley (see Proctor, 1984, for a discussion of colluvial/alluvial deposits).

Figure 4. The Americana and Santana valleys have produced approximately 95% of the chrysoberyl and cat's-eye chrysoberyl found in Minas Gerais during the last 50 years. The major deposits are identified. See the first article in this series (Proctor, 1984) for a map of all the major gem pegmatite mines in northeastern Minas Gerais. Artwork by Jan Newell.

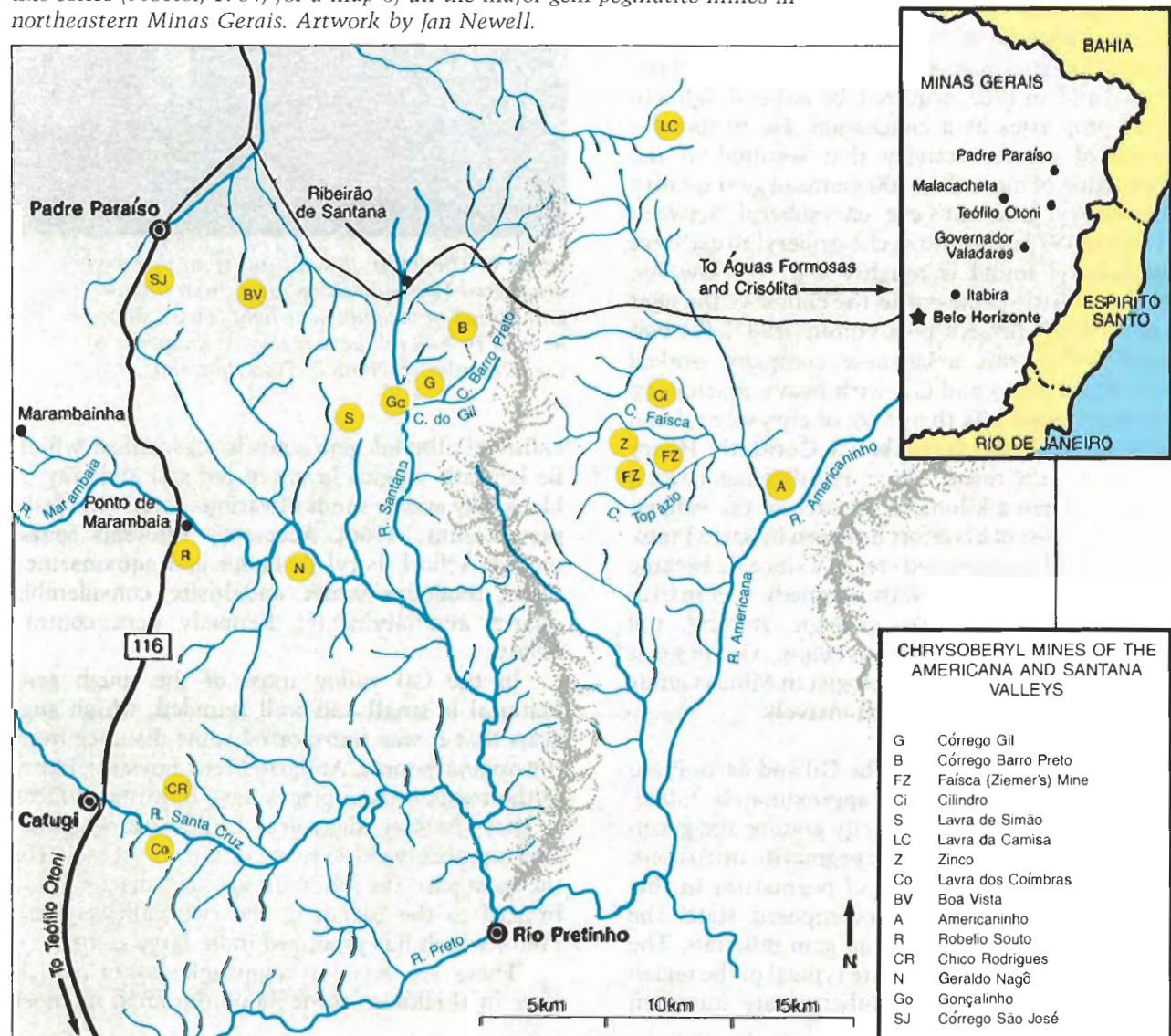




Figure 5. Water is an on-going problem at Barro Preto. Periodically during the day, the miners must pump the water out in order to gain access to the gem-bearing gravels. Photo by Henry Kennedy.

4. A black clay (similar to layer no. 2) that contains so much organic matter that, when dried out, it will actually burn like peat. Local geologists suggest that this layer, which blankets the entire valley, resulted from the destruction of a great *rajn* forest. The roots of this forest held back erosion of the surrounding hills; when the forest was destroyed, erosion accelerated rapidly, thus laying down the upper *cascalho* layer.
5. A gray clay layer from 10 to 20 cm (4–8 in.) thick that is sometimes extremely hard and is believed to be the product of sedimentation in ancient lakes, ponds, or streams.
6. A fine sand layer of different colors—yellow or red when iron oxide-rich; white if the iron oxide has been leached out—that usually grades into coarser sands as one goes deeper.
7. A lower *cascalho* layer in which the gems are mixed with coarse, rounded, mostly granite river rocks with perhaps only 10–20% quartz gravels and some sand (unlike that at the Marambaia and Tres Barras deposits—see Proctor, 1984—which is 99% quartz pebbles).

The color of this *cascalho* layer varies from white, rose, brown, or orange to gray; it is frequently “braided,” with intertwining strands of different colored gravels, each of which probably represents a different creek and different time period. The most productive gem-bearing gravel “braids” are pink and brown; the least productive are white. Tremendous effort is expended in searching for this *linha mestra* (master gravel). The gravels are cemented into hard masses by a combination of a silica and

iron oxides, and must be broken up with long steel bars.

In contrast to the upper, colluvial, gem-bearing layer, the bottom *cascalho* is between 0.5 to 1 m thick and is usually found in the river bottom. As before, the thicker the layer is, the greater its gem potential. In some areas, the chrysoberyls found in this layer are well worn, a truly alluvial deposit. As mining activity moves northwest toward the granite hill, there is a greater concentration of gem chrysoberyls and those recovered show fewer signs of alluvial wear, with complete terminations on some specimens; this material has not moved far from its original source. Approximately 80–85% of the gem production at Barro Preto comes from this layer.

The altered, decomposed “spongy” gneiss bedrock lies directly under the last *cascalho* layer, and looks like thick, hard clay, as it does at Marambaia and Tres Barras. The latter deposits, however, each have only one gem-bearing layer.

Because the area is so highly weathered, it is difficult to determine whether the chrysoberyl formed within a pegmatite or in the host rock into which the pegmatites were intruded. However, some gem-quality chrysoberyl has been found *in situ* in a nearby pegmatite at the Simão mine (H. Kennedy, pers. comm., 1988).

Mining. Hundreds of pits have been dug in these valleys in recent years, but there is a constant problem with water; until pumps were used consistently, little mining progress could be made (figure 5). To find the bottom *cascalho* layer,



Figure 6. Here a backhoe is used to remove the red soil overburden and the first layer of black clay mixed with sand to get to the top *cascalho* layer (the yellowish material in front of the backhoe) at Barro Preto. Water is a threat to mechanized mining as well; note the pump on the left. The granite *inselberg* behind the operation may have been the original source of the chrysoberyl. Photo by Henry Kennedy.

Figure 7. Large granite boulders often block access to the top gem-bearing layer at Barro Preto and must be blasted into smaller pieces for removal. Here the hole has already been drilled and the dynamite (note the sticks in back) with fuse has been put in place. The miner puts newspaper on top of the dynamite to protect the charge and then packs it with soil so that the rock will break uniformly. Photo by Henry Kennedy.



"modern" *garimpeiros* (independent miners) dig square pits down through the layers in the valley floor, stake the walls with wood to prevent cave-ins, and then pump the water out periodically so they can work the gem gravels. Kennedy also reroutes the stream during the dry season and then excavates. Some miners give up the search for the lower layer altogether and just work the upper layer with a back-hoe; even then, water pumps are usually required (figure 6).

Another obstacle is big granite boulders, which often lie above and even intermixed with the gem gravels. These have to be pried loose or dynamited so they can be hauled away (figure 7). During the course of one six-week project, Kennedy and his men tediously bored two-foot-deep holes, one after another, into each of literally hundreds of large granite boulders (73 in one day alone) to gain access to a very thick layer of *cascalho*. They were devastated to find only one very poor cat's-eye in the tons of gem gravel that they extracted.

Once it is removed, the *cascalho* must be washed and sorted. Kennedy uses a system he devised of four screens, one on top of the other,

with about 15–25 cm (6–10 in.) separating them (figure 8). From the top down, each screen has a smaller mesh, and since the chrysoberyl pebbles are generally small, most eventually end up on the bottom screen. When the upper “box” is loaded with *cascalho*, a water cannon is used to separate the gems and clean the gravel. The sands and clays fall through to the ground, and the remaining gravels in each size group are hand sorted for the gem rough.

Production. The Gil valley produces many more gemstones than Barro Preto produces, but Barro Preto yields much bigger pieces of rough. According to Kennedy (pers. comm., 1988), the 40 garimpeiros who work this region consistently produced (as of 1985) 100 grams of good rough in an average week. For most of 1986 and 1987, however, production dropped to 10 grams per week because many of the garimpeiros moved to the Hematita alexandrite deposit. In January 1988, however, Kennedy and a small crew removed 300 grams of chrysoberyl rough from two small pits in Barro Preto. Since 1960, these two valleys have produced only 12–15 kg of fine gem chrysoberyl. Only 30 to 40 ct of clean stones result from 100 grams of chrysoberyl rough, and only approximately 20% of these stones are the far more valuable cat’s-eye. With all of this activity, however, the area is still comparatively untouched; both Kennedy and the concession holder, Tavares, predict several decades of low productivity and estimate that only 30% of the Americana/Santana valley area has been depleted.

The chrysoberyl and cat’s-eye chrysoberyl found at Barro Preto is similar in color to that found elsewhere in Brazil, ranging from pale yellow through yellowish green and “honey” to greenish brown and even dark brown (the last, at times, with a blue “eye”); rarely, there are even some bicolors (yellow and dark brown). Most of the material is yellowish green to “honey” (figure 9). The cut cat’s-eye chrysoberyls average 5 ct in weight; the nonphenomenal chrysoberyls are usually clean but small, seldom cutting stones larger than 2 ct. While the rough Kennedy has mined ranges up to 10 grams, he has seen a 63-gram piece of gem-quality cat’s-eye chrysoberyl from the Gil/Barro Preto region. The largest cut chrysoberyl the author knows of, which was probably mined from these valleys, is a 114-ct cushion cut that is now at the Smithsonian Institution (Desautels, 1979).

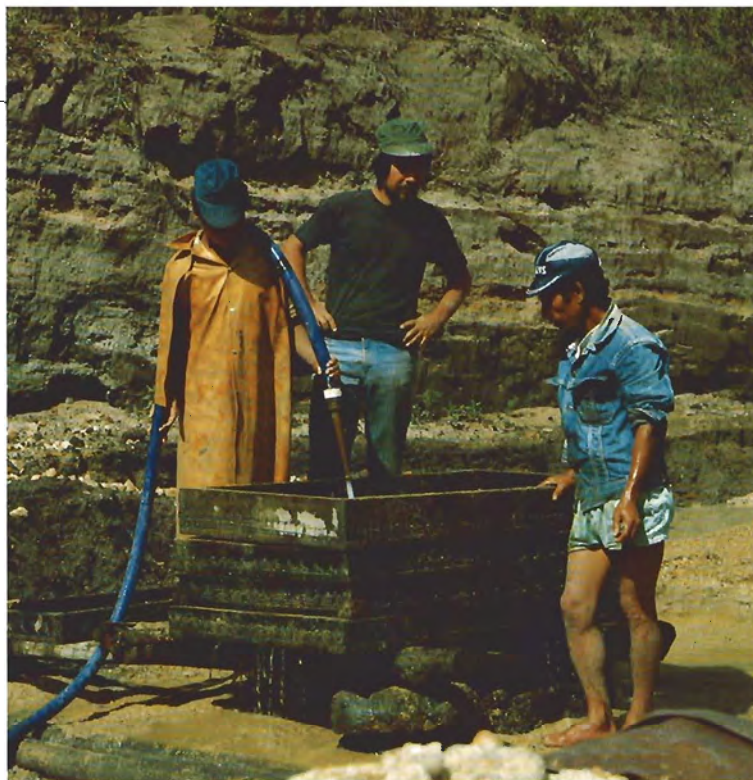
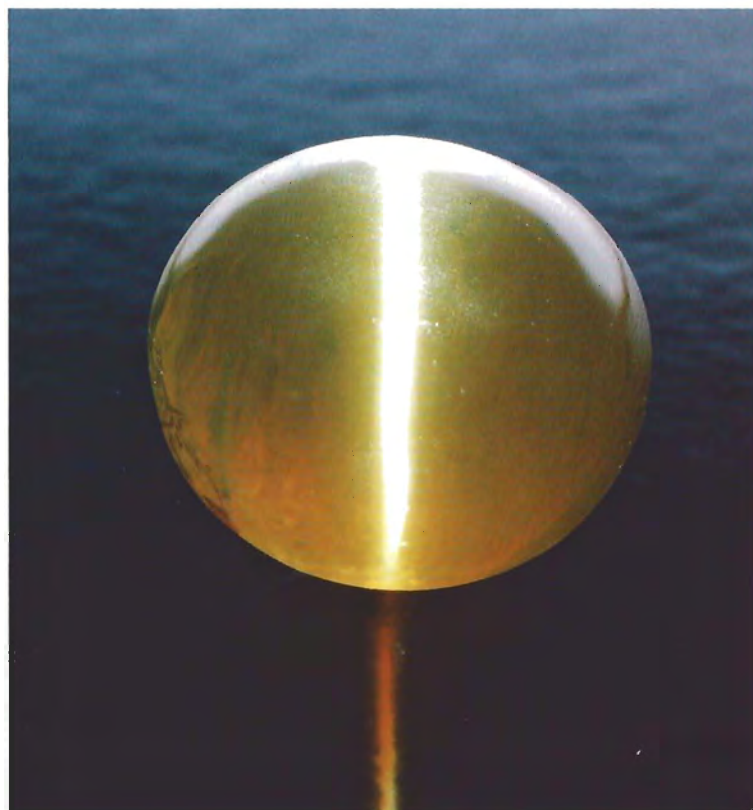


Figure 8. To sort the gem gravels quickly and efficiently at Barro Preto, the miner uses a water cannon to force them through four screens of different mesh. Photo by Henry Kennedy.

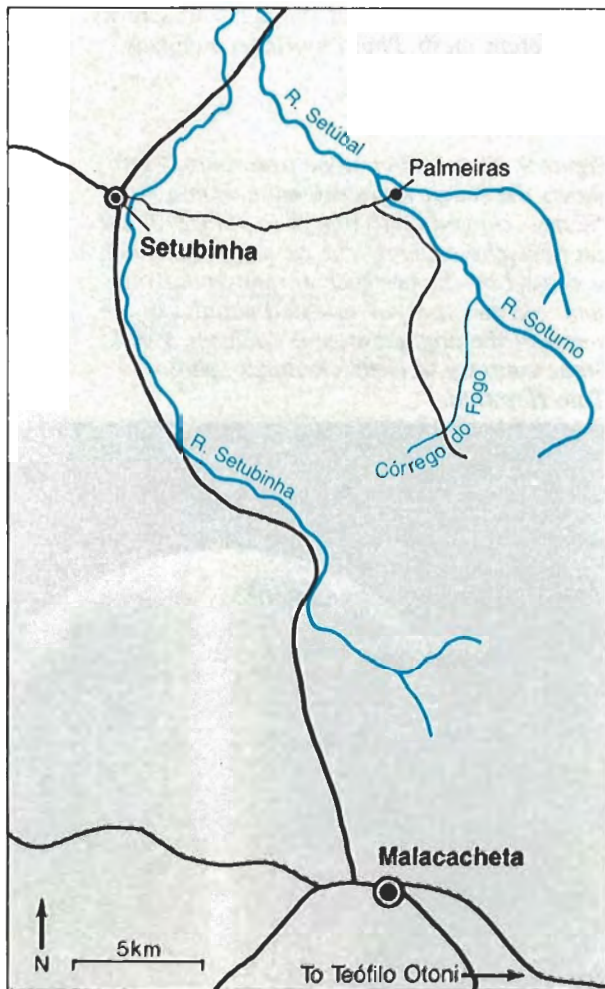
Figure 9. This 11.5-ct stone from Barro Preto shows the sharp, well-centered eye on a “honey”-colored body that is so valued in fine cat’s-eye chrysoberyl. The cat’s-eye phenomenon is caused by the presence of many relatively short needles that are oriented parallel to the *c*-axis of the original crystal (Webster, 1983). Stone courtesy of Henry Kennedy; photo © Tino Hammid.



ALEXANDRITE FROM THE MALACACHETA REGION

More than 100 (air) km southwest of Barro Preto lies what for 13 years was one of the few regions in the world that produced fine alexandrite—Malacacheta (also known as Córrego do Fogo or just Fogo). Until the recent discovery at the Lavra de Hematita (discussed below), it was Brazil's foremost producer of this rare gem material.

Figure 10. For 13 years, the Malacacheta region produced some of the finest alexandrite in Brazil. The greatest mining activity was along 8 km of both sides of the Córrego do Fogo, along 20 km of the Soturno River, and along a few kilometers of the Setúbal and Setubinha rivers. See the inset map in figure 4 for the location of Malacacheta in relation to the other mining areas discussed in this article. Artwork by Jan Newell.



Location and Access. The Malacacheta region is 20 km directly north of Malacacheta City in the watershed of the Setúbal and Soturno rivers (figure 10). Diggings extend about 8 km along both sides of Fogo Creek, along 20 km of the Soturno River, and along a few kilometers of the Setúbal River. Minor deposits have also been found in a small section of the Setubinha River. The valley regions can be reached from the city of Malacacheta by taking a (sometimes impassable) dirt road due north or, more easily, from Setubinha City by taking a dirt road due east to the village of Palmeiras and then south on another dirt road into the valleys.

History. One evening in 1975, João Rodrigues and his sons set up camp along the Fogo Creek. As the sons carried mud from the creek to encase the mandioca roots being prepared for the evening meal, a native *fubá*, they found nodules of what they thought were green tourmaline. When these were later identified as fine alexandrite, garimpeiros from all over rushed to the region (H. Kennedy, pers. comm., 1987). Over the course of the next 13 years, the search for the rare but very valuable pieces of rough would lead to robberies, claim jumpings, and even several killings.

During the period of peak production, 1980–1982, approximately 4,000 to 5,000 miners worked these valleys. At first, they found relatively productive alluvial deposits along a 150- to 300-m-wide swath down the Fogo valley encompassing both sides of the creek. The garimpeiros dug the typical square pits to reach the gem-bearing *cascalho* layer and then shoveled the gravels onto the pit bank. After allowing the pit to fill with water—which required about the same time as eating lunch and having a cigarette—the miners waded into the water and used circular screens (called *peneiras*) to wash the gravels (H. Kennedy, pers. comm., 1987; see Proctor, 1985a, figures 14 and 15, for a similar process).

Geology and Occurrence. All of the alexandrite found to date has been purely alluvial with no *in-situ* occurrences to determine the nature of the original host rock. At the Itabira emerald deposit in Minas Gerais, as at the Goiás and Carnaíba emerald deposits, small amounts of alexandrite have been found in a metamorphic mica-schist with the emeralds. This is also the environment in which alexandrites have been found at the Takowaja River, USSR; Uмба River, Tanzania; Fort

Victoria, Zimbabwe, and at the Transvaal in South Africa (Pough, 1976). There are, however, numerous pegmatites in the Malacacheta region. Further study is needed to determine the exact origin of these deposits.

Production. Since 1975, all of the mining activity has produced only about 2 kg of very good, mostly clean rough and approximately 6–8 kg of lesser quality material. Most of this production was alexandrite; very few pieces of “honey”-colored chrysoberyl and cat’s-eye chrysoberyl were recovered. The author knows of alexandrite rough as large as 18 grams; the finest faceted stones include a 13 ct and a 15.6 ct. A 14.6-gram piece found in the Soturno River in 1985 yielded a superb 18.5-ct cat’s-eye alexandrite, one of the world’s largest (figure 11). In addition, also in 1985, an 8.1-gram twinned crystal of very rare dark red chrysoberyl (with no color change) was recovered at Córrego do Fogo (again, see figure 2). Limited amounts of very fine, but small (2–3 ct) blue sapphires have been found in these valleys along with some, also small (2–3 ct) gem peridot as well as 50–70 kg of good rubellite crystals.

Overall, the alexandrites from Malacacheta are much smaller than those from the Hematita deposit discussed below, because the rough is not as clean or as large. These stones generally are yellowish green in sunlight and pink in incandescent light. The best gems from Malacacheta do not compare with those from Hematita.

The author feels that the Malacacheta region will continue to produce very small quantities of good alexandrites for many years. The most easily accessible and obvious deposits have been extensively but not completely worked. Currently only about 50 garimpeiros are working in this region, not because of a total lack of potentially good areas, but because Hematita is the new El Dorado.

ALEXANDRITE FROM THE LAVRA DE HEMATITA DEPOSIT

Although the Malacacheta region represents one of the world’s great alexandrite locations, in 1987, over a period of less than three months, the size and quality of production from a new discovery called Lavra de Hematita dwarfed its importance. Many prominent dealers and collectors already acclaim this new area as history’s greatest alexandrite discovery. To date, Hematita has yielded tens of kilos of alexandrites, including many 10-ct and

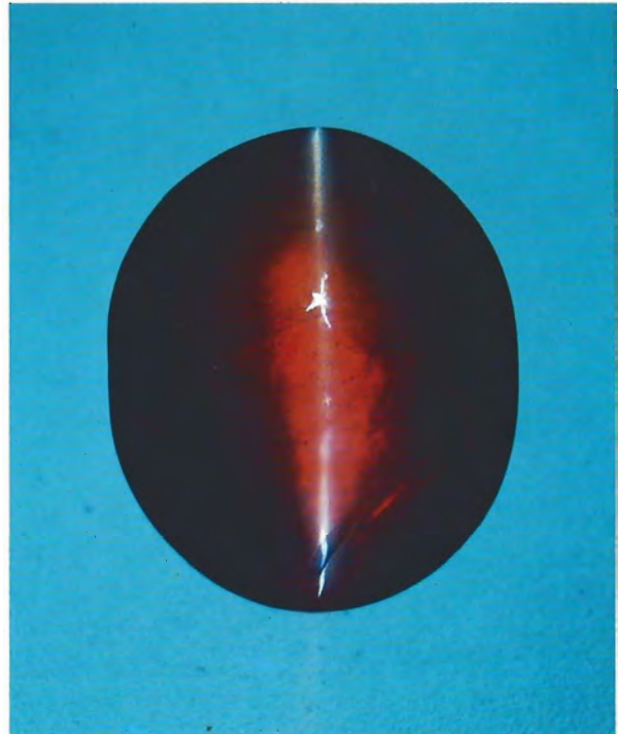


Figure 11. One of the rarest stones to emerge from the Malacacheta region is this 18.5-ct cat’s-eye alexandrite. Courtesy of Henry Kennedy; photo © Harold & Erica Van Pelt.

even some 25- and 30-ct clean faceted gems of exquisite beauty that exhibit an extraordinary color change.

Location and Access. The Hematita alexandrite workings can be reached from either Governador Valadares or Belo Horizonte by taking main highway 381 to an unnumbered dirt road that is 15 km southwest of the city of Antônio Dias and 5 km northeast of Nova Era; follow this road (which has a sign labeled Hematita) due north 23 km to the mining area, which is just off the right side of the road and only 3–4 km southwest of the hamlet of Hematita (figure 12). The mine is correctly called Lavra de Hematita (*lavra* means mine), but it is also known internationally as Nova Era; most Brazilians refer to it as Lavra de Itabira, or more commonly just Itabira. For the purpose of this article (and to avoid confusion with the Itabira emerald locality, where alexandrites have also been found), *Hematita* will be used.

History. The history of this discovery begins with two 10-year-old boys, one the son of a local farmer

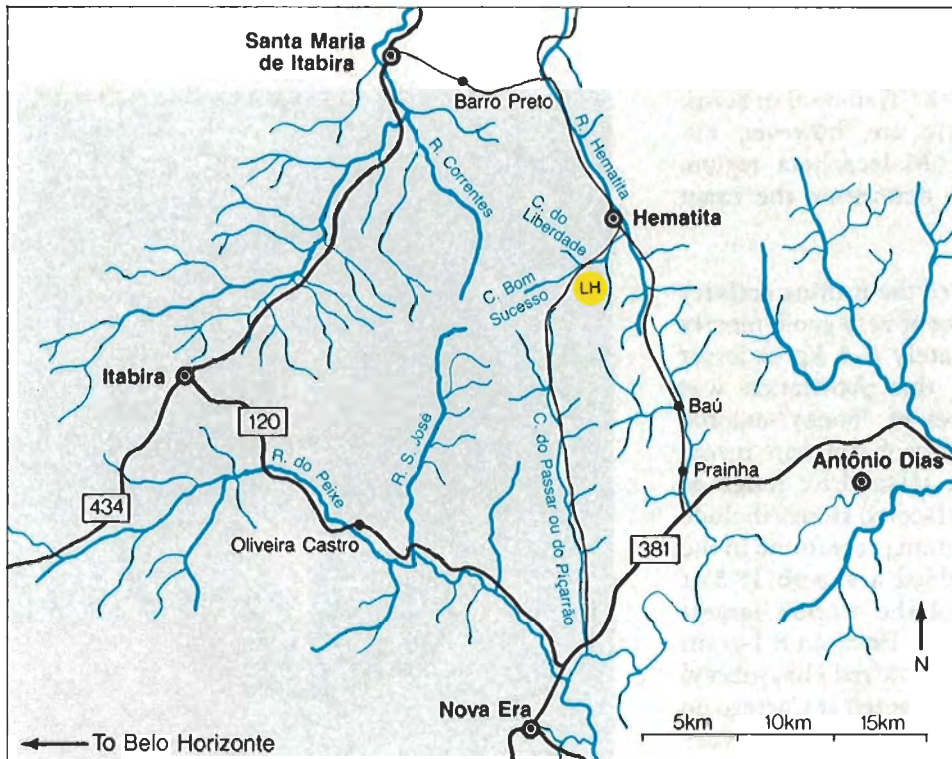


Figure 12. Perhaps the largest deposit of alexandrite ever discovered was found at the Lavra de Hematita (LH), a small area just southwest of the small town of Hematita in the Itabira mining district. See the inset map in figure 4 for the location of Itabira in relation to the other mining areas discussed in this article. Artwork by Jan Newell.

named Xisto. The boys often played in two brooks that cut through part of the homestead owned by a farmer named Policarpo, which is located within a eucalyptus plantation owned by Ferro Brasileira, an Itabira steel company. (The eucalyptus trees are burned for charcoal that is used to produce steel.) The boys put together a collection of small rough gems that they had found in the creeks, and in October 1986 took them to the nearby city of Santa Maria de Itabira. They sold the stones to a man named Rodazio who, thinking they were andalusite, purchased them for a pittance and told the boys to come back with more if they could. During November, the two boys dug more of the stones, selling some and showing others to Policarpo, Xisto, Socrates (who owns Macil, a hematite mining company nearby), and Arthur (another homesteader living within the plantation); all attempted, at first unsuccessfully, to identify the stones (A. Tavares, J. Drew, L. Nercessian, pers. comm., 1987).

In the meantime, Rodazio sold his ever-growing collection of "andalusite" to a visiting Teófilo Otoni gem dealer, Joaquim Feijão. Feijão's suspicions were confirmed when he took the rough to Teófilo Otoni: This was indeed alexandrite—and among the best anyone had seen from Brazil. As he sought the source, he eventually met Socrates, Arthur, Xisto, and Policarpo, who by now were all

attempting to dig some of the rough. In November 1986, two Brazilian companies headed by Socrates and Xisto almost simultaneously requested an exploration permit from the government to open the alexandrite occurrence. By December, after much squabbling among themselves, the two groups combined their efforts and began mining the area by hand (as yet without the official government license). They agreed to keep the new discovery quiet for fear garimpeiros would invade the property. Although Ferro Brasileira owned almost all of the land, the mining rights in Minas Gerais belong to the state and any licensed garimpeiro can invade the property and mine at will.

Infighting and clandestine digging continued until the first big parcel—21.5 grams—arrived in Teófilo Otoni on January 28, 1987, and was shown to A. Tavares, K. Elawar, and other prominent dealers. Each recognized that this was among the finest alexandrite ever seen and sensed the real importance of the find. On February 8, the first five faceted stones (totaling only 11 ct) sold for US\$40,000 to Japanese buyers (A. Tavares, pers. comm., 1988). By February 15, several dealers and garimpeiros had discovered the location of the deposit. By March 15, the trickle of garimpeiros had turned into a flood; by the end of March, 3,000 pit diggers had invaded this very small valley deposit (see figure 13). A tent city sprang up



Figure 13. Within a matter of weeks after the Hematita deposit was discovered by local miners and dealers, both sides of this meandering brook, and even the brook itself, were invaded by thousands of miners. Note in the pit on the right the clear demarcation of three layers—an overburden of clay and sand, the heavily quartz- and kaolin-bearing gem gravel, and a dark layer of what appears to be clay below that. The apex of this small, triangular-shaped valley pinches in at the top of the photo. Photo by Agenor Tavares.

overnight with extremely primitive living conditions.

At the mine, pandemonium broke out as each garimpeiro attempted to stake out a few square meters for himself. There was not enough land to go around and huge fights, including gunplay, erupted. In their frenzy to get their share, many garimpeiros dared not leave their pits, even to buy food; they slept virtually standing or sitting up, body to body (R. Nash, pers. comm., 1987). The men were so close together that a shovel of clay or dirt thrown anywhere infringed on a neighbor's rights and sensibilities.

This extremely intense digging activity, plagued by arguments, outbreaks of violence, and numerous robberies (as professional thieves also invaded the area) continued for almost three months. The stakes were high: The equivalent of approximately US\$5 million was spent on alexandrites at or near the mine during this period (L.

Nercessian and K. Elawar, pers. comm., 1987). One small handful of rough from one little pit could take a garimpeiro from abject poverty to instant wealth. As usual, though, many garimpeiros received little or none of this treasure and were unable even to make expenses; several team leaders of groups of 20 to 30 miners reported that they did not find one piece (K. Elawar, pers. comm., 1987).

Most of the alexandrites were found during these three months, with the best 70–80% coming out between April 15 and May 15. Eventually, though, the violence became so widespread that the military police were called in. On June 18, the area was “closed.”

After the “closure,” many of the garimpeiros stayed, hoping that the area would reopen at any time. With no production, money, food, or sanitary facilities, it did not take long for an ugly mood to develop. The federal military police put up a

barbed wire fence around the entire mining area, but most of the remaining miners were willing to risk everything for a chance to dig. The reader can imagine the situation of 60 to 100 military police trying to control thousands of hungry and angry miners. They became more brazen after dark, and every night many (sometimes hundreds) of miners would go through the fences and mine by moonlight, which resulted in several shootings. Many who were there to maintain control were seen digging in the pits themselves.

The mine remained "closed" in this fashion until August 18, when Warren Brennan, a geologist and gemstone dealer from Los Angeles, arrived with a group of people, including 10 federal plainclothes police and a judge from Hematita. This group "re-opened the mine," and 150 of the 800 garimpeiros who still remained outside were let in late that afternoon, with another 150 allowed in the following day. On the 20th, 2,000 more miners returned, expecting open mining to start again; a line of parked cars more than a kilometer long dominated the scene. Violence ensued almost immediately, and the army closed the area again on August 23.

That night was one of the most violent in Minas Gerais mining history. The garimpeiros set fire to the eucalyptus forest opposite the mining area, and even to several cars. At least one soldier was shot and approximately two dozen miners were wounded in the fighting that ensued (D. Schwartz and W. Brennan, pers. comm., 1987). Between 10 and 15 people have died at these diggings so far. On August 24, the military police rerouted one of the creeks and flooded most of the mining area so that it was virtually unworkable.

On October 1, with special permission from the Minister of Mines, 60 to 70 members of the International Gemmological Conference (IGC) visited the closed mine (Koivula, 1987), but were allowed to stay only 45 minutes. Although the mine remains "closed" (with periodic clandestine digging) at this writing (February 1988), it was scheduled to reopen officially in March 1988 (D. Schwartz, pers. comm., 1988).

Geology and Occurrence. It is important to visualize just how small this deposit is. The mining area is only 200 m long by 150 m wide (approximately 650 by 500 ft.), with the diggings extending over a roughly oval area. However, 70–80% of the choicest rough came from a triangular-shaped area only

500 m² (again, see figure 13). Two small brooks cut through this alluvial deposit and meet at the center of the richest find (S. Domingos, pers. comm., 1987). This brook divides again and then rejoins before leaving the deposit area, at which point it passes over a waterfall and empties into the *Córrego do Liberdade* (Liberty Creek), which runs almost perpendicular to the fall line of the valley itself. Significantly, little or no gem alexandrite was found below the *Córrego do Liberdade*, although a backhoe operation near this creek did yield small amounts of rough.

At least four geologists and/or mining engineers have visited this deposit. They have identified three distinct "environments" (and variations thereof; again, see figure 13) containing the gem-bearing gravel layers.

In part of the valley, Dr. Rex Nash found evidence of the typical Marambaia-type alluvial deposit (see, e.g., Proctor, 1984), with the gem-bearing gravels probably lying on top of bedrock and under interbedded layers of sand and clay. Unlike the granite pebbles and boulders of Barro Preto, 99% of the gem-bearing gravel in this area appeared to be rolled quartz pebbles in sizes of 2 to 10 cm (1 to 4 in.). Dr. Nash noted that the overburden—mostly clay with some sand and only a small amount of red soil—was 1.5 to 2 m thick.

Another geologist, Sabastião Domingos, noted that elsewhere in the deposit the *cascalho* layer averaged 50 cm (20 in.) thick and varied from 1 to 5 m below the surface. Domingos also reported a 20-cm-thick layer of sand—which also contained fragments of alexandrite—approximately 1 m above the main *cascalho* layer.

Warren Brennan noted quite different conditions in a separate region of the same narrow valley. The exposed walls of several pits over 3 m deep showed three distinct quartz-pebble gravel layers. The top layer began approximately 30–60 cm (1 to 2 ft.) deep under the surface clay layer (with very little sand showing) and was 30–45 cm thick. Under that was another 30–45 cm layer composed mostly of clay, which overlay the middle gravel layer, 30–45 cm thick. Another clay layer, over 30 cm thick, covered the bottom gravel layer almost 3 m below the surface. Some clay was found in the three predominantly quartz layers, and some quartz in the clay layers. The quartz layers also contained significant amounts of kaolin. Brennan examined about eight piles of previously washed quartz pebbles from all three layers and noted that

most of the pebbles ranged between 1 and 10 cm. Half were about 90% rounded, with the rest only slightly (perhaps 10%) rounded. Brennan found one 7.5-cm (3-in.) perfectly terminated quartz crystal.

The three quartz-pebble layers undoubtedly represent three different periods of deposition. The top two quartz-pebble layers, lying on clay layers, are apparently colluvial deposits similar to those found at Barro Preto. The interbedded layers of clay and quartz, and the extremely high concentrations of kaolin clay (figure 14), are seldom if ever seen in a purely alluvial environment, where the swift waters typically wash most of it away.

Much of the alexandrite also showed sharp edges or, frequently, one complete crystal face, as well as a number of complete crystals, some twinned and some as large as 1.4 cm (L. Nercesian, A. Tavares, K. Elawar, and K. Schmetzer, pers. comm., 1987). The good crystalline condition of some of the quartz, the abundant alexandrite fragments with sharp edges and crystal faces, and the great amounts of kaolin indicate that the deposit moved less than 100 m downstream after it eroded and weathered out of the hillside in which it had formed (R. Nash, pers. comm., 1987). Or, as at the Salinas tourmaline deposit (Proctor, 1985a), the Hematita alexandrines actually may have moved very little but rather decomposed in place as the hillside in which they were originally contained eroded and became part of the valley floor (R. Nash, pers. comm., 1987).

Nash believes that several factors strongly suggest that this alexandrite deposit, unlike the others reported in the literature (e.g., the Urals, Itabira, Carnaíba, etc.), may actually have formed in a pegmatite. Although the presence of quartz, kaolin (from weathered feldspar), and even aquamarine—which are commonly associated with pegmatites—could be explained by the weathering of pegmatites in the granite host rock at the same time as the alexandrite, the large pieces of clean alexandrite found are typical of pegmatite mineral crystallization, as is the unusually large proportion of transparent material. Again, though, no alexandrite crystals have been found *in situ*, so further study is needed.

Statements by some dealers closely associated with this mining operation strongly suggest that most of the best gems were found in the lower, truly alluvial bedrock gravels of this valley, just as they were at Barro Preto, Gil, Marambaia, and Tres



Figure 14. Great quantities of kaolin (decomposed feldspar) were found at Hematita, turning many of the pits almost completely white. Photo by Agenor Tavares.

Barras (K. Elawar and A. Tavares, pers. comm., 1987).

Mining. The first diggings in the surface dirt here involved just pick and shovel work, with the soil and clay being washed with screens in the nearby creeks. This method quickly evolved into the excavation of square pits as deep as 5–6 m (D. Schwartz and S. Domingos, pers. comm., 1987; again, see figures 13 and 14). After the garimpeiros dug their pits and extracted what gravels they could, they let the pit fill up with water and began the tedious washing operation with circular screens. More sophisticated garimpeiros used two “stacked” screens, with different meshes, for better sorting. Pumps were necessary to keep most of these pits workably dry (figure 15). Most of the areas mined were worked by hand.

Production. As with most gem deposits in Minas Gerais, production statistics are elusive, but major dealers estimate that approximately 50 kg of alexandrites have been found at Hematita thus far. Of this, however, only approximately 10 kg show the best clarity and color change, resulting in 10,000 to 15,000 ct of fine to superior gems (L. Nercessian, pers. comm., 1987). Some clean, large pieces of 16 and 20.5 grams yielded almost exactly 50% when cut (K. Elawar, pers. comm., 1987). Several clean or mostly clean pieces of rough of 17 to 56 grams were also seen by H. Bank, K. Elawar, A. Tavares, and L. Nercessian, but most of the rough found weighed less than 1 gram (L. Nercessian, pers. comm., 1987).

Several large faceted alexandrites – many over 10 ct and at least one as large as 30 ct – have been cut from the Hematita rough. A few superb cat's-eye alexandrites over 10 ct were also cut (K. Elawar, pers. comm., 1987). The bulk of the material was

Figure 15. Pumps were required to rid most of the pits of water at Hematita. Note also the many circular screens, which the miners use to wash the gravels in their search for the gem alexandrites. Photo by Agenor Tavares.



faceted into many thousands of medium to very fine stones between 0.20 and 6 ct. One- to 2-ct stones were abundant, but 3-ct and larger stones made up no more than 15% of the total number. Roughly 50–60% of all sizes, and especially the very small sizes, are “clean” (K. Elawar, pers. comm., 1987), with 40–45% exhibiting a good color change from greenish blue to some shade of pink or red. Some stones that display a very attractive color change are far from clean (K. Elawar, pers. comm., 1987).

The lion's share of the production was purchased by four companies: K. Elawar, Ltda., Tamil (owned by A. Tavares), and the two companies owned by the two brothers Hilton (Zequinha) Lopes and Lopes Duarte. As of January 1, 1988, roughly one-third of the total production remained in Teófilo Otoni. About 40% had gone to Hong Kong and Japan, German buyers had purchased approximately 20% of the total, and the remainder was sold primarily to American buyers (K. Elawar and L. Nercessian, pers. comm., 1987). Although much of the valley floor was dug up, it appears that many sections remain untouched (D. Schwartz and L. Nercessian, pers. comm., 1987). However, clandestine digging during 1988 has produced little of value (R. Nash, pers. comm., 1988), which raises some questions as to the true potential of the deposit.

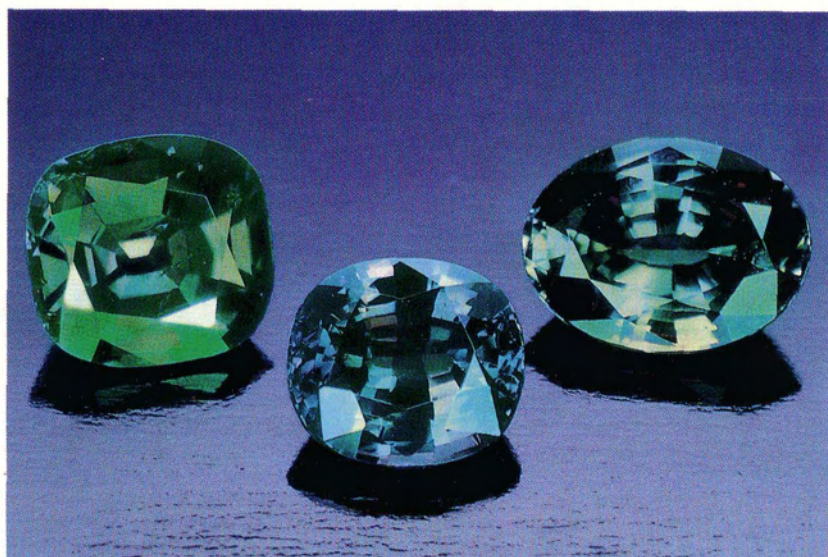
The Hematita Alexandrites. The Hematita alexandrites contain 0.30–0.44 wt.% Cr_2O_3 , 1.11–1.59 wt.% Fe_2O_3 , and 0.01–0.03 wt.% V_2O_5 (H. Bank and K. Schmetzer, pers. comm., 1987). The best Hematita gems compare very favorably with the best Russian material: greenish blue to blue in sunlight and pink to red in incandescent light (figure 16). Since alexandrite is trichroic, the best color can be achieved only if the cutter uses the correct orientation of the gem's table in relation to the c-axis.

The best pink to red colors exhibited by this gem in incandescent light are invariably coupled with a very distinctive slightly greenish blue to blue color the Brazilians call *pavão* (peacock). The best (or most complete) color change involves *pavão* in sunlight changing to a strong pink, raspberry, or deep “rhodolite” or “ruby” red in incandescent light. About 30% to 45% of the best 10 kg exhibited this color change (K. Elawar, pers. comm., 1987).

A more greenish or yellow-green color in



Figure 16. The color change of the two Hematita alexandrites (1.06 ct—center, 1.32 ct—right) is very similar to that of the fine Russian stone (1.29 ct) on the left. The photo at the top was taken with incandescent light; the one at the bottom with fluorescent light. The two Hematita alexandrites are courtesy of Mayer & Watt; the Russian alexandrite is courtesy of Mary Murphy Hammid. Photo © Tino Hammid.



sunlight is usually coupled with more purplish tones in incandescent light, while a very dark blue (with some brown or even a gray-brown) as the predominant daylight color is usually associated with a dark brownish red or reddish purple in incandescent light (K. Elawar and A. Tavares, pers. comm., 1987).

With the increased interest in alexandrites stimulated by the Hematita discovery, there appear to be more synthetic alexandrites on the market. The buyer is advised to be aware of the distinctions between natural and synthetic alexandrites before he or she purchases any stone (see, for example, Stockton and Kane, 1988). Inclusions observed in the Hematita alexandrites include apatite, fluorite, mica of the biotite group, and two- and three-phase inclusions (E. Gübelin, H. Bank,

K. Schmetzer, and H. Hänni, pers. comm., 1988; see Koivula and Kammerling, 1988, for photomicrographs).

OTHER CHRYSOBERYL AND ALEXANDRITE DEPOSITS IN BRAZIL

In Minas Gerais, small amounts of chrysoberyl have also been found near Santo Antônio do Jacinto, located on the border with Bahia. In 1972, a six-month production from Lavra dos Coimbras, southwest of the Americana/Santana valley region, yielded significant amounts of alexandrite (H. Kennedy and A. Tavares, pers. comm., 1987). In August 1987, small amounts of small but clean alexandrite were taken from another location in the Hematita region, approximately 8 km in the

direction of the city of Antônio Dias (and referred to by that name). Other deposits are shown on the map in figure 4.

Quite a few locations in the state of Bahia have produced chrysoberyl and/or alexandrite, including Sócota, Jaguda, and Jacundá (principally alexandrite; H. Bank, pers. comm., 1987) as well as Jaqueto (chrysoberyl and some alexandrite; the 6,250-gram [20 cm high] *Mitra* [or Bishop's hat] cat's-eye was found here as was a 25.2-kg chrysoberyl crystal). The Carnaíba emerald mine (in the Campo Formosa area) produced some primarily low-quality alexandrite and some superb sixling crystals. Chrysoberyl or alexandrite has been found near the cities of Águas Frias, Itanhém, Teixeira de Freitas, Cachoeira do Mato, Itamaraju, Faria Lemos, and on the Córrego de Água Preta (J. Raggi and A. Lúcio, pers. comm., 1987). In southern Bahia, Lagôa da Prata has produced approximately 10–15 kg of alexandrite with a light green to pink color change, and consistently produces chrysoberyl and cat's-eye chrysoberyl (K. Elawar and H. Kennedy, pers. comm., 1987).

Several locations in the state of Espírito Santo also produce chrysoberyl and cat's-eye chrysoberyl (but insignificant amounts of alexandrite): the Colatina region is represented by São João Grande and lime-green stones from Município de Vila Panca; the Itacriso mine, 40 km west of Colatina, has been one of the largest producers outside Minas Gerais (J. Raggi and L. Necessian, pers. comm., 1987). Mineral collectors know the famous deposit at Itaguaçu, some 35 km southwest of Colatina, where a few superb cyclic sixling chrysoberyl twin crystals (called trillings) as large as 9.5 cm were found ("Interview: Allan Caplan," 1980).

CONCLUSION

For the past 50 years, the Americana and Santana valleys have been one of the most productive regions in the world for chrysoberyl and cat's-eye chrysoberyl. The Faisca and Cilindro deposits, together with the Barro Preto and Gil claims, are the largest and most consistent producers in the region. Exceptional alexandrites and cat's-eye alexandrites have also been found in this region, at the Coimbras deposit.

Since 1975, the Malacacheta region has developed into one of the world's premier alexandrite-producing areas. In 1987, however, the production at Malacacheta was eclipsed in size and quality by

the gems found at Lavra de Hematita, which is probably the single most significant alexandrite deposit in history.

Throughout this series of articles on gems from the pegmatite districts of Minas Gerais, we have observed how gem rough occurs in a great variety of environments. Primary, *in situ* deposits are not common but often produce the finest materials (see, e.g., the Jonas rubellite mine, Proctor, 1985b). Most primary deposits have decomposed over time, so that the gems are found dispersed in secondary deposits with either kaolin-clay (see, e.g., the Santa Rosa and Golconda III tourmaline mines; Proctor, 1985b) or red soil, which represents a further degree of dispersal (see, e.g., the Ouro Fino tourmaline mine as well as the Pioneer and Pine Tree aquamarine mines; Proctor, 1984, 1985a). In all of the chrysoberyl and alexandrite deposits discussed in this article, we have witnessed the complete dispersal of gems into alluvial as well as colluvial gravels.

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FACETING LARGE GEMSTONES

By Michael Gray

The quest for the largest permeates all societies and disciplines. With the advent of new machinery and techniques, size records for faceted gemstones are falling constantly. Currently, a 22,898-ct yellow topaz holds the record for weight and a 19,548-ct citrine holds the record for size. This article discusses some of the more important gemstone giants, and describes the specialized equipment and techniques developed to cut and polish them.

ABOUT THE AUTHOR

Mr. Gray, who has more than 20 years' experience cutting unusual stones, is president of Graystone Enterprises, P.O. Box 1110, Venice, California, a company specializing in collector stones and unusual gem materials.

Acknowledgments: John Sinkankas provided invaluable help through his books and the personal experiences he has related. Without the various cutting books of Glenn and Martha Vargas, every different gem material would mean many hours of experimentation and research. Art Grant and John Bradshaw proofread the manuscript and made valuable comments. Special thanks to my father, Elvis "Buz" Gray, whose confidence in me allowed me to work with many materials that a normal cutter would never see. And very special thanks to my wife, Patricia, whose persistence and belief in me made this article a reality.

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Since earliest history, the maxim "bigger is better" has held almost universal sway. Whether it is the longest automobile, the tallest building, or the largest airplane, the human animal is caught up in the frenzy of always reaching to expand our limits. Such is the case with the fashioning of gemstones.

As an example, at the heart of the Crown Jewels of England are the 167-ct Edwardes ruby, the Timur "ruby" (actually a 361-ct red spinel), and the Cullinan I, at 530.20 ct the largest faceted diamond in the world (Arem, 1987). The fashioning of these stones required not only special pieces of rough, but also special equipment and special skills. Yet it is human nature that when presented with a challenge, the individual will rise to meet that challenge.

A new challenge was met over 30 years ago by John Sinkankas, when he first tackled the problem of how to maximize the yield and creative possibilities of various extremely large (some weighed several pounds) pieces of rough beryl, quartz, and topaz. To fashion such large pieces into the sizes and shapes that he desired, Sinkankas determined that he would have to have a special faceting machine built, one that could cut stones that were more easily measured in pounds or kilograms than carats. After studying the attributes of the faceting machines available at the time, Sinkankas decided that the design of the Allen faceting machine (now no longer on the market) would suit his needs best. With the permission of Mr. Gene Allen, he had a faceting machine built with components that were 1.5 times larger than normal, and that could handle cutting and polishing laps with more than twice the working area of normal laps. It is with this machine that Sinkankas fashioned the quartz eggs on his custom-made jeweled stands that are found in major museums today (Sinkankas, 1984). The largest of these magnificent faceted eggs, at 7,000 ct, is located in the Smithsonian Institution, Washington, DC. Other gemstones cut by Sinkankas on

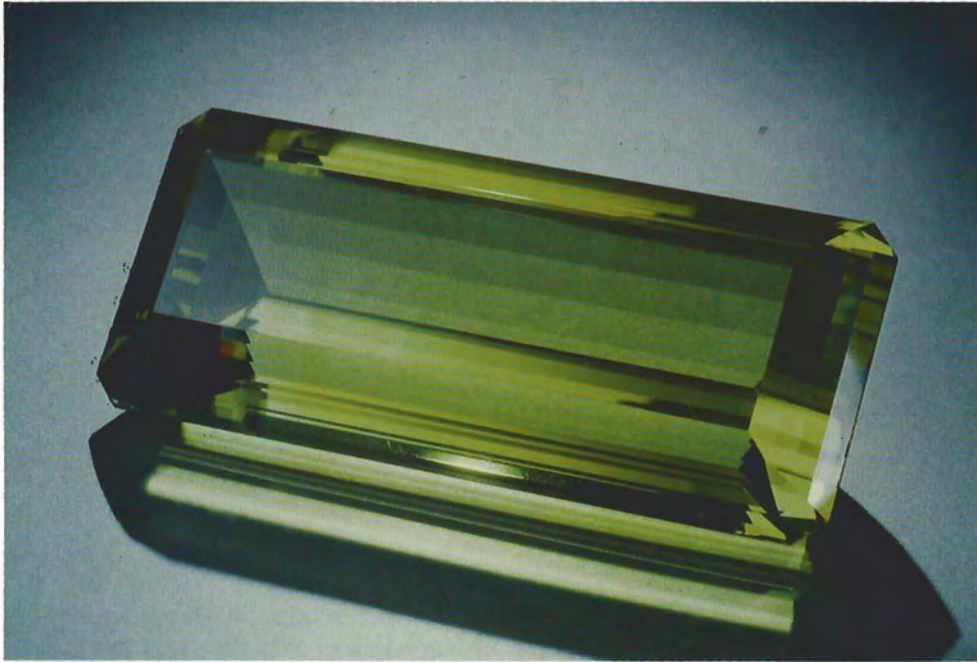


Figure 1. John Sinkankas cut this 2,054-ct green-gold beryl (12 × 5 cm) in the early 1960s on a special machine he designed based on the Allen faceting machine. Courtesy of the Smithsonian Institution.

this machine in the early 1960s include a 2,054-ct green-gold beryl (figure 1) and a 3,273-ct light blue topaz, both also in the Smithsonian, as well as an 1,800-ct greenish yellow spodumene that is currently in the Royal Ontario Museum in Toronto, Ontario.

In the mid-1970s, another milestone was

Figure 2. The Brazilian Princess, at 21,005 ct (14.3 × 14.3 × 12.7 cm), is the largest faceted natural-color blue topaz in the world. Cut by Elvis "Buz" Gray, it took over two months to complete. Stone courtesy of the American Museum of Natural History; photo © Harold & Erica Van Pelt.



reached when gem and mineral dealer Edward Swoboda commissioned Elvis "Buz" Gray to fashion the largest stone possible from a 90-lb. (41 kg) crystal of natural-color blue topaz that he had brought from Brazil in the 1950s. The machine used to facet the stone was based on the one developed by John Sinkankas, which had previously held the record for cutting the largest faceted stone, the 7,000-ct quartz egg mentioned above. Various technological improvements were made on the design of the machine, such as adding calibrations for accuracy, incorporating cheaters to provide greater flexibility in adjusting the stone during cutting and polishing, and reinforcing various components so that the machine could hold the 15-lb. preform. The use of diamond-impregnated laps enabled cutting to proceed much faster than it had for Sinkankas 10 years earlier, when the laps had to be charged with diamond powder by hand. By using a vibrating polishing machine, Gray was able to finish the table of the stone without giving it constant attention. Even with these new cutting and polishing advantages, though, it took "Buz" Gray over two months in 1976 to complete this 21,005-ct square cushion-cut stone, christened the Brazilian Princess, which is now on display at the American Museum of Natural History in New York (figure 2).

Since then, other cutters have sought to push the limits even higher, although they are hampered by the lack of large gem-quality rough and by the expense of the specialized machinery, as well as by



Figure 3. This 19,548-ct (25.5 × 14.1 × 10 cm) citrine, cut by the author, is the largest (in volume) faceted stone in existence. Photo © Tino Hammid.

the time involved to complete these behemoths. In the past couple of years, though, several significant stones have been faceted. In 1987 alone, Richard Homer of GIA cut a 20,769-ct irradiated blue topaz (see Christie, 1987); Leon Agee cut the heaviest faceted stone on record, a 22,892-ct yellow topaz (J. White, pers. comm., 1988); and the author cut the largest stone on record, a citrine that is 20% larger (in volume) than Agee's stone but, because of the lower specific gravity of quartz, weighs in at just 19,548 ct (see Thompson, 1987; figure 3). Table 1 lists the largest stones (over 1,000 ct) faceted to date, to the author's knowledge. The green beryl, the Brazilian Princess, the citrine, the blue fluorite, the kunzite, and the yellow spodumene are illustrated in figures 1–6.

Cutters do not facet large stones, especially the giants, to make a lot of money. In almost every case, a cutter could make much more by cutting up the rough into jewelry-size stones and selling them

Figure 4. Fluorite can cause special problems during faceting because of its softness. Art Grant cut this 3,969-ct (8-cm square) blue fluorite, the largest of its kind. Photo © Tino Hammid.



Figure 5. Kunzite in a size and quality to yield a large cut stone is very uncommon. This 1,267-ct (7 × 5.4 × 3.7 cm) kunzite is a rare specimen indeed. The brass dopsticks shown here are of the type used to facet large stones. The V-shaped dopstick attaches to the pavilion; the flat dopstick attaches to the table. The silver “dop-chuck” serves to convert normal dopsticks for use on the larger faceting machines required for large stones.

Courtesy of the Los Angeles County Museum of Natural History; photo by Dick Meier.



in quantity. The same holds true when he or she facets stones for someone else. In many cases, the cutter is lucky to make expenses when fashioning such large pieces, considering the costs of the equipment and materials, the enormous amounts of time involved in the cutting, as well as the limited market for the stone once it is completed. However, the challenge of the task and the prestige of the accomplishment prods the cutter on—the desire to be able to cut any size stone.

While extremely large stones are not suitable for use in jewelry, they do serve several purposes. First, these stones help educate the public. Since large stones are enlarged versions of stones that can be worn, they demonstrate the function that the facets play in giving beauty to a stone. They also illustrate just how large some gem materials may occur and can be cut. Large stones are popular exhibits at gem and mineral shows and museums. In the same manner, such stones are used in jewelry store displays not only to help educate the public, but also as a promotional tool to draw customers to the store.

This article examines the fashioning of such large stones using today's technology and equipment, with specific remarks related to the cutting of the author's 19,548-ct citrine (figure 3) since that stone is the largest (in volume) faceted stone at this time, and any problems encountered would be magnified on it. To many faceters, a large stone

would probably mean one that would be over 100 ct when cut. However, one can cut stones up to 1,000 ct from topaz, spodumene, fluorite, and calcite, and up to 800 ct from quartz (due to its lower specific gravity), without much difficulty on standard faceting machines and with special attachments being manufactured today. Basic faceting procedures are covered in the excellent manuals written by Sinkankas (1984) and the Vargases (1977). This article covers those areas where the size of the stone dictates modifications in equipment, materials, and techniques. Once one reaches about the 1,000-ct mark, special machinery is needed to facet these remarkable gems.

THE FACETING PROCEDURE

Equipment. Before one can begin to cut a large stone, one needs to have the proper equipment. The requirements for most stones over 1,000 ct include access to 24-in. self-feeding table saws and heavier grinding units for preforming, a special faceting machine that can accommodate 12- to 16-in. cutting and polishing laps, and a lathe for turning the stone over when one half of it is finished.

Preforming. Much time and effort can be saved by preforming any stone before it ever touches a faceting lap, but this is especially true for larger stones. The more one can saw and grind off on



Figure 6. The yellow spodumene shown here, accompanied by a large crystal of the same material, weighs 1,240 ct ($9.5 \times 5.3 \times 4.6$ cm). Photo © Harold Erica Van Pelt.

relatively inexpensive diamond grinding wheels, the less time one must spend grinding away material on more expensive diamond flat laps.

Most heavy-duty preforming can be done with remarkable accuracy on a 24-in. self-feeding table saw, which is commonly available through local gem and mineral clubs or rock shops. The stone should be clearly marked with indelible ink (a Marks-a-Lot pen works well) exactly where it is to be cut and lined up with the saw blade. Remember that the saw cut will be several millimeters wide. The stone should be securely fastened and wedged in place, so that it will not move or wobble; always recheck the alignment after set-up. If the stone is lined up correctly, the self-feeder advances it at a predetermined rate and makes the cut along the

marked line. In the case of the big quartz, approximately six hours were needed to line up and saw off all extraneous material; it might have taken several days to grind off the same amount.

Once the stone has taken a preliminary form through sawing, it must be further shaped on a coarse grinding wheel, 80 grit or rougher, mounted in a cabochon-making machine (figure 7). With practice, one will produce a preform that requires very little grinding on the faceting machine and thus will save days of slow lap cutting. On very large stones (those over 5,000 ct) it is often desirable to lap and polish the table of the stone on a vibrating lapping machine, such as a Vibra-Lap or Recipro-Lap before cutting any other facets. It is at this point that there is the smallest surface polish-

TABLE 1. Largest gemstones on record for those materials from which single stones over 1,000 ct can be faceted.^a

Species and variety	Weight (ct)	Cutter	Current location
Quartz			
Citrine ^b	19,548	M. Gray	Private collection
Smoky	8,580	J. Johnston	GIA
Crystal	7,500	M. Gray	Private collection
Topaz			
Yellow	22,892	L. Agee	Smithsonian Institute (destined)
Natural blue ^b	21,005	E. Gray	American Museum of Natural History
Irradiated blue	20,769	R. Homer	Private collection
Beryl			
Aquamarine	2,594	J. McLean	Private collection
Green-gold ^b	2,054	J. Sinkankas	Smithsonian Institute
Spodumene			
Greenish yellow	1,800	J. Sinkankas	Royal Ontario Museum
Kunzite ^b	1,267	Unknown	Los Angeles County Museum of Natural History
Yellow ^b	1,240	M. Gray	Private collection
Fluorite			
Blue ^b	3,969	A. Grant	Private collection
Yellow	1,032	M. Gray	Los Angeles County Museum of Natural History
Calcite			
Twinned	1,800	A. Grant	New York State Museum

^aBased on research by Michael and Patricia Gray.

^bPhoto appears in this article.

ing area in relation to the greatest weight on the stone to help hold it down flat. Also at this point, there are no polished facets, which would be susceptible to damage while the stone is on the machine. Even a dopstick (the rod that attaches the stone to the faceting machine) can throw the stone off-balance during cutting and polishing of the table. It is necessary to follow closely all the grinding and polishing steps recommended in the instructions that come with the machine to get the flattest table, and thus the best polish possible. Any rounding that occurs along the edge of the polished table will be cut away when the crown facets are ground in. Cutting and polishing the table may take as long as a week if one starts with a fairly flat, even table surface, but it is only necessary to check on the progress of the stone once or twice a day (figure 8).

Dopping. Large stones do not lend themselves to the normal hot-wax dopping procedure. It is difficult to heat the stone uniformly to a high enough temperature to get the wax to seal, and heating a stone unevenly may cause even non-heat sensitive materials, such as topaz or quartz, to fracture. Furthermore, when the wax hardens, it becomes

brittle and may crack, separating the dop from the stone. Another worry is that the hard wax will not hold up to the rigors or the pressure necessary during cutting and polishing.

Most contemporary large-stone cutters use cold-dopping procedures (A. Grant and J. Bradshaw, pers. comm., 1988), since epoxy is much easier to work with than dopping wax, does not require heating the stone, and is readily available in any hardware store. The epoxy is not applied between the stone and the dop; rather, the stone is held to the dop with a material such as modeling clay, and the epoxy is then applied over the connecting end of the dopstick onto the stone, covering the holding material in the process. Care must be taken not to seal the dopstick directly onto the stone, since epoxy dissolvers cannot easily penetrate the thin film that joins the dopstick to the gem. Should this happen, the cutter would have to saw through the dopstick, ruining the polished facets or table in the process, as well as the dopstick.

Even the brand of epoxy can make a difference: Through trial and error, many cutters have found that Devcon epoxies are among the most reliable (A. Grant and J. Bradshaw, pers. comm., 1987). In large stones, since the tensile and shear strength of



Figure 7. After the stone has been sawed, it is preformed on a coarse grinding wheel that has been mounted in a cabochon-making machine. Here, a calcite is being rough ground prior to dopping. Photo by Robert Weldon.

Five-Minute and the longer-drying Two-Ton epoxy is essentially the same, the choice between them is dictated by the specific dopping procedure. On the initial dopping to the table of the large citrine, Two-Ton epoxy was chosen because it is slightly more durable, is water-resistant, and the drying time required, about 30 minutes, is of little consequence. When the stone was transferred to another dopstick (the operation of turning the stone over), Five-Minute epoxy was used because it doesn't flow as fast and it hardens more quickly, making it easier to apply for this purpose. Through experience, however, it has been found that in the large quantities used for large stones, Five-Minute epoxy does not seem to harden as well as Two-Ton epoxy, and it is not completely water-resistant. These factors do not play as big a part once the stone has been transferred, though, as most of the

strain of cutting will have already been experienced. One advantage of the quicker drying epoxy for the large citrine was that when the stone was finished, it was possible to cut through the epoxy with a red-hot knifeblade to remove the dopstick from the stone. The remaining epoxy was then removed by soaking the stone in Attack, an epoxy remover available through jewelry supply houses. By removing the dopstick from the stone first, the cutter both reduces the time needed to remove the epoxy (from several days to overnight) and decreases the amount of epoxy remover needed to soak off the dop. As with any chemical, and epoxy removers are more dangerous than most, be sure that all label instructions are followed to the letter, and that contact with the chemical is avoided as much as possible.

Transferring the stone between dopsticks is accomplished the same way as for jewelry-size stones, that is, on a transfer block. In the case of a large stone, however, the transfer block takes the much larger form of a lathe, which is usually used for turning woods or metals into items such as chair legs or bolts. A lathe provides a very accurate way to align the stone when turning it over; just make sure that the power is disconnected before the stone is attached. The dopsticks generally have to be custom made to fit the stone, as it is important to seat the stone firmly over a large area for maximum safety while cutting. Again, model-

Figure 8. On large stones, it is advisable to cut and polish the table before any other facets. Here, a Recipro-Lap is used to touch up the table on the large citrine. A waterproof clay-like substance has been placed around the girdle to protect the finished portions. Photo by Robert Weldon.



ing clay is used to hold the dopstick to the stone. Very large stones require two applications of epoxy, one on each side of the stone, as the epoxy runs until it is almost hard, and much attention must be paid to keeping the epoxy on the stone and off the lathe and table. Once the epoxy hardens, the stone (with both dops still attached to it) should be set aside so that the new epoxy can cure thoroughly, usually allowing at least a day for proper set-up. After the new epoxy is cured, the old dop can be removed by cutting through the epoxy with a jewelers' saw (or a hack saw for the really big stones), being careful not to saw into the stone and only to saw up to and completely around the dop, making it easy then to separate the dop from the stone with gentle pressure.

Cutting. On a jewelry-size stone, the lapidary would usually dop the stone and begin grinding on the pavilion or crown. There are several reasons for beginning with the pavilion (once the table is completed) on large stones. First, it is much easier to center the stone during the initial dopping procedure by using the flat surface of the table. What may be a minor misalignment on a small stone is magnified on a large one. For example, what is one to do if the dopstick is affixed to a rough-ground keel-line (or point) and the stone comes out a degree off? This mistake would be very evident at the table of the large stone. Second, the depth of the stone is dictated by the depth of the pavilion; a shallow pavilion can be corrected more easily if the crown has not been finished. The stones being cut should not be windowed, as their large size will make this fault even more obvious than on smaller gems. Third, if the epoxy were to separate from the stone it would be easier to realign the stone on the flat surface of the table than on the rough unfinished pavilion surface.

The time involved in cutting any facet depends on a number of factors. First, the wheels or laps should not be worn to the point that the stone glides on the coolant above the cutting surface even when pressure is applied. Second, the amount of material that is ground off decreases as the facet grows larger, which is due in part to the fact that the amount of pressure that can be applied to any one portion goes down as the pressure is distributed over the larger surface, thus decreasing the amount ground away not just arithmetically, but exponentially.

The actual faceting of the stone is most commonly done by a "peeling" process, in which the

facets are ground down a little at a time, around and around the stone until the desired depth is reached. This way the cutter can avoid grinding larger facets than necessary, which get more difficult to cut as the surface area increases. Surprisingly, the stone's weight alone usually is not sufficient to hold the facet onto the lap, as the coolant, oil or water, forms a thin film between the surfaces, in effect causing the stone to "float" over the surface of the lap. The machine must be strong enough so that the cutter can "stand" — that is, put all of his weight — on the stone for long periods of time (figure 9). Literally hundreds of hours of this intense physical exertion were required for the large citrine. With a heavy-duty faceting machine, the stone should not turn in the chuck (the dopstick holder). Extra care is needed on end facets, though, to keep a stone from turning in the chuck.

Typically, the actual cutting of the stone takes place in three steps, each of which requires a different cutting lap (the disc that is impregnated with diamond). The rough (60 or 100 grit) lap is the workhorse, grinding away the excess material and imparting shape to the stone. One does not worry about the absolute alignment of the facets at this stage, just about getting the facets cut in. The stone is next ground on a medium (260 or 360 grit) lap, which takes out the nicks and chips left by the rough lap, as well as any surface flaws that may have appeared during the initial faceting. The final faceting work is done on a fine (1200 or 1500 grit) lap. The cutter takes off very little material with this lap, but it is at this stage that individual facets are lined up and readied for polishing. When aligning the facets, the cutter should take into account the differences in the size of the facets and their different rates of polishing, inasmuch as smaller facets tend to polish more quickly and, therefore, to enlarge slightly as compared with larger facets, especially on softer materials such as calcite and fluorite. Even topaz and quartz display this characteristic, although to a lesser degree.

Polishing. Polishing facets on a large stone can be the most time-consuming step in the process, but this stage may be shortened considerably if a combination of polishing techniques is used.

As with almost any polishing procedure, it is up to the cutter to evaluate the attributes of the various methods available to determine which to use for the stone at hand. For example, a wood lap used with the desired polishing compound will shorten the time required to polish most large

facets. This lap, suggested to the author by John Sinkankas, can easily be made from ordinary hardwood plywood found as sheets at lumberyards; it polishes most materials in less than half the time as other laps. However, this same lap usually leaves the facets slightly rounded, and accentuates twinning planes in the material. A second polishing on a harder material, such as on a tin lap, will help flatten out the facets and give an excellent polish. Polishing the stone as a two-step process on a combination of laps requires less time than a single polishing on the better lap because one combines the best properties of the two—in this case, the speed of the wood lap and the fine polish of the tin lap. Wood laps can be used on soft stones (those materials that have a hardness of seven or less on the Mohs scale) as long as the cutter is aware that heat can build up in the stone at the point of polishing, and takes proper precautions to keep the stone from fracturing because of the heat. This can be accomplished by placing the stone on the lap for only a few seconds at a time, and waiting long enough between polishings for the heat to disseminate into the stone. In most cases, however, either a Pellon lap or a wax lap, such as those made by Moyco, can be used to polish such soft stones as calcite and fluorite. One of these laps is also essential for polishing facets situated on a cleavage on harder material, such as topaz or spodumene.

Almost all of the polishing compounds (e.g., both Linde A and B aluminum oxides, cerium oxide, tin oxide, and diamond) can be used on every type of polishing lap, but it is imperative that every effort be made to prevent contamination of the laps by more than one compound at a time and even by simple dust in the air. All laps must be thoroughly cleaned and protected between uses, and wood laps must never be used with a different polishing compound from that which is first introduced to the lap, as the different compounds may have different polishing characteristics. Most materials may be polished with either aluminum oxide or diamond, which tend to give the most consistent results. There are, however, a few notable exceptions. Because of its distinctive structure, quartz cannot be polished with aluminum oxide, so cerium oxide, tin oxide, and/or diamond may be used instead. Since aluminum oxide is synthetic corundum, ruby and sapphire can only be polished by diamond. Although some lapidaries use diamond to polish all stones, it is not necessarily the polishing compound of choice. Diamond powders

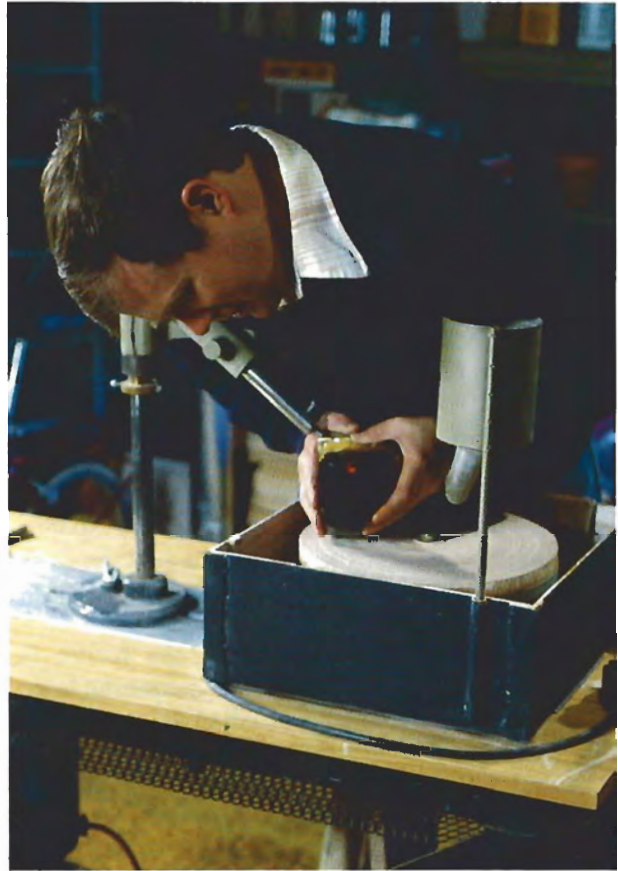


Figure 9. Because the weight of even an extremely large stone is not sufficient to hold the facet on the lap, the cutter can speed the cutting and polishing process by “standing,” or putting all of his weight, on each individual facet. On a very large stone, this may require hundreds of hours of intense physical exertion. Photo by Robert Weldon.

are more expensive than other compounds, and are messier to work with. Some materials, such as spodumene, actually polish faster with aluminum oxide, but there are other materials, such as topaz, for which diamond is the only practical choice.

Approximately one month was needed to facet and polish the large citrine after completion of the table. The amount of time required will, of course, vary depending on the experience of the cutter.

CONCLUSION

Different lapidaries have different standards and develop different methods to achieve the same ends. It is through this variation in practice that new faceting methods are developed. The lapidary who is cutting a large stone for the first time must

use the methods that are most comfortable for him. The author offers the methods in this article only as guidelines, and recommends that the lapidary develop his or her own methods based on personal experience.

The large stones in the photographs accompanying this article are beautiful works of art that can also serve a useful purpose—education. Some day, these stones will be viewed as treasures unto themselves, much like a carving or a painting. Even as our knowledge continues to expand, we are running out of material from which to cut these large stones, relying on erratic new finds now that the plentiful materials that were mined in the past have already been cut up into jewelry-size stones and cannot be replaced. Currently we must rely on new localities, such as Afghanistan for spodumene, and more intensive mining in areas such as Brazil, which has historically produced large crystals of topaz and quartz.

As new materials are found, the future is promising for even greater feats of fashioning large gemstones. The use of lasers in diamond cutting is only a precursor to what may be accomplished by

laser technology on large colored stones. New materials and equipment are also being developed to aid in polishing, such as the Spectra Ultra-Lap developed by Moyco Industries, which speeds the polishing of quartz facets up to a certain size. Eventually, better technology in machinery and polishing compounds will result in brighter, crisper large stones. Certainly, this same technology will help in the development of better methods for faceting jewelry-size stones.

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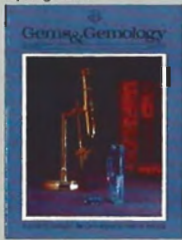
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NOTES · AND · NEW TECHNIQUES

THE DISTINCTION OF NATURAL FROM SYNTHETIC ALEXANDRITE BY INFRARED SPECTROSCOPY

By Carol M. Stockton and Robert E. Kane

Infrared spectroscopy provides a means to distinguish natural from synthetic alexandrites in the range 2000–4200 cm⁻¹, as determined by a study of spectra obtained from 15 natural and 28 synthetic alexandrites from a variety of sources. The technique is nondestructive and, with Fourier transform instrumentation, extremely rapid. It is especially useful for identifying stones that contain no distinguishing inclusions.

The recent discovery of fine-quality alexandrite in Brazil (Koivula, 1987; Proctor, 1988) and the continued production of synthetic alexandrite (Nassau, 1980; Trossarelli, 1986; Guo et al., 1987; Kane, 1987) prompted an examination of the infrared spectra of these gem materials as additional means to distinguish the natural gems from the synthetic products (figure 1). The possibility had already been explored and found promising in a survey study of infrared spectra of various gem materials including alexandrite (Leung et al., 1983).

In most instances, characteristic inclusions serve to distinguish between natural and synthetic alexandrites (see references above). The natural gemstones usually contain distinctive natural-appearing inclusions such as: ultra-fine parallel growth tubes or needles; solid crystal inclusions of actinolite, quartz, mica, apatite, and other minerals; two- and three-phase fluid inclusions; and various internal growth features (Gübelin and Koivula, 1986). Flux-grown synthetic alexandrite—for example, that produced by Creative

Crystals (Cline and Patterson, 1975)—is differentiated by inclusions of flux and platinum platelets. Alexandrite synthesized by melt methods—including the commercially available Czochralski-pulled products from Allied Signal (Morris and Cline, 1976) and Kyocera (Machida and Yoshihara, 1980; Uji and Nakata, 1986), and floating-zone material from Seiko (Koivula, 1984)—may show gas bubbles and identifiable curved, irregular, and/or swirled growth features. In addition, some synthetic alexandrites may show unusual features such as the weak chalky yellow short-wave fluorescence confined near the surface of the Inamori synthetic cat's-eye alexandrites (Kane, 1987).

In the absence of such distinctive features, however, there may be no other standard gemological properties that can conclusively identify the natural or synthetic origin of an alexandrite. Thus, laboratory identification techniques such as infra-

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Acknowledgments: The authors thank the following for loaning material for this study: Prof.-Dr. Hermann Bank (Mineralogisch-Petrographisches Institut der Universität Heidelberg), Gerhard Becker (Friedrich-August Becker), Robert Middleton (Los Angeles County Museum of Natural History), Judith Osmer (J. O. Crystal Co.), Jane Smith (Jewelers'-Circular Keystone), MSB Industries, and Ken Takada (Inamori Jewelry Division of Kyocera International, Inc.).

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red spectroscopy are of some significance, especially considering the appreciable differences in market value involved.

MATERIALS AND METHODS

The current study examined 15 natural and 28 synthetic alexandrites from a variety of sources (see table 1). Spectra were obtained with a Nicolet 60SXB FTIR spectrometer (see Fritsch and Stockton, 1987) in the range 400–5000 cm^{-1} . However, only the range 2000–4200 cm^{-1} is of interest here since total absorption occurs below 2000 cm^{-1} (due to the presence of SiO_2), and no features were observed between 4200 and 5000 cm^{-1} . Although the spectra vary considerably according to crystallographic orientation (a property that is difficult to control with faceted gemstones), key distinguishing features can, nevertheless, be easily identified (see figure 2).

RESULTS

Table 2 shows clearly how distinct the spectra of natural and synthetic alexandrites are. Most notably, the natural alexandrites examined invariably exhibit absorption features centered at about 2160, 2403, 4045, and 4150 cm^{-1} that were not observed in any of the synthetics. In fact, features present in the synthetic alexandrites generally were limited to the range 2800–3300 cm^{-1} , regardless of orientation, with a few specimens showing bands between 2500 and 2700 cm^{-1} , and some with features between 3300 and 3700 cm^{-1} . In addition,



Figure 1. New sources of natural alexandrite, including Tanzania (crystal, top left, 51.81 ct) and Brazil (four faceted stones on left, ranging from 0.95 ct to 2.49 ct) are producing enough fine material to create increased demand for this unusual gemstone. In addition, the manufacture of flux synthetic alexandrite (on the right; the crystal is 36.18 ct and the faceted stones range from 0.72 ct to 3.88 ct.) by companies such as Creative Crystals and Inamori has raised the importance of being able to distinguish between the natural and man-made materials. Faceted natural alexandrites courtesy of Kremetz & Co. Photo © Tino Hammid.

TABLE 1. Origin and number of samples of natural and synthetic alexandrites examined by means of Fourier transform infrared spectroscopy.

Origin	No. of samples
Natural	
Brazil	8
Sri Lanka	2
Tanzania	3
USSR	2
Synthetic	
Czochralski pulled	
Allied Signal	2
Inamori/Kyocera	9
Unknown	2
Floating zone	
Seiko	1
Flux-grown	
Creative Crystals	13
Unknown	1

the absorption features between 2800 and 3300 cm^{-1} are always stronger in the natural stones (again, see figure 2). This is probably due to the lack of water in the synthetics, which are manufactured by flux, floating zone, or Czochralski-pulling techniques (see Kane, 1987, for a summary), while the natural gems invariably incorporate H_2O and OH during their growth (Aines and Rossman, 1984).

Hydrothermal synthetic alexandrites have reportedly been manufactured (Trossarelli, 1986) and, should they become commercially available at some future date, further study will be necessary. However, the distinguishable infrared spectra of natural and synthetic hydrothermal emeralds

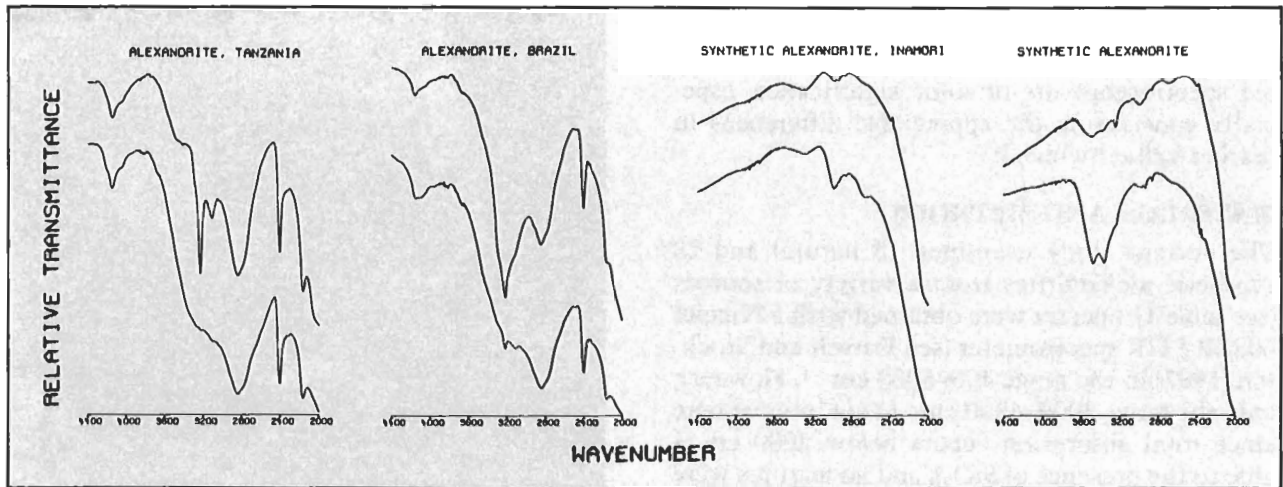


Figure 2. These infrared spectra illustrate both the variety of features within each category as well as the obvious differences between the spectra of natural and synthetic alexandrites in this wavenumber range. Spectra for two different orientations of each gem are illustrated.

(Stockton, 1987) suggest that similar distinctions will be possible for alexandrite should the need arise. In the meantime, separation of natural and synthetic alexandrite by infrared spectroscopy is straightforward.

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TABLE 2. Major and distinguishing infrared features (in cm^{-1}) of natural and synthetic alexandrites, with ranges of observed band locations.

Natural	Synthetic
2159–2165***	
2401–2404***	
2415*	
2480–2487**	
	2509–2512*
	2601*
	2620–2680**
2775**	
2829–2850***	2848–2853**
	2971–2975*
2913–2917*	2917–2924**
	2927–2931*
2951–2954*	2952–2983**
3033–3038*	
	2078–3082*
3102–3109*	
3115–3135*	
3212–3230***	3224–3229*
	3250–3258*
4044–4050***	
4140–4155***	

*Sometimes present.

**Usually present.

***Always present.

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Gem Trade LAB NOTES

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Synthetic ALEXANDRITE

With the recent influx of material from Brazil, the New York laboratory has identified more natural alexandrites in the past few months than it had in the last several years. Because of the new public awareness of natural alexandrite, an expanded marketing effort for synthetic alexandrite has also developed. A New Jersey distributor of synthetic gems is now selling a Czochralski-grown synthetic alexandrite and recently submitted six samples to the New York laboratory for examination. Two of these stones (1.50 ct each) are shown in figure 1 as seen in incandescent light. In daylight or fluorescent light they are blue-green with areas of purple. The color change is very similar to that of the natural Brazilian material.

As was to be expected of the synthetic material, all six samples fluoresced a very strong bright red to both long- and short-wave ultraviolet

Figure 1. These two 1.50-ct synthetic alexandrites have a color change very similar to that of natural Brazilian alexandrite. Here they are seen in incandescent light.



radiation; in contrast, most natural alexandrites display only a moderate to weak red fluorescence to both types of radiation. The synthetic stones appeared to be without inclusions or any other internal characteristics, which is consistent with the Czochralski method of manufacture. *David Hargett*

Artistically Stained CHALCEDONY

Recently submitted to the Los Angeles laboratory for identification was the scenic stone ring shown in figure 2. Subsequent testing identified the stone as chalcedony that had been stained with a black dendritic design on the top surface.

Microscopic examination revealed that the design had an extremely shallow penetration; it also revealed faint agate-like banding in the stone. As would be expected with dyed chalcedony, no dye was removed when the stone was tested with a cotton swab dipped in either acetone or a 10% hydrochloric acid solution.

Exposure to long-wave ultraviolet radiation revealed a very weak to weak patchy, dull, chalky yellow fluorescence aligned with the agate-like banding. Of interest was a very thin (0.2–0.3 mm) layer of moderate to strong dull, chalky yellow fluorescence that was confined to the top of the tablet. No phosphorescence was observed. Exposure to short-wave ultraviolet radiation revealed much the same reaction, except that the fluo-



Figure 2. The dendritic pattern on this 18.5 × 13.6 × 2.1 mm chalcedony cabochon is actually a stain that was painted on the stone.

rescence was much weaker and had a greenish cast. *RK*

CLINOHUMITE

The Santa Monica laboratory recently identified another rare gem-quality clinohumite (see p. 236 of the Winter 1986 issue of *Gems & Gemology* for an earlier report on this material), a brownish yellow round brilliant-cut stone that weighs approximately 0.5 ct (figure 3). The laboratory determined that this particular stone has refractive indices of 1.630 and 1.668, with a corresponding birefringence of 0.038, and is

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

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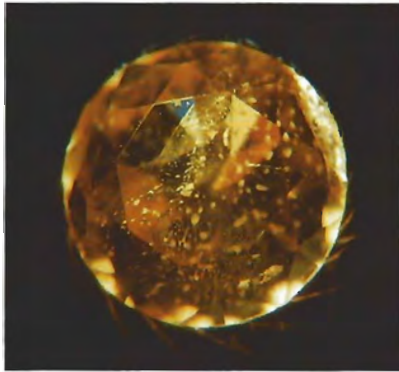


Figure 3. This 0.5-ct stone is a rare faceted clinohumite.

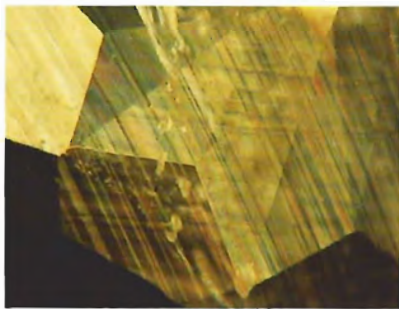


Figure 4. The numerous intersecting twin lines in the clinohumite shown in figure 3 are readily apparent in polarized light. Magnified 63 \times .

biaxial positive. The specific gravity, estimated with heavy liquids, is approximately 3.18. There was no distinctive absorption spectrum. Although the stone did not fluoresce to long-wave ultraviolet radiation, it did fluoresce a very strong orangy yellow

to short-wave U.V. The stone had a fine fingerprint inclusion, several three-phase inclusions, and an acicular inclusion of unknown identity. In addition to being heavily included, the stone was also highly twinned, with numerous intersecting twin lines (figure 4). This material is reportedly from the USSR. KH

DIAMOND

Cyclotron-Treated

The New York laboratory recently received for identification a 20.22-ct yellowish brown emerald-cut diamond. The "umbrella effect" that is typical of a cyclotron-treated diamond was readily apparent (figure 5). (In an emerald-cut diamond, there is a strong color band parallel to the elongated culet; the term *umbrella effect* originates from the appearance of this phenomenon as seen in a round brilliant cut, where it does indeed resemble an umbrella.)

Also in keeping with cyclotron treatment, this stone displayed a 594-nm absorption line. Interestingly, though, it was also a "green transmitter"; that is, it luminesced green when exposed to visible light with wavelengths of 503 nm or shorter. Green transmission is usually encountered in natural-color diamonds, but as evidenced here, it is occasionally seen in treated ones as well. In the latter case, it can be present either naturally prior to laboratory irradiation or can arise as a result of that treatment. The green

luminescence in this diamond (figure 6) is clearly the result of the cyclotron treatment, inasmuch as it, too, shows the umbrella effect.

Clayton Welch

Damaged

Unfortunately, the laboratory occasionally still sees diamonds that have been needlessly damaged by hardness tests. The 0.80-ct round brilliant-cut diamond shown in figure 7 was recently submitted to the Los Angeles laboratory for grading. A hardness test that had been performed on the table lowered the clarity grade from VVS₁ to VS₂. A series of feathers and bruises along the scratch extend deep into the stone.

Whenever we have encountered this kind of damage in the past, it invariably was caused by an uninformed person testing the stone to see if it is a diamond or a simulant. Such people operate on the mistaken

Figure 7. Even diamonds can be damaged by scratch hardness tests, as this 0.80-ct stone proves; its clarity went from VVS₁ to VS₂. Magnified 20 \times .

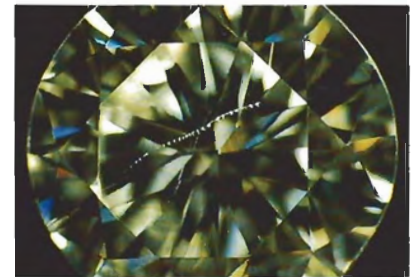


Figure 5. The "umbrella effect" characteristic of cyclotron-treated diamonds is evident as a line of darker color parallel to the culet (here, at the top of photo) in this emerald-cut diamond. Magnified 30 \times .



Figure 6. Green transmission and the "umbrella effect" proved that this diamond had been cyclotron treated. Fiber-optic side lighting, magnified 30 \times .





Figure 8. This 4.5-ct lapis lazuli cabochon has unusual straight parallel banding.



Figure 9. Parallel banding in the lapis lazuli cabochon shown in figure 8 conforms to the cabochon cut. Magnified 6×.

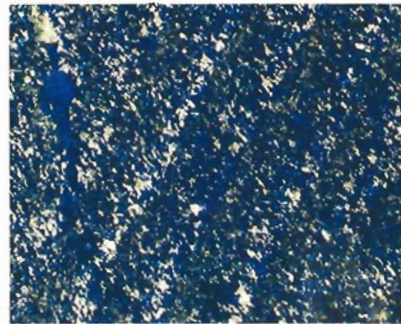


Figure 10. Banding is also evident in this thin section of the lapis cabochon shown in figure 8. Magnified 80×.

belief that a "real" diamond cannot be scratched, even by another diamond. Needless to say, a diamond should never be used for a hardness test. Rapid methods for identifying diamonds and their simulants exist, with many tests requiring only a trained eye. An exceptional article on this topic by Jill Hobbs, "A Simple Approach to Detecting Diamond Simulants,"¹ was published in the Spring 1981 issue of *Gems & Gemology*. RK

Banded LAPIS LAZULI

The Santa Monica laboratory received an opaque blue oval cabochon for identification. The approximately 4.5-ct stone appeared to be top-quality lapis lazuli (figure 8). Preliminary testing seemed to verify the initial thoughts. The refractive index was determined (by the spot method) to be 1.51; the specific gravity, estimated by heavy liquids, was approximately 2.85; and there was a distinct rotten-egg odor when a small drop of hydrochloric acid was applied to the back of the stone. Although the stone was inert to short-wave ultraviolet radiation, it fluoresced a chalky greenish yellow to long-wave U.V.

Magnification revealed a structure quite unlike the usual granular appearance of the components that make up lapis lazuli. Straight parallel banding was seen, some of which appeared curved as a result, no doubt, of the cabochon cut (figure 9). When

strong light was passed through a thin edge of the cabochon, the material did indeed show a granular structure. There seemed to be at least two different constituents: near-colorless grains surrounded by opaque blue grains. The grains were arranged in such a way, however, that they produced a striated, or banded, effect.

We were given permission to have a thin section made in order to document further the unusual structure (figure 10). X-ray diffraction revealed a pattern consistent with lapis, showing a mixture of lazurite, hauyne, mica, and another undetermined mineral. This is a most unusual piece of lapis. It is unfortunate that the source of the material is not known. KH

PEARLS

Early "Japanese" Pearls

In the Lab Notes section of the Summer 1983 issue of *Gems & Gemology*, a lattice-work necklace of cultured blister pearls was illustrated. It was surmised then that these blister pearls might be of the type cultivated in Japan as early as 1890, before whole cultured pearls became available. Recently at the New York laboratory, we received a pair of earrings that we believe even more convincingly indicate manufacture before 1900. The blister pearls are button shaped with the mother-of-pearl nucleus clearly exposed on the back (figure 11). The X-ray shows that one

blister pearl is very similar to that illustrated in the 1983 issue (p. 116), with a rectangular mother-of-pearl insert. The other three do not have this type of insert, but their backs seem to resemble those of modern Mabe pearls. The fact that these cultured blister pearls, like those in the lattice-work necklace, did not fluoresce to X-rays indicates that the nuclei are of saltwater shell, rather than the freshwater shell used in most whole cultured pearls today.

Figure 12, from G. F. Herbert Smith's ninth edition (1940) of *Gemstones*, illustrates the method by which most of these so-called "Japanese" pearls were produced. This is one of the few references in the

Figure 11. The early "Japanese" cultured blister pearls in this and the matching earring measure 7 1/2 mm in diameter; the nucleus is clearly exposed on the back of each pearl.



literature to a once-flourishing practice that gave way to an even more vigorous whole cultured pearl industry. In view of the fact that these blister pearls were produced at the rate of more than 50,000 a year beginning in 1890 [Kokichi Mikimoto was the principal producer, with over 1,000 acres of leased seabed], it is surprising that the Gem Trade Laboratory has only encountered them mounted in jewelry in these two instances. RC

Natural Pearl and Diamond Tiara

The impressive diamond and pearl tiara in figure 13 was brought to the Santa Monica laboratory for identification of the pearls. The tiara measures approximately 5 1/2 inches long and 2 1/2 inches high (14 cm × 6.3

Figure 12. This illustration from G. F. Herbert Smith's Gemstones (9th ed., 1940) shows how most of the "japanese" pearls were cultured. Top = in the oyster; bottom = finished "pearl." A = nacre; B = shell; C = outer shell of oyster; D = mother-of-pearl back added.

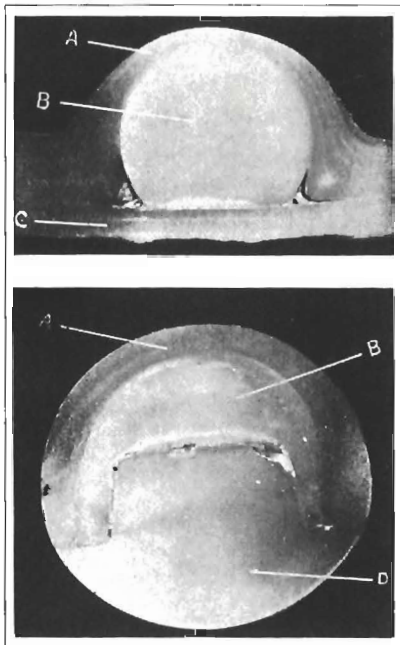


Figure 13. The largest pearl in this tiara of natural pearls and diamonds measures 10 × 18 mm long.

cm). There are a total of seven rows of pearls: five rows of round drilled pearls of various sizes, one of round and drop-shaped pearls, and a top row of all drop-shaped pearls ranging from approximately 3 mm to 10 mm in diameter and up to 18 mm long. The pearls are all well matched for color, are fairly lustrous, and, considering the apparent age of the piece, show very little wear. At the client's request, only the three center drop-shaped pearls and the five in the row underneath and between them were identified. None of these showed any fluorescence to X-rays and, since the radiograph revealed a natural structure, the pearls were identified as saltwater natural pearls. The piece also included numerous near-colorless rose-cut diamonds in white metal settings. The open setting of the diamonds in what appeared to be

silver mountings on yellow gold indicates that the tiara dates to the early 19th century, when this type of stone setting was popular. KH

SAPPHIRE

Color Zoned

A 1.06-ct blue sapphire was submitted to the New York laboratory for identification. A spall cavity, the fire-skinned surface, and discoid fractures easily proved that the stone had been heat treated. However, the dark blue hexagonal color zoning seen through the table (figure 14) is unusual. It appears that a "phantom crystal" within the sapphire was affected by the heat treatment, leaving the edges fuzzy and partially diffused into the stone. When the stone was viewed with a Beck hand-held type of spectroscope, the 450-nm (iron) line

was quite strong. Perhaps this was originally a very dark sapphire that had been heated to lighten the color, with the perimeter of the "phantom crystal" remaining dark in spite of the treatment. *David Hargett*

With Needles

One of the characteristics that proves that a sapphire has not been heat treated is the presence of coarse, well-formed, undisturbed needle-like inclusions and/or their shorter wedge-shaped relatives. Such inclusions often light up with spectral colors when illuminated by a strong overhead or fiber-optic light source, as seen in the approximately 40-ct sapphire shown in figure 15, which was submitted to the New York laboratory for identification. These needles produce asterism when the stone is cut en cabochon. An interesting trick is to place a small drop of methylene iodide (the 3.32 specific gravity liquid) on the surface of a faceted stone and observe the star effect in the bead of liquid (figure 16). *Clayton Welch*

TOURMALINE from Nepal

The Los Angeles laboratory had the opportunity to examine four faceted tourmalines that were reported to be from Nepal: a 5.69-ct light pink, a 4.73-ct dark purplish red, and two yellow stones of 5.16 and 5.61 ct (figure 17). Tourmaline crystals from



Figure 17. These four tourmalines, which range from 4.73 ct for the purplish red emerald cut to 5.48 ct for the pink oval mixed cut, are reportedly from Nepal.

Figure 14. The strong blue hexagonal color zoning in this heat-treated sapphire is not common. Magnified 30x.

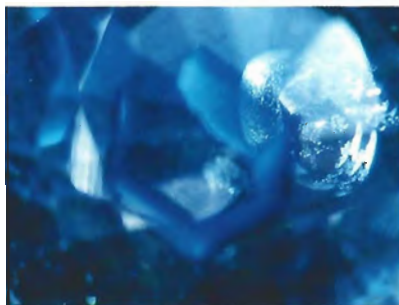


Figure 15. Needles and wedge-shaped inclusions in a sapphire prove that it has not been heat treated. Magnified 30x.

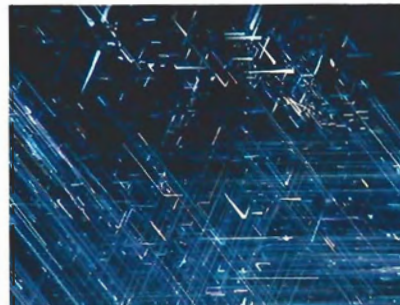


Figure 16. Drops of methylene iodide on a faceted needle-filled natural sapphire can produce a star effect. Magnified 10x.





Figure 18. This imitation turquoise necklace is actually gibbsite; the beads range from 5.7 to 14.5 mm in diameter.

Nepal first began to appear in the 1960s. They occur in a wide variety of colors, the most distinctive and most common of which are the bright greenish yellow to brown-yellow, pink, "lemon-yellow," green tricolored, and watermelon crystals which are well terminated and measure up to 20 cm (8 in.) in length. Collector crystals remain quite rare, as nearly all of the material has gone to India for faceting. In addition, there reportedly has been little production during the 1970s and 1980s. Although more than two dozen pegmatites are known to exist in Nepal, virtually the entire tourmaline production comes from only two sources: the Hyakule mine and the Phakuwa mine. Since the discovery of the Hyakule mine over 50 years ago, estimates put the yield of gem tourmaline at just over 1,300 kg (2,800 lbs.) with only about 10% of gem quality. Now, mining has virtually ceased, primarily due to the landslides that occur every summer during the heavy monsoon rains. For more information, see the excellent

1985 article by A. M. Bassett, "The Tourmalines of Nepal," in the *Mineralogical Record*, Vol. 16, No. 5, pp. 413-418.

The gemological properties of the four stones we examined are as follows: refractive indices range from 1.619 and 1.637 for the pink, to 1.620 and 1.648 for the greenish yellow, with birefringences from 0.018 to 0.028. The absorption spectra were typical for their respective colors, except that the yellow showed only a weak general absorption up to 410 nm, with no distinct lines or bands. The red and the two yellow stones were inert to both long- and short-wave ultraviolet radiation; the pink tourmaline had a very slight suggestion of a blue fluorescence to long-wave U.V. and fluoresced a moderate chalky violetish blue to short-wave U.V. The inclusions are typical of tourmaline: thin needles, growth tubes, "fingerprints" composed of gaseous and fluid inclusions, and small transparent, colorless, birefringent, euhedral crystals.

RK

Imitation TURQUOISE with "Veins" and Pyrite

A quite attractive turquoise-colored necklace (figure 18) was sent to the Santa Monica laboratory for identification. At first glance, the beads appeared to be fashioned from fine-quality turquoise; most were evenly colored, some had characteristic "matrix" veins, and many also showed readily visible pyrite inclusions.

A spot refractive index reading of 1.55 was obtained with a standard gemological refractometer. Even though this figure is too low for natural turquoise (1.61), it is still within the range for treated material. Under magnification, the beads had a sugary, speckled appearance that is often seen in treated turquoise. The application of the thermal reaction tester (hot point) inside the drill hole of a bead produced a reaction characteristic of plastic treatment. However, the absorption line at 432 nm that is usually seen in turquoise was not evident. It was decided that X-ray diffraction would be needed to identify this material conclusively.

A minute amount of powder was scraped from inside the drill hole of one of the beads. The pattern produced matched that of gibbsite, a clay-like aluminum hydroxide. Gibbsite is encountered fairly frequently as a substitute for turquoise, but these particular beads—plastic treated and with pyrite inclusions—represent one of the most authentic-looking turquoise imitations our staff has ever seen. KH

FIGURE CREDITS

The photos used for figures 1 and 14 were taken by David Hargett. Chuck Fryer is responsible for figures 3, 4, and 18. Figure 2 was produced by Shane McClure. Robert E. Kane furnished figure 7. Clayton Welch supplied figures 5, 6, 11, 15, and 16. Scott Briggs photographed figure 8. John I. Koivula took the photomicrographs for figures 9 and 10. Figure 12 is reproduced from page 361 of G. F. Smith's book *Gemstones*, (9th ed., 1940). Figures 13 and 17 are © Tino Hammid.

A HISTORICAL NOTE

Highlights from the Gem Trade Lab 25, 15, and five years ago.

SPRING 1963

The Los Angeles laboratory received a large stone that was represented to be diamond but lacked transparency and brilliance. Testing proved that it was indeed a diamond, in spite of its appearance. A pair of earrings and a matching brooch with diamonds and green stones set in platinum were submitted for identification of the green stones. The large one in the brooch was natural emerald, but the green stones in the earrings were glass.

Reports of new finds of gem materials include brown topaz from San Luis Potosi, Mexico. The green material found at what was believed to be a new locality (unidentified) for emerald proved to be fluorite. Rare materials encountered and identified include scoxodite, translucent lapis, transparent staurolite, a greenish blue phenakite, clinozoisite, proustite, scheefite, and zincite.

In the same issue, the New York laboratory reports on shallow emeralds set with dark green aventurine quartz behind them to enhance the color, orthoclase cat's-eyes, massive pink grossularite garnet, a natural-color brown diamond, and a cyclotron-treated green diamond.

SPRING 1973

The New York laboratory discusses the imitation jade "Inamori stone" or "Meta-jade," as it is sometimes called. It is actually a devitrified glass, that is, a glass that partially crystallized in a dendritic pattern as it cooled. Several different stones were submitted for identification at different times. Some fine natural jadeite was also seen. A glass cat's-eye material examined contains what resembled fiber-optic bundles when viewed from the side of the stone. This material is known by the

trade name "Cat's-eyte." Other items of interest seen in New York were a 13-ct diamond with a nicely faceted girdle, some synthetic emeralds, an unusual agate, and a diamond that had a somewhat squarish cross section which contained some erratic tubules that meandered through the stone near one side.

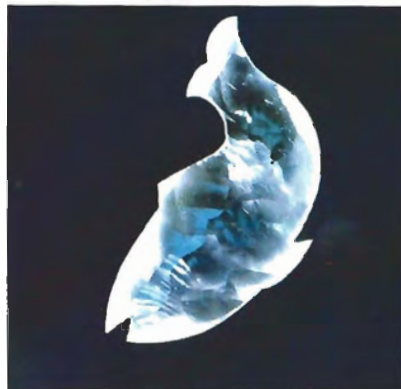
The Los Angeles laboratory discusses and illustrates various aspects of laser drilling of diamonds. A cabochon of "emerald turquoise" was submitted for identification. The stone seemed to have all the gemological properties of normal blue turquoise except its color. An X-ray powder diffraction pattern was the same as that of turquoise, but a spectrochemical analysis revealed the presence of over 4% zinc. This led to its identification as faustite, the zincian analogue of turquoise where zinc replaces some of the copper normally found in turquoise. Other items of interest include several trapiche emeralds, a synthetic ruby with an unusual pattern of bubbles, a large parasite crystal, Umba River corundums, and a quartz crystal with a movable bubble in a two-phase inclusion.

SPRING 1983

The Santa Monica laboratory reports on a beautiful 4.02-ct cat's-eye alexandrite, with a very good color change and a fine eye. An alexandrite-like spinel and a fine 19-ct cat's-eye quartz were also seen. The most unusual item was a broken semitranslucent concretion that was found in a can of tuna fish. At the time the column was written, we did not have any idea what the item might be. However, a student subsequently provided information and an example indicating that it was probably the eye of a tuna.

Speaking of fish, the New York

laboratory had the opportunity to examine a 2.87-ct diamond carved in the shape of a fish. The natural surface skin that was left on the carving even resembled fish scales. In addition, several pink diamonds are discussed, as are tubular inclusions in a flux-grown synthetic emerald, a fluorite and quartz necklace, several different types of pearls, a cat's-eye opal, and some assembled stones.



Carved fish-shaped diamond. The stone weighs 2.87 ct and measures 18.38 mm × 8.95 mm × 2.26 mm thick.

A matched suite of jewelry, consisting of a necklace, earrings, and a combination ring and pendant, all set with what appeared to be emeralds and diamonds, were submitted to the Los Angeles lab when it was discovered that the green stone in the ring/pendant combination seemed to lose color when it was steam cleaned. The stone in question proved to be natural beryl with a green coating. The other green stones proved to be natural uncoated emeralds. A word of warning should be repeated here: NEVER, NEVER steam clean emeralds. The thermal shock can easily fracture natural stones (and remove the color from coated ones).

Gems & Gemology

C · H · A · L · L · E · N · G · E

Gems & Gemology places you at the forefront of gemological knowledge. We invite you to test this knowledge by taking the second annual *Gems & Gemology* Challenge. Last year, hundreds of subscribers successfully met the Challenge and received congratulatory letters, suitable for framing. The more than 100 who received perfect scores were publicly applauded in the Summer issue.

We are pleased again to offer our readers this opportunity to test their familiarity with some of the most important issues in gemology today. The following multiple-choice questions, prepared by the GIA Education Department, are based on the articles published in the four 1987 issues of *Gems & Gemology*. Feel free to refer to those issues to find the single best answer and then mark the appropriate letter on the card provided in this issue (photocopies or other facsimiles of this card will not be accepted). Return the card with your answers (be sure to include your name and address) by Monday, August 15: Don't forget to put sufficient postage on the card (15¢ in the U.S.). All entries will be acknowledged, and those with a passing grade (75% or higher) will receive an attractive letter that acknowledges your successful completion of the exam and your commitment to continuing your gemological education. Those readers who receive a perfect score (100%) will also be recognized in the Fall issue of *Gems & Gemology*.

So . . . get out those 1987 issues and **take the challenge!**

Note: Questions are taken only from the four 1987 issues. Choose the single best answer for each question.

- Probably the most common type of setting, appropriate for almost any cut of stone, is
 - pavé.
 - bezel.
 - prong.
 - channel.
- The rarest fancy color for diamonds is
 - purplish red.
 - reddish violet.
 - pure red with no secondary hue.
 - pure pink with no secondary hue.
- Natural and synthetic emeralds can always be distinguished by
 - inclusions.
 - refractive index.
 - infrared spectrum.
 - ultraviolet fluorescence.
- All of the sugilite studied at GIA was found to be
 - dyed.
 - irradiated.
 - not enhanced.
 - heat treated.
- The valence state of an ion exerts a strong influence on a stone's hue and
 - tone.
 - brilliance.
 - crystal structure.
 - intensity of color.
- When exposed to long-wave U.V. radiation, the De Beers gem-quality synthetic diamonds
 - were inert.
 - fluoresced a weak yellow.
 - fluoresced a strong yellow or greenish yellow.
 - fluoresced a moderate yellow or greenish yellow.
- The essential compositional difference between Inamori Created Opals and natural opals is the absence of
 - water in the Inamori opals.
 - water in the natural opals.
 - amorphous spheres in Inamori opals.
 - amorphous spheres in natural opals.

8. The greatest potential danger of steam cleaning is
 - A. fading.
 - B. frosting.
 - C. color change.
 - D. thermal shock.
9. Iridescent orthoamphibole, also known by the trade name Nuummite, has to date been found only in
 - A. Tanzania.
 - B. the USSR.
 - C. Australia.
 - D. Greenland.
10. The natural habitat of the conch is
 - A. the Indian Ocean.
 - B. the Persian Gulf.
 - C. from Bermuda to the Caribbean.
 - D. from Bermuda to the Gulf of California.
11. The distinctive pink to purple color of sugilite is due to the presence of
 - A. sodalite.
 - B. sodianite.
 - C. manganese and iron.
 - D. chromium and vanadium.
12. Lennix synthetic emeralds can be identified by a combination of inclusions and
 - A. low R.I.
 - B. high S.G.
 - C. spectrum.
 - D. color zoning.
13. Conch "pearls" cannot be considered true pearls because they are
 - A. nacreous.
 - B. nonnacreous.
 - C. always enhanced.
 - D. usually cultured.
14. Lennix synthetic emeralds are grown by the
 - A. Czochralski method.
 - B. flux-fusion process.
 - C. hydrothermal method.
 - D. flame-fusion process.
15. Identification of treated opals by infrared spectroscopy applies only to opals treated with
 - A. smoke.
 - B. sugar.
 - C. radiation.
 - D. polymer-type materials.
16. The most striking characteristic of jewelry of the late 1940s and the 1950s was
 - A. the return of the Art Deco style.
 - B. a lingering regimentation of design.
 - C. an almost ostentatious use of gemstones.
 - D. the use of synthetic gems in modern designs.
17. The term *infrared* is derived from being
 - A. equal in energy to the red end.
 - B. lower in energy than the red end.
 - C. higher in energy than the red end.
 - D. equal in absorption to the red end.
18. In April 1987, the highest per-carat price on record for a gem sold at auction was paid for a
 - A. violet painite.
 - B. blue taaffeite.
 - C. Russian alexandrite.
 - D. purplish red diamond.
19. Using conventional gemological testing techniques, faceted De Beers gem-quality synthetic diamonds can be identified by a combination of
 - A. metallic inclusions, S.G., and spectrum.
 - B. U.V. fluorescence, color zoning, and S.G.
 - C. graining, spectrum, and cathodoluminescence.
 - D. color zoning, U.V. fluorescence, and metallic inclusions.
20. Although some included topaz from Brazil has been sold as "rutilated," in reality it contains
 - A. copper inclusions.
 - B. open channels colored by limonite.
 - C. narrow tubules filled with ilmenite.
 - D. a fine network of small thin fractures.
21. One feature that distinguishes synthetic lavender jadeite from natural lavender jadeite is the synthetic's
 - A. lower hardness.
 - B. more intense color.
 - C. radically higher S.G.
 - D. noticeably lower R.I.
22. The only way a treatment can affect color caused by dispersed metal ions is by modifying the
 - A. valence state.
 - B. crystal structure.
 - C. chemical composition.
 - D. coordination geometry.
23. Yellow sapphires that fade rapidly when exposed to light also
 - A. darken when heated.
 - B. fade when irradiated.
 - C. lose their color when heated.
 - D. regain their color in the dark.
24. The only method proven effective in separating natural from the USSR-produced synthetic malachite is
 - A. X-ray diffraction.
 - B. hydrothermal testing.
 - C. infrared spectroscopy.
 - D. differential thermal analysis.
25. One way to separate Inamori synthetic cat's-eye alexandrite from its natural counterpart is by its reaction to
 - A. incandescent illumination.
 - B. differential thermal analysis.
 - C. long-wave U.V. radiation.
 - D. short-wave U.V. radiation.

GEM NEWS

John I. Koivula and Robert C. Kammerling, *Editors*

TUCSON '88

The Tucson Gem and Mineral Show, held the first two weeks of February, has grown tremendously since last year, with never-ending crowds of buyers and dealers everywhere. The following report of some of the highlights of this year's Tucson Show was prepared with the help of Mr. Dino DeGhionno, Dr. Emmanuel Fritsch, Ms. Patricia Gray, Mr. Gary Roskin, and Ms. Carol M. Stockton.

Beryl. Because beryl was the theme mineral of this year's show, many fine specimens and faceted stones were on display or offered for sale. A large number of fine emeralds were available, with Zambia, Brazil, and Colombia well represented. Unlike past years, few trapiche emeralds were seen.

A novelty from last year's show, "mint green" Nigerian beryl, was being offered both in the rough and as faceted stones by many dealers. Color-unstable Maxixe-type dark blue beryl was also being sold in both

Figure 1. One of the most exciting new trends in lapidary work is the free-form cut. Los Angeles cutter Bart Curren created these stones: (clockwise from upper left) 37.85-ct rhodolite; 113.69-ct amethyst-citrine, 9.46-ct citrine, 5.14-ct bicolored tourmaline, and 12.56-ct tourmaline, with a 13.49-ct tourmaline in the center.



rough and cut forms. In some cases, it was being marketed as Maxixe-type, while in others it was promoted as "rare sapphire-blue aquamarine." Regardless of the name, in a few months time under normal lighting conditions the material will revert to its original pale pink to near-colorless hue.

Carvings. Gemstone carving, a trend that seemed to take life last year, was in full swing in 1988. Especially prominent were the free-forms and so-called fantasy cuts in sizes suitable for fine jewelry. These carvings tend to have softer edges and angles than conventional faceted gems. They also tend to use, rather than hide, the natural color zoning and inclusions, often incorporating them directly into the design. More and more American carvers have become active in this style of lapidary work (figures 1 and 2) which was originated by Bernd Munsteiner of Idar-Oberstein. Michael Duber of New Hampshire and Bart Curren of Los Angeles have both won lapidary awards for their free-form carvings.

Figure 2. Some of the lapidaries involved with free-forms are experimenting with "interlocking" stones as well as with more valuable materials, as this interlocking emerald with tourmaline (cut by David Stanley Epstein) illustrates.



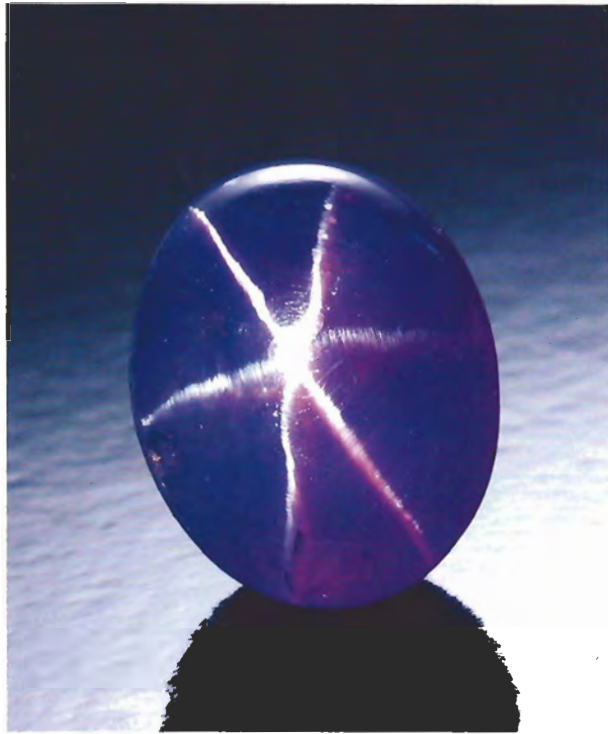


Figure 3. This 23.97-ct purple star sapphire from Sri Lanka is notable for its color, quality, and size. Courtesy of N. V. Malhotra, New York; photo © Tino Hammid.

Charoite. Once considered little more than a curiosity, charoite was being sold in several booths. The presence of large amounts of rough charoite, which is found only in the USSR, may be a sign that we will be seeing more gem materials from the Soviet Union at future shows. Perhaps *glasnost* has reached the gem community as well.

Chrysoberyl. Alexandrites from the year-old find near Hematita, Minas Gerais, Brazil, were available, but mostly in sizes under 1 ct (although faceted stones larger than 5 ct were seen).

For the first time, cat's-eye chrysoberyl from Zimbabwe (reportedly mined in the Karoi area) was available. The stones ranged from about 0.30 to 3 ct and were slightly greenish yellow with fair to excellent chatoyancy and good to fair translucency.

Corundum. "Hot pink" sapphires were available from many dealers. These "pinks" come from Burma, Kenya, Tanzania, and (the largest ones) Sri Lanka. A few small pieces from the Umba region of Tanzania were actually red, but they lacked the brownish component typical of rubies from this region. Perhaps heat treatment is being used to drive this component off (for more information, see *Gem News*, Fall 1987).

Many star sapphires in a variety of colors were also seen. One stone of special note because of its color, quality, and size was a magnificent 23.97-ct translucent purple Sri Lankan gem (figure 3). The presence of a fluid



Figure 4. These two stones—a 50.21-ct hessonite garnet and a 12.23-ct sillimanite (believed to be the largest transparent faceted sillimanite on record)—represent two new finds in Sri Lanka. Courtesy of William E. Pinch, Rochester, NY; photo © Tino Hammid.

inclusion near the "heart" of this stone proved that the color was natural and not the result of heat treatment. A few translucent to semitranslucent green star sapphires, said to be from East Africa, were also available. The color of the two we observed was a slightly grayish pastel green. These are the first truly green asteriated corundums the editors remember seeing.

Garnet. A surprising number of fine, large (10–15 ct) tsavorites were available. This material was reportedly from the Komolo mine in Tanzania, but rumors were circulating of a new East African locality.

About six months ago, an important new find of spessartine garnet was made at the Little Three mine in Ramona, California. Cut stones from 1.25 to 2 ct are now on the market. A spectacular necklace containing over 165 ct of Little Three spessartines (the largest stone weighs 39.50 ct) was displayed at Tucson.

Beautiful light orange hessonite grossulars from Tissamaharama in the Kataragama region of southeast Sri Lanka were seen; they are remarkable for their size and degree of transparency. The largest of these (50.21 ct) is shown in figure 4.

A new find of "raspberry" rhodolite from the Kangala mine in Tanzania was also reported. Facet-grade rough as well as some cut stones, many in the 5–10 ct range, were available. The magnificent color of this material was found by energy-dispersive X-ray fluores-



Figure 5. "Raspberry" rhodolite garnet like the 5.08-ct faceted stone shown here (courtesy of Tsavo Madini, Costa Mesa, CA) is now being mined in East Africa. The 17.08-ct rough sample (courtesy of New Era Gems, Grass Valley, CA) is from the Kangala mine in Tanzania. Photo © Tino Hammid.

cence (analyst, Carol M. Stockton) to be enhanced by traces of chromium. Rhodolite of a similar color is also being mined elsewhere in East Africa (figure 5).

Scapolite. A few beautifully translucent pink, "candy-like" cat's-eye scapolites from the Mogok area of Burma were at the show. The 19.04-ct stone that we examined (figure 6) has a razor-sharp eye when viewed with a single incandescent spotlight or in the sun.

Sillimanite. Gem-quality sillimanite from a new find in Sri Lanka was seen. The stones are reportedly from Morawaka, in the district of Deniyaya, 30 miles (48 km) southeast of Ratnapura. The color of the largest cut gems, a very slightly grayish green, is most unusual for sillimanite. The largest cut stone from this find is also the world's largest transparent faceted sillimanite (again, see figure 4).

Synthetics, imitations, and treatments. Paul Marrujo, of Syntho Tek, displayed a large variety of 1-kg-plus blocks

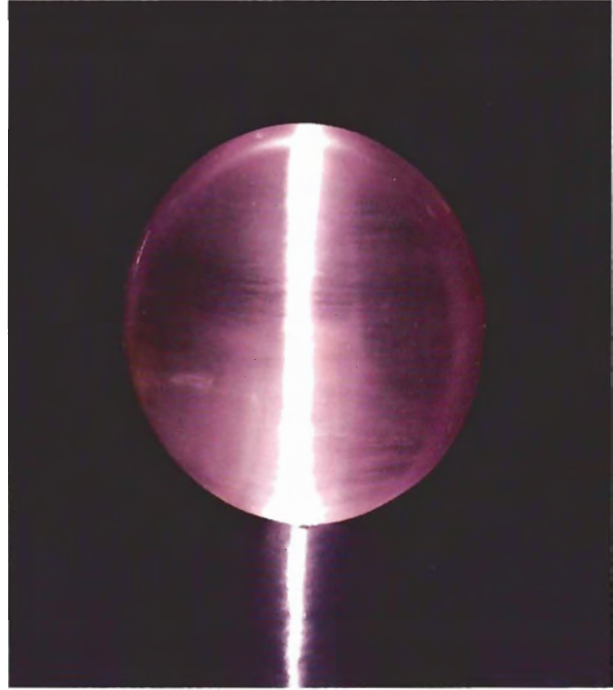


Figure 6. A number of fine pink cat's-eye scapolites from Burma were available at the February 1988 Tucson Gem and Mineral Show. This 19.04-ct stone is courtesy of Lorna Davison, Mullica Hill, NJ; photo © Tino Hammid.

of "synthetic and reconstructed materials" that looked quite good to the unaided eye. Of particular interest were a number of purple to violet blocks of "synthetic sugilite." Also displayed at this booth were "reconstituted turquoise with and without matrix and veins, coral, lapis lazuli with and without pyrite, ivory, black onyx, variscite, and rhodonite." The motto on their business card is "You can fool mother nature," but they make no such claims concerning GIA.

Thomas Chatham informed us that he is now successfully heat treating his dark blue and dark red synthetic corundums to lighten the color. We do not know yet what temperatures he is using and what this heat treatment does to the internal characteristics that are key features in the identification of the Chatham products.

A plastic opal imitation with a very convincing play-of-color (giving it to the appearance of fine white opal) was being sold as Opalite. We borrowed two pieces of this material and are currently working on a report to be published in a future issue of *Gems & Gemology*.

Cabochons of "cat's-eye" (actually star material with only one leg) quartz of a yellow-green color, which was said to have been produced by irradiation, were being sold as cat's-eye chrysoberyl.

Manfred Kammerling of Viktor Kammerling, Idar-Oberstein, the firm that invented the beryl triplet, is making sapphire-synthetic ruby doublets using light-colored Sri Lankan material for the crown instead of

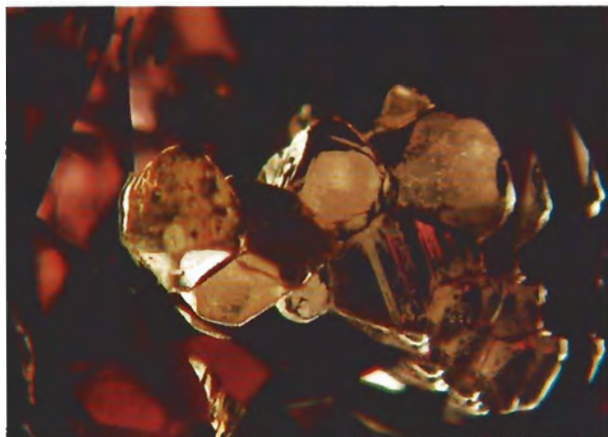


Figure 7. Inclusions of fluorite in alexandrite from Hematita, Minas Gerais, Brazil, were identified by Dr. Henry Hänni and Dr. Edward Gübelin. They are distinctive of their locality. Magnified 12 \times ; photomicrograph by Edward J. Gübelin.

dark green Australian material. The result is that, face-up, the finished doublet looks more like a fine Burmese ruby and less like a dark-colored ruby from Thailand.

Tourmaline. Some excellent faceted bi-colored tourmalines from Kaffi, Nigeria, were being shown for the first time. They were of good clarity and weigh up to 25 ct. Also, significant amounts of fine tourmaline from the Kaduna state in Nigeria, showing virtually every elbaite color except blue, were available in weights up to 15 ct. The gems were beautifully cut and seemed to come exclusively through Idar-Oberstein.

Zircon. Heat-treated blue zircons from Kampuchea (formerly Cambodia) in sizes up to 15 ct were available in quantity, in contrast to past years when this material was quite scarce. Their presence may reflect increased smuggling or the renewed interest of the Vietnamese government (which now controls most of Kampuchea) in developing the country's natural resources. The reappearance of the zircons leads us to hope that Pailin, also in Kampuchea, will once again become an important source for sapphires.

COLORED STONES

Inclusions identified in new Brazilian alexandrites. Two characteristic mineral inclusions observed in the alexandrites from the recent discovery at Hematita in Minas Gerais, Brazil (see the article by K. Proctor in this issue), have been identified by means of detailed chemical analysis. Dr. Henry Hänni found inclusions of fluorite (figure 7) in one of the alexandrites, and Dr. Karl Schmetzer and Mr. Charles Schiffmann confirmed the identification of apatite (figure 8). Dr. Edward Gübelin initiated the study and followed it through to completion.



Figure 8. Dr. Edward Gübelin, Dr. Karl Schmetzer, and Mr. Charles Schiffmann identified apatite as an inclusion in the Hematita alexandrites. Stone courtesy of Robert Van Wagoner, Aspen, CO. Magnified 25 \times ; photomicrograph by John I. Koivula.

This is the first time that fluorite has been recognized as a mineral inclusion in chrysoberyl.

SYNTHETICS

Synthetic diamond thin films. Laurie Conner, marketing manager of Crystallume, loaned the GIA Research Department a synthetic diamond thin film made at their facility in Palo Alto, California, so that GIA could effectively evaluate the potential danger for the jewelry industry of this new, low-temperature, low-pressure method of synthetic diamond deposition. Close examination with a microscope of the 1- μ m-thick polycrystalline film, deposited on silicon, revealed an easily detectable granular structure. If this type of synthetic diamond film were deposited on a faceted diamond or a diamond simulant, assuming this is possible, it would be easily recognizable by its granular nature.

Synthetic red chrysoberyl. A most unusual sample of transparent dark red synthetic chrysoberyl was loaned to us by Mr. Rex Harris, co-owner of the red beryl-producing "Violet Claims" in the Wah Wah Mountains of western Utah. At first we thought that this might be a large synthetic alexandrite with a deep body color, but it showed no signs of a color change.

This sample, which had been cut from a larger crystalline mass, measured about 1 in. (2.5 cm) in its largest dimension and contained rib-like rows of light tan-colored flux. Its synthetic origin was confirmed by the infrared spectrometer (analyst, Carol M. Stockton).

The sample had been given to Mr. Harris by a Mexican miner, who said it was natural red chrysoberyl. The miner claimed that it came from a new find in Mexico.

FAMOUS DIAMONDS

By Ian Balfour, 224 pp., illus., publ. by William Collins Sons and Co., Ltd., London, 1987. US\$34.95*

Ian Balfour is especially well qualified to write about famous diamonds, having spent a lifetime in the diamond industry both with De Beers and as a consultant to the important sight brokers, I. Hennig and Company. For many years he has been an avid student of the recorded history of the diamonds that have played a part in historical events. Many of his fascinating stories about these various diamonds have appeared in the magazine *Indiaqua*.

Over the years, a number of books have been written about diamonds known in history. One of the early efforts was Edwin Streeter's *The Great Diamonds of the World*, first published in 1882. It was followed many years later by Robert Shipley's *Famous Diamonds of the World*; Lawrence Copeland's *Diamonds, Famous, Notable, and Unique*; and the De Beers publication, *Notable Diamonds of the World*. No one, however, has written as entertainingly, nor researched so exhaustively to present complete stories, as has Ian Balfour. The book holds the reader's interest and seems to be very accurate.

In most instances, the coverage in *Famous Diamonds* is much more detailed than any previous work. The main body of the book consists of 75 entries of historically significant and well-documented diamonds, beginning with the Koh-i-noor, "the most famous of all diamonds," and concluding with the Premier Rose, the exceptional D-flawless gem cut only in 1978, but still the second-largest pear-shaped diamond in history.

This book is especially noteworthy in that Balfour spends considerable time discussing the historic situations surrounding these famous (and infamous) diamonds. As a result, the reader (gemologist and non-gemologist alike) cannot help but develop an appreciation for the many notable gems that have participated in human history. *Famous Diamonds* is very well illustrated and, where possible, modern photographs

BOOK REVIEWS

Elise B. Misorowski, Editor

of stones are shown. This book represents an important addition to the literature on diamonds and is enjoyable reading for all those interested in these fascinating gems.

RICHARD T. LIDDICOAT
Gemological Institute of America

HOW TO CARVE JADE AND GEMS

By June Culp Zeitner with Hing Wa Lee, 130 pp., illus., publ. by Northern Gem Press, 1987. US\$21.50*

Carving is the most demanding of all the lapidary arts, because it requires not only the mastery of numerous techniques but also the artistry to ensure that the finished object is aesthetically pleasing as well as competently executed. Furthermore, no convenient supports (such as dopsticks for cabochons or the rigid mechanical devices of the faceting head) are available for the gem material during carving. The carver must hold his work in his hands while he guides it through the many intricate maneuvers necessary to reach and work on every surface. These demands are daunting, and it is no surprise that carvers are so few in number. The literature is correspondingly meager; thus another text on gemstone carving is most welcome.

June Culp Zeitner, author of many articles for various lapidary magazines, bases the information she provides in this book on the methods of carving employed by Hing Wa Lee, a superbly qualified master carver in the classic Chinese tradition. His masterpieces have been displayed widely and pictured in many journals; a considerable number of them, small to large, are illustrated here in black-and-white and color. An examination of the text shows that while considerable information can be at-

tributed to Lee, much more information that already is found in current books is incorporated by Zeitner. Aside from a short (well-illustrated and useful) section on how Hing Wa Lee makes small wheels, disks, ball-shapes, and the like, from the ancient Chinese shellac-abrasive melt, the reader will find few "secrets" revealed, or "tricks of the trade" explained, that are not already in print elsewhere. Basically, the ways in which hard gemstones are shaped, smoothed, and polished in carvings are the same everywhere—there are no secrets or tricks, just a great deal of patience, skill, and experience. Both text and illustrations show that Hing Wa Lee uses modern, electrically powered tools, not the ancient foot-powered lathe-like bench.

The text begins with an appreciation of the artistry of carvings. A second chapter describes the gem materials, divided into classes according to hardness, the final class being "hard" gemstones of Mohs 7 or greater. Most of the attention here is paid to varieties of quartz; other species such as tourmaline and beryl unfortunately are passed off with few words. Chapters 3 and 4 give instructions for making numerous types of small tools to be used from shaping to polishing. Regrettably, very little is said about the use of slabbing and table saws for rapid removal of material. Chapter 5 contains step-by-step instructions on how to carve a series of small objects of increasing difficulty, from a stylized peach to a three-link jade chain. Chapters 6 and 7 are *pot pourris* and include brief discussions of many topics and supplements to matters previously discussed. Four appendices provide lists of supplies; matching pairs of buffs and polishing agents, and the Mohs scale of hardness; a very short and inadequate glossary that omits many terms that appear in the text; and a long list of subjects that could inspire designs for carvings.

*This book is available for purchase at the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone: (800) 421-7250, ext. 282.

The bibliography includes several lapidary/carving books but consists mostly of articles from *Lapidary Journal*. The often excellent and informative articles that have appeared in *Gems & Minerals* and *Rock & Gem* are not included. The bibliography (and readers) also would have profited from inclusion of such excellent works on carving as F. W. Long, *Lapidary Carving*, 1982 (easily the best of the lot but now out of print); E. and L. Wertz, *Handbook of Gemstone Carving*, 1968; G. I. Hemrich, *Handbook of Jade*, 1966 (with considerable information on lapidary treatments of the jades); H. Hunt, *Lapidary Carving for Creative Jewelry*, 1980 (especially valuable for its instructions on tool-making); and F. W. Pond's *How to Make and Use Gem Carving Tools*, 1971.

The beginning carver will find a great deal of useful information in this book, albeit sometimes presented in disjointed fashion. The contribution by Hing Wa Lee on making shellac-abrasive tools is a most valuable feature of the work, but the remainder is primarily standard information on materials, tools, and techniques. The use of matte-finish text paper has resulted in less crispness of line than desired in the black-and-white photographs, with some dark areas showing little detail. In many instances, line drawings would have been far more helpful to the reader. The color photographs of carvings and some jewelry items are printed on a glossy-paper insert and paged with the text; they are mostly of high to very high quality. Zietner's book is a useful addition to a library of gemstone carving books.

JOHN SINKANKAS
Peri Lithon Books

LEGENDARY GEMS OR GEMS THAT MADE HISTORY

By Eric Bruton, 239 pp., illus., Chilton Book Co., Radnor, PA, 1986. US\$35.00

Bruton, former editor of *The Gemmologist* and author of *Diamonds*,

has taken on a very difficult task, one fraught with frustration because the records surrounding most of the world's most fabulous gemstones and their various owners are woefully incomplete. The researcher is often faced with more mysteries than answers, for gaps in the record are plentiful. Unfortunately, this book does little to provide answers to those mysteries. In addition, as intriguing as the title may be, little in the physical appearance of the book promises quality. The design is uninspired, and many of the 23 color and 75 black-and-white photographs vary from mediocre to terrible.

The book consists of 12 chapters with altogether fascinating titles, including: "Diamonds of Destiny," "The Greatest Gem of All Time," "Pearls of Great Price," and "Dealers and Collectors of Great Gems." Regrettably, the author's writing style, which is often disjointed and awkward, does not live up to their promise. In the first two chapters the reader is overwhelmed with dozens of names of Indian maharajas, Persian and Afghan shahs, Turkish sultans, Sikh chieftans, and so on. Yet each is usually given only a sentence or two in developing histories wherein the diamonds appear to have been passed around like hot potatoes. There are far too many characters and far too few stones to hold the reader's interest.

Bruton's meanings are often hard to interpret, and events and ideas frequently are poorly developed. In addition, the author often fails to provide a full description of the featured gem when he first introduces it. At the very least, the color, shape, weight, and (where known) date of discovery should be given at the outset. In some cases, one must read many paragraphs before learning an important detail of the stone. The date of discovery of Brazil's Star of the South is never given; nor does the author ever describe the color or mention the current situation of the Sancy diamond, which Streeter called "the very Sphinx of diamonds." Bruton also fails to identify

the Transvaal as part of the Smithsonian collection, where it has been since 1977.

The histories of many gems appear sketchy, hastily assembled, and not at all carefully researched. The Sancy diamond again provides a good example. Bruton states that "an unknown writer" declared that Charles the Bold lost the Sancy diamond on the battlefield in 1477. Bruton continues, "If the event is true, the stone lost by Charles could have been another double rose-cut stone, the Florentine, but not the Sancy because of its history" (*italics added*). First, he fails to point out that the confusion is unlikely because the Florentine was yellow and the Sancy is white. Second, Bruton does not explain what "because of its history" means in this context. Elsewhere Bruton writes about several stones sold to "the Gaekwar of Baroda," yet he never explains who this assiduous collector is, even in the "Collectors of Great Gems" chapter. As yet another example of the inconsistencies in this book, on page 107 the Noor-ul-Ain is described as though it hadn't already been introduced on page 53 and once again similarly described in the caption for plate 2. Interestingly, Bruton gives three different spellings: Noor-ul-Ain (p. 53), Noor-ul-Aim (plate 2), and Noor-ul-Din (p. 107). Further, the Orloff, a diamond that is currently on display at the Kremlin, is unaccountably included in the chapter "Famous Diamonds that Vanished."

What is most distressing is that there are so many similarly bad books, especially on gems, being published. It is apparent here, as in so many other books in this field, that the publisher is not giving the author the editorial support that he needs and, especially in this instance, deserves. *Legendary Gems* is yet another volume with far too many erroneous statements and details, a condition that is more serious than the fact that it is poorly written.

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Smithsonian Institution

GEMOLOGICAL ABSTRACTS

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COLORED STONES AND ORGANIC MATERIALS

The emeralds of the Belmont Mine, Minas Gerais, Brazil. H. A. Hänni, D. Schwarz, and M. Fischer, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 446–456.

The Belmont emerald mine in the Itabira mining district of Minas Gerais is described as probably the richest emerald occurrence in Brazil. The authors review the regional and local geology, including a general map of this and other emerald localities in Brazil as well as a geologic map of the Itabira district. Optical and density

values are provided as reported by previous studies.

The current study provides microprobe chemical analyses of nine samples of Belmont emeralds, a valuable addition to the scant chemical data published on gemstones. A thorough discussion of the inclusions observed in more than 300 emeralds from this locality is supplemented by some excellent photomicrographs as well as by microprobe analyses of three types of mineral inclusions: andesine, biotite/phlogopite, and Fe-dolomite. Not previously observed in other Brazilian emeralds are disc-like stress fractures centered around filled cavities that can be considered characteristic of emeralds from this locality. The article concludes with a discussion of the probable conditions of formation.

CMS

This section is designed to provide as complete a record as practical of the recent literature on gems and gemology. Articles are selected for abstracting solely at the discretion of the section editor and her reviewers, and space limitations may require that we include only those articles that we feel will be of greatest interest to our readership.

Inquiries for reprints of articles abstracted must be addressed to the author or publisher of the original material.

The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names. Opinions expressed in an abstract belong to the abstracter and in no way reflect the position of Gems & Gemology or GIA.

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Ein neuer Typ orientierter leistenförmiger Einschlüsse in Spinell (A new type of lath-like oriented inclusion in spinel). K. Schmetzer, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 36, No. 1/2, 1987, pp. 11–17.

Four sets of lath-like oriented inclusions were studied in a faceted bluish violet spinel from Sri Lanka. Using X-ray single crystal diffraction, the author determined that these doubly refractive elongated crystals are oriented parallel to the three crystal axes of the spinel. Microprobe analysis indicates that the inclusion consists mostly of Al and Si, and is therefore assumed to be one of

the Al_2SiO_5 polymorphs, quite possibly sillimanite. Six photographs clearly show the inclusions. EF

Optical absorption spectrum of Ti^{3+} and Fe^{2+} in uvite.

L. Reddy, A. S. Jacob, and B. J. Reddy, *Indian Gemmologist*, Vol. 1, No. 3, 1987, pp. 19–21.

A brownish yellow uvite (a member of the tourmaline group) from Sri Lanka was studied using optical absorption in the visible and near-infrared (400–2000 nm) range. All of the absorption bands in the visible range are attributed to trace amounts of dispersed Fe and Ti ions. It is concluded that the Ti^{3+} ion is in a tetragonally distorted octahedral site, and the Fe^{2+} ion is in a distorted octahedral environment. A few bands in the near-infrared are absorptions due to molecular water. EF

Les perles (The pearls). J.-P. Poirot, *Monde @ Minéraux*, No. 81, 1987, pp. 28–38.

This article provides a nice overview of the basic gemology of pearls. After a brief introduction to pearl history and nomenclature, M. Poirot describes how the formation of pearls is related to the disease margaritosis, in which a small worm fixes itself to the mollusk mantle. The various pearl-producing mollusks are reviewed in some detail, and the scientific names of the species are given together with the type of pearl each produces. The author emphasizes that all of these mollusks are from quite primitive species. The most important fishing grounds are listed, and the structure, physical properties, color, shape, and weight of the gems are briefly discussed. The various materials used to imitate pearls are also mentioned. The history of cultured pearls goes back to the 13th century in Japan. The currently used Nishikawa process is described in some detail, as are the processes for culturing freshwater pearls. The latter techniques are so efficient that China now produces up to 120 tons of freshwater pearls a year. The author then discusses gemological methods of separating natural from cultured pearls. He concludes with a few thoughts on pearl value criteria. EF

La topaze imperiale (Imperial topaz). J. P. Cassedanne and D. A. Sauer, *Revue de Gemmologie a.f.g.*, No. 91, 1987, pp. 2–9.

Imperial topaz is found only in a 25-km wide region west of Ouro Preto, in southern Brazil. Primary deposits are aligned in four bands and there are numerous alluvial secondary deposits. Although the deposits have a long history, only recent mining information is provided in this article.

The primary deposits are in brown earth, believed to be either deeply altered pegmatites or a discontinuous layer of volcanic origin, where topaz would have crystallized later hydrothermally. Associated minerals include euclase, hematite, quartz, rutile, magnetite, and a number of accessory minerals. Small deposits are mined with

only picks and shovels. Larger occurrences are scraped with bulldozers and washed on a grizzly; heavy minerals are separated out with a jig, and the resulting concentrate is sorted by hand. Only a very small proportion of the material is gem quality (5 ct per ton). Fourteen of the most important deposits (including Capão and Vermelhão) are described in some detail. Physical properties and a description of the inclusions follow, as do some precautions about cutting. Sixteen figures, a map, and some geological cross sections are also provided. EF

DIAMONDS

Elucidation of the scintillation (in Japanese with an English abstract). M. Kato, *Journal of the Gemmological Society of Japan*, Vol. 12, No. 1–4, 1987, pp. 12–18.

In this supplementary article to "Re-examination of Optimum Cutting Angle between Main Facets of Gemstones Based on Geometrical Optics," which appeared in a 1982 issue of the same journal, the author uses six computer-generated diagrams to illustrate the concepts of scintillation and brilliance. Kato contends that the most widely accepted definition of *scintillation*, as put forth in *The Diamond Dictionary*, is too vague and should be augmented by the in-depth analysis available with today's computer graphic technology.

In Japanese trade terminology, the word *chiri* combines the concepts of surface reflection and radiation; Kato believes that the English term *scintillation* best approximates the Japanese word. He emphasizes that radiation (defined as light that is refracted internally in the gemstone) is the most important component of scintillation. Dynamic radiation from the facets is responsible for brilliancy; the terms *twinkling* and *flashing* are used in Kato's analysis of brilliancy.

In measuring radiation for this study, a Tolokowsky-cut diamond and a faceted quartz were used. Three different light angles through the stone are measured and illustrated with diagrams—table to table, table to main, and main to table.

Andrea Saito/Hiroshi Saito
Malibu-Orient Trading
Malibu, CA

Famous diamonds of the world (XXV): The "Sancy." I. Balfour, *Indiaqua*, Vol. 43, No. 1, 1986, pp. 127–132.

Balfour begins this article in his series on famous diamonds by stating that the Sancy, a 55.23-ct pear-shaped diamond named for 16th-century lawyer and financier Nicolas Harlay de Sancy, "has the most confused story of all famous diamonds."

Two accounts appear in the literature hypothesizing how Sancy acquired the diamond. Balfour relates both and also discusses the inconsistencies that both raise with known historical facts. Nicolas de Sancy allegedly

sold the diamond to French monarch Henry III so that the king could pledge the gem to raise troops in Switzerland. The Sancy remained in the French Crown Jewels until the French Revolution, at which time it was pawned to a Spanish nobleman to raise funds. It is suspected that the diamond fell into the hands of the widow of Charles IV of Spain, who then passed it on to her lover, Godoy.

In 1828, Russian Prince Nicholas Demidoff bought the Sancy. After his death the following year, the diamond was passed on to his son who presented it to his bride. The stone remained in her possession until 1865, when it was apparently sold to Sir Jamsetjee Jejeebhoy. In 1889, it was purchased by goldsmith Lucien Falize, who sold it, in 1902, to William Waldorf Astor.

The Sancy remained in the Astors' possession until 1978, when it was sold to the Banque de France and Musées de France reputedly for \$1,000,000. The Sancy is now on display at the Gallerie d'Apollon in the Louvre Museum, in Paris. A brief description of the quality and properties of the Sancy concludes this article, which is accompanied by illustrations of people and places as well as the diamond. JLC

GEM LOCALITIES

An account of chrysoberyl-bearing pegmatite near Patara, Sri Lanka. E. G. Zoysa, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 486–489.

This article briefly describes a new *in situ* pegmatitic deposit of gem-quality chrysoberyl (including cat's-eye and alexandrite) in Sri Lanka. So far, the crystals recovered have been small, only 1–8 mm. Chemical analysis of one sample revealed 80.9 wt.% Al_2O_3 , 1.04 wt.% Fe_2O_3 , and 17.3 wt.% BeO (with 600 ppm Cr and 700 ppm Ga) by atomic absorption. Area maps and a stratigraphic cross-section are included. CMS

Die Himalaya Mine bei Mesa Grande in Kalifornien (The Himalaya Mine near Mesa Grande, California). R. Hochleitner and C. Weise, *Lapis*, Vol. 12, No. 10, October 1987, pp. 11–22, 32.

After a brief summary of the history, geology, and future prospects of North America's most-productive tourmaline mine—the Himalaya—the authors describe the major minerals and list 39 mineral species that have been found in the mine to date. The article concludes with a description of the authors' visit to the mine in Spring 1987.

Rubellite was first found in the Mesa Grande (San Diego County) region of California in 1895; the Himalaya mine started to produce important amounts of fine tourmaline in 1898. Most of the gems were exported to China, but the subsequent fall of the Chinese government ruined the mine financially. Several attempts to reopen the Himalaya failed until Pala International, Inc., took over in 1977. Today, the Himalaya mine is the

source of spectacular gemstones and collector specimens. The minerals are found in the pockets of two parallel pegmatite dikes that generally do not exceed about 50 cm (1.5 ft.) in diameter. Open-pit mining of the early days has been replaced by tunnel mining that follows the pegmatites into the hillside (this is illustrated in the article by two cross-sections of the mine). Future prospects are quite promising, as large parts of the pegmatites have not yet been worked and additional pegmatites have been located nearby.

The discussion of the minerals concentrates on the tourmalines, describing their various colors (red and green as well as multicolors) and forms (e.g., bent, broken, and healed crystals), including Eugene E. Foord's theory on their formation in the pockets. Other minerals described include apatite, lepidolite, quartz, albite, stilbite, hambergite, microcline, and stibiotantalite. The most fascinating part of the article is the authors' report on their recent visit to the mine. The mine is well run, and is worked by local miners. When pockets are found, mine manager John McLean picks out big crystals on the spot. The remaining filling (usually clay) is carried out in buckets and washed to expose smaller crystals and mineral specimens.

The article is lavishly illustrated throughout by seven black-and-white and 13 color photos that show the mine, mine workers, open pockets in the pegmatite, and, of course, magnificent tourmaline crystals. Although the article does not provide much new information (or any references to the literature that has already been written on this locality), it is a well-written and comprehensive introduction.

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JEWELRY ARTS

No magic but vital still. R. S. Medoff, *Lapidary Journal*, Vol. 41, No. 6, September 1987, pp. 22–30.

This is a well-written essay on a topic that many current jewelry designers either ignore or forget, that is, that "jewelry speaks a universal language that transcends all ages."

The author begins by pointing out how some current styles echo those of previous civilizations. Beginning with ancient Egypt, Medoff analyzes the use of scarabs in jewelry as amulets to call on the gods for protection; this gave jewelers a high social status and power. Later they developed faience (the first material made specifically to imitate gems) and used glass as enamel and for beads.

Medoff then shows how the Phoenicians disseminated these jewelry-making ideas throughout the Mediterranean and to coastal cities of Europe and Africa. This exchange of ideas and techniques provided inspiration and a "broadening of jewelry horizons" for civilizations in Greece, Italy, Africa, Spain, and Britain.

Using these ancient examples as a key, we can see the unfolding of jewelry history as a continual rejuvenation of various styles and techniques. Granulation, inlay, and enameling are three examples that are discussed in the article; there also is a sidebar exclusively on beads.

Although only four photos illustrate the article, the text itself is richly descriptive. *EBM*

JEWELRY RETAILING

Counter talk: What are your salespeople really saying?

L. F. Dellwig, *Modern Jeweler*, Vol. 86, No. 12, December 1987, pp. 59–61.

This article stresses the deficiencies in information that jewelry salespeople may be passing along to the customer. The author (a University of Kansas professor) discusses and gives examples of instances where salespeople have acted unethically or have relayed inaccurate information to a customer (in these cases, one of his students). Dellwig further reports that the salespeople are often confused (or ignorant about) the nomenclature for certain gemstones, for example, referring to all citrine as topaz.

This article concludes with a paragraph that provides some basic rules that jewelers and salespeople should follow in dealing honestly and knowledgeably with customers. Unfortunately, though, there are no suggestions as to how these rules could be implemented and regulated within the industry itself. *JLC*

SYNTHETICS AND SIMULANTS

The development of the Lennix synthetic emerald. L. Lens, *Gem Instrument Digest*, Vol. 3, No. 2, 1987, pp. 26–28.

This brief first-person report is by Leonard Lens, the developer of the Lennix synthetic emerald. In 1952, taking Carroll Chatham's success in synthesizing emeralds as a challenge, the author decided to try his hand at emerald synthesis. He started by examining the Chatham product and then followed, in turn, with a survey of the applicable literature, duplication of reported experiments, and original research.

Mr. Lens faced a problem common to producers of synthetic emerald: finding a suitable container material. He started with platinum, but soon found that mechanical abrasion was wearing down his containers—and accounting for some 80% of his production costs. Hence, he discovered a material that, in his words, is inexpensive, resists heat and corrosion, avoids danger of contamination, and contributes “actively to the regular growth of emerald crystals of high quality,” but he will not disclose what that material is. Mr. Lens also claims to be able to stop and restart the growth process at any time to examine the growing crystals and make any necessary adjustments. *RCK*

Genèse du béryl, synthèse de l'émeraude (Genesis of beryl, synthesis of emerald). D. Robert, *Monde @ Minéraux*, No. 80, 1987, pp. 39–42.

This well-written article sums up the various methods used to synthesize emeralds, as well as the criteria by which natural emeralds can be separated from their synthetic counterparts. The role of fluorine in beryllium dissolution is strongly emphasized as integral to the growth of both natural and synthetic emerald. The author then describes the results of his own attempts to grow synthetic emeralds. One of the main by-products obtained with inappropriate temperature conditions is a lithium-rich feldspar. *EF*

Notes from the Laboratory—11. K. Scarratt, *Journal of Gemmology*, Vol. 20, No. 7/8, 1987, pp. 406–422.

Mr. Scarratt reports on the examination of samples of Sumitomo synthetic yellow diamonds by the Gem Testing Laboratory of Great Britain. The results confirm those reported previously by GIA. Luminescence to ultraviolet radiation and patterns of zoning are the most important characteristic features. Also described are a blue sapphirine from Sri Lanka that was identified by X-ray powder diffraction, a partly nacreous natural brown pearl from Scotland, a calcareous saltwater mussel “pearl” from Norfolk, an opal with unusual inclusions and a honeycomb-like structure, and a necklace of imitation lapis lazuli beads. Testing of the beads revealed a greenish fluorescence, low hardness, sweating or stickiness to a hot point, a “rotten egg” odor with dilute HCl, and the presence of dye. However, limited time precluded a positive identification.

An in-depth description of the properties of two samples of the new Russian hydrothermal synthetic emerald, include R.I.'s (1.567–1.570 and 1.580–1.587), S.G.'s (2.68 and 2.71), absorption spectra, and internal features. Photomicrographs illustrate distinctive growth features and platelets that can be used to identify this material, which is inert to both ultraviolet radiation and the Chelsea filter. The notes conclude with a description of a synthetic ruby containing a cavity filling. *CMS*

TREATMENTS

Optical absorption spectroscopy of natural and irradiated pink tourmaline. M. Bueno de Camargo and S. Isotani, *American Mineralogist*, Vol. 73, 1988, pp. 172–180.

Three light pink tourmalines from Minas Gerais, Brazil, and one light green sample from Goiás, Brazil, were irradiated using ^{60}Co rays. All turned a dark pink. Polarized optical absorption studies show that the absorption band increasing with irradiation is correlated to Mn^{3+} . Detailed examination of the absorbance values suggests that two centers of unknown structure are involved. The presumed precursor of the Mn^{3+} ion is

Mn⁴⁺. The irradiation process is reversible for these pink tourmalines: Heating at 600°C for some hours turns the crystals colorless, but subsequent irradiation will restore the pink coloration. EF

Resin bonded malachite. R. Brightman and M.-L. Wilhelm, *Australian Gemmologist*, Vol. 16, No. 6, 1987, pp. 239–240.

This brief note reports on a bangle bracelet purchased in Tanzania that consists of resin-bonded blocks and small fragments of malachite. Gemological properties were determined as follows: R.I.—1.54/1.55 (resin areas); S.G.—3.295; fluorescence in the resin areas—moderate bluish green to long-wave U.V. and weak greenish to short-wave U.V.; thermal tester reaction of the resin—melted surface, leaving a dark brown mark. Magnification showed randomly oriented, angular fragments of malachite in a fine groundmass of tiny malachite particles with gas bubbles in the resin. The overall appearance reportedly resembled a natural breccia that had been healed. Also present were fractures which indicate a potential breakage problem. The authors conclude that while the average tourist may be misled, examination with a 10× loupe will reveal the true nature of the material. RCK

Sri Lanka bans topaz imports. *Jewellery News Asia*, No. 38, October 1987, pp. 1, 44.

Last June, at the urging of the Sri Lanka Lapidarists Association, Sri Lanka's State Gem Corporation issued a ban on the importation of colorless topaz. Reportedly, one dealer was selling Nigerian topaz as Sri Lankan; other dealers feared that if the practice became widespread it would damage the reputation of Sri Lankan stones. Sri Lankan topaz commands a premium in the world market because after treatment in a nuclear reactor to produce a "London blue" color, it loses its latent radioactivity more quickly than material from other sources. Ironically, the dealer accused of misrepresenting his topaz operates under a charter granted by the Greater Colombo Economic Commission (GCEC), which allows chartered companies to import any goods as long as they are re-exported, so his stones are unaffected by the State Gem Corporation's decision.

The Sri Lanka Lapidarists Association originally asked only for tighter scrutiny of imported stones, but they were told it was impossible to examine every incoming parcel. According to the Association, Sri Lanka imported 50 kg (25,000 ct) of topaz in 1987, compared to exports of 813,000 ct during the first three months of 1987. Over 2 million carats were exported in 1986.

Some cutters claim the ban will hurt Sri Lanka's cutting industry, which employs over 30,000 cutters. The Export Development Board, charged with promoting local exports, says a ban on imports runs contrary to

the policy of a free economy. The Sri Lankan government is expected ultimately to liberalize all gemstone imports.

Sharon Elaine Thompson

MISCELLANEOUS

The Peking Geological Museum, China. P. Bancroft, Z. Huang, and F. Wang, *Mineralogical Record*, Vol. 18, No. 5, 1987, pp. 325–332.

This article gives a brief description of Dr. Bancroft's recent visit to China and the Geological Museum of Beijing (formerly Peking). China is an excellent source for many minerals. Unfortunately, in the past, many valuable crystals were inadvertently destroyed by miners ignorant of their worth. The Geological Museum of Beijing now houses some of the finest specimens in the country, including the largest diamond recovered from the Changma district—a 119-ct octahedron.

The primary value of this article, however, is the spectacular array of color photographs of both classic and contemporary Chinese mineral specimens. The author photographed all the specimens, which were selected by the museum staff from a supplied list of species, including the cinnabar crystal that has appeared on Chinese postage stamps. PASC

The price of gold. S. D. Strauss, *California Geology*, Vol. 40, No. 10, October 1987, pp. 234–239.

This article is actually a transcript of an address presented by Mr. Strauss, an expert in mineral economics, at a meeting of the University of California Mining Association held in the spring of 1987. The text basically reviews the price of gold throughout history and its relationship to government economics.

Few may realize that an ounce of gold remained at a fixed monetary value (\$20.67) in the United States for 141 years (from 1792 to 1933), and at \$35 for the following 38 years. Mr. Strauss points out that since the tie between gold and the dollar was dissolved in 1971, trends in the recent gold market can be interpreted in varying manners in relation to other world currencies. This situation should translate into an ideal condition where gold-producing countries (e.g., the United States) see a rise in the price of gold as expressed in their units of currency, while countries that consume large quantities of gold (e.g., Japan) can buy it at a lower price in relation to their own currency. There are, however, many deviations from this scenario, and Strauss discusses several trends. He also stresses that, ideally, orderly price patterns should be maintained to stimulate economic growth and settle international trade deficits.

The article includes a helpful graph of gold production from 1850 to the present, which reflects important economic events that have had an impact on the output of gold. JLC