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ABOUT THE COVER: The metal in which a gem is set is often as important as the gem itself. Gold is the most popular metal for fine jewelry, and yet there may be as many difficulties determining the actual gold content of a piece as there are establishing the identity of the gem set therein. Four different methods of testing gold content are evaluated in the article by Meredith Mercer in this issue.

The pieces shown here, designed by internationally renowned goldsmith Elizabeth Gage, combine exquisite goldwork with fine mabe pearls, diamonds, and cultured pearl drops. The largest mabe pearl is 16 mm x 13 mm; 18k white gold and yellow gold are highlighted by wirework and granulation. Jewelry courtesy of Elizabeth Gage. Photo by Hanover Studios, London.

GEMS & GEMOLOGY

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WHAT DID YOU SAY THE NAME WAS?

I n this issue are letters to the editor regarding gemological nomenclature in general, and, in particular, the suggested use of *heliolite* for the transparent labradorite feldspar found to date only in Oregon. We applaud this type of dialogue. In gemology, the matter of nomenclature is never far from the center of any misunderstanding. Often the name chosen for a newly discovered gem material becomes the subject of serious disagreements between well-intentioned and competent gemologists. Even more often, the disagreements occur between marketer and gemologist.

In the science of mineralogy, there is a widely accepted procedure for naming a new mineral. The name proposed is either accepted or rejected by a formally established nomenclature committee of the International Mineralogical Association. Names that have been assigned since those that came to us from antiquity are usually based on considerations such as: the desire to honor a scientist (e.g., kornerupine); the chemistry of the new mineral (e.g., fluorite); the relationship of this mineral to others that are associated in some fashion, such as by structure or chemistry (e.g., phosphophyllite); the color or another obvious characteristic (e.g., azurite, axinite); or some geographic connotation (e.g., andalusite).

Usually, no economic factor is involved in the choice of a name for a new mineral that does not have any gem potential. However, if a new species or variety has the beauty and durability that portends a probable gem use, the situation becomes much more complicated. Marketers who are given some measure of opportunity, either by control of the new source or by access to an important market segment, can assign a name of their choice without any established authority to prevent their action. The market seems to regulate itself, as we have seen in some unsuccessful efforts such as the attempted use of *red emerald* for the beautiful red beryl from Utah and *pink emerald* for morganite. Market-driven nomenclature, therefore, is not always a bad situation. We know that traditionalists on a scientist-dominated board with authority over names might well have opted for *zoisite* over *tanzanite*, for example, when Tiffany and Co. first introduced the term in the 1970s. We at *Gems & Gemology* have supported an author's right to use a term that has a reasonable gemological basis and is not fraudulent or otherwise misleading.

Attempting to establish the makeup of an all-powerful nomenclature board to serve the gemological community would require more diplomacy than the United Nations has ever mustered. In spite of a few disturbing examples, the system established by the world market may be better than one more bureaucracy.

Richard T. Liddicoat
Editor-in-Chief

LETTERS

MORE ON "MISNOMERS" IN GEMOLOGY

While Dr. E. Gübelin [in his letter in the Fall 1992 issue of *Gems & Gemology*] was merely dismayed by the misnomers in American gemology, I—"a more delicate creature"—have been shocked and horrified. As Mr. Liddicoat said in his reply, terminology in gemology is often driven by market forces. However, the duties of the *science* of gemology are to preserve knowledge and to resist merely becoming a shill.

It was indeed within the rights of Tiffany to coin the term *tanzanite* for blue zoisite from Tanzania. Inasmuch as the campaign was successful, it became the duty of scientific gemology to duly record this definition and establish it as the name of a mutually exclusive category in the nomenclature scheme of gemstones. However, Mr. Liddicoat tells us that brown zoisite is currently "referred to as tanzanite by American and European jewelers alike." Since I question whether the general public accepts this concept, I would classify such an appellation as merely "jargon of the trade."

Now, it becomes the duty of scientific gemology to either ratify and promulgate this concept by changing the definition so that tanzanite means gem-quality zoisite (of any color?) from Tanzania, or to take a stand and say that some things are simply wrong—by definition.

The trend in the latter decades of this century has been to give equal acceptance to all ideas. As a consequence, it appears that nothing can be judged to be right or wrong anymore. It's just, "whatever works." Fortunately, science doesn't function that way. Unless gemology chooses to follow the dictates of good science, the future holds disaster.

Mr. Liddicoat says he does not like "the proliferation of separate names for each color variety of a gem material." However, he feels one could make a good case for the name *green tanzanite*. This is confusing. If brown zoisite is called tanzanite and blue zoisite is also called tanzanite, but green zoisite is called *green* tanzanite, then I assume that the yet-to-be-discovered *red* zoisite would be called red tanzanite—unless, of course, it was found in some other country. Isn't all this simply a proliferation of separate names for each color variety?

From the commercial as well as the gemological point of view, I believe this proliferation is ideal. It has done wonders for quartz, beryl, and corundum. *Emerald*, *aquamarine*, and *morganite* are certainly more salable names than *green beryl*, *blue beryl*, and *peach beryl*. This also explains the trade's desire to use the term *tan-*

zanite instead of the scientifically acceptable *zoisite*. However, *tanzanite* has already been defined, and science doesn't allow for the continual redefinition of terms for commercial gain.

The point I believe Dr. Gübelin is trying to make is simply that gemologists, as scientists, should use a little intelligence in choosing which names they accept or promote. While Mr. Liddicoat says that *Gems & Gemology* would relish the opportunity to be the arbiter of terminology in the gem world, he admits that it is not and uses that to justify the policy of allowing any author to create a new "trivial name."

The GIA has always prided itself on being a recognized leader in the field of gemology and is fully aware that, through *G&G*, it is indeed the de facto arbiter of gem terminology in the U.S. Now the world, through the pleas of Dr. Gübelin, is asking the GIA to act responsibly. If *G&G* does not wish to become part of the *solution*, then it must be prepared to be recognized as part (if not most) of the *problem*.

W. WM. HANNEMAN, PH.D.
Castro Valley, California

ANOTHER PERSPECTIVE: HISTORY OF HELIOLITE

With regard to the nomenclature controversy, I agree with Mr. Liddicoat that *sunstone* in gemological literature is generally regarded as an aventurescent feldspar, and is not, as Dr. Gübelin suggests, restricted just to oligoclase. Although most aventurescent feldspars are of oligoclase composition, Bauer (1904), Goodchild (1908), and Galvão (1899) clearly refer to orthoclase *and* oligoclase sunstone [*pedra de sol*, literally "stone of the sun," is the Portuguese term]).

In modern sources, Webster's *Gems* (e.g., 3rd ed., 1975) creates some confusion in the nomenclature of this gem material with the statement: "The gem mineral of the oligoclase variety of feldspar is sunstone, or as it is sometimes known aventurine feldspar, . . ." This supports Dr. Gübelin's contention, but poses a further problem by implying that all gem oligoclase is aventurescent. However, Webster goes on to note that some "sunstone" may be orthoclase or labradorite. Thus, Webster uses the term *sunstone* both in a restricted sense, and in the broader sense for any aventurescent feldspar. Shipley (1951) defines *sunstone* as an aventurescent feldspar, usually oligoclase. Liddicoat (1989) places sunstone in the albite-oligoclase group, restricting the term to

feldspars showing red-brown to orange spangles of hematite; where green spangles are present, he uses the term *aventurine* [feldspar].

From this, I would second the suggestion of Dr. Pough (1989) that sunstone be used only for an aventurescent variety of feldspar, but it should not be restricted to oligoclase, as this only would cause confusion due to past usage. Thus, for accuracy, when the term *sunstone* is used in gemological literature, it should be modified by the type of feldspar that exhibits aventurescence. The purist may wish to stick with *aventurescent labradorite*, or the like, which is clear and poses no problem.

More important, in my opinion, is Dr. Pough's introduction of a new meaning for the term *heliolite*, which is seconded by Dr. Gübelin. This term was "reintroduced" by Dr. Pough for the valid reason of providing a convenient name for the magnificent red and green labradorite now coming from Oregon. He suggests using the term for any plagioclase feldspar that is clear enough to facet and does not have aventurescence. Dr. Pough cites two early references where *heliolite* was used: Delemeth (1811) and Dana (1896). However, there are other, more recent, references in which *heliolite* has been used as a synonym for sunstone or aventurescent feldspar. (That *sunstone* and *heliolite* are synonymous should be no surprise: *Heliolite* ·is· a modified transliteration of the original Greek word, while *sunstone* is a translation of the sense of the Greek term.)

The famous Russian mineralogist A. Ye. Fersman, in his 1921 work *Description of Precious and Colored Stones of Russia*, uses the Russian term for *heliolite* as synonymous with aventurine feldspar. In Sofiano (1960), a slightly different Russian spelling is given, but the translation is *heliolite*. Galvão (1899) also provides a fine lexicon of mineralogical names, whereby *heliolite* is equivalent to *sunstone* which is equivalent to *aventurescent feldspar*. Both Goodchild (1908) and Moraes Branco (1989) also use *heliolite* as synonymous with *sunstone*.

These uses of *heliolite* were found with less than two hours of searching. No doubt there are more such references. It appears that *heliolite* continues to be used, if not widely, as an alternate term for aventurescent feldspar. Therefore, it seems inappropriate that the term now be adopted for a different type of gem feldspar. This new usage would only add to the confusion.

I recommend that the gemological community reject the use of *heliolite* as proposed by Drs. Pough and Gübelin. Either a different term should be found or, as Mr. Liddicoat suggests, we should ask whether we really need another term.

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CONFUSION AT THE TOP? HELIOLITE VS. SUNSTONE

"It is not really a mark of distinction for a geologist's writing to be so obscure that a glossary is required for its comprehension."—Jules Braunstein

In response to Dr. Gübelin's letter and Mr. Liddicoat's reply in the Fall 1992 issue of *Gems & Gemology*, I hope the following will serve as clarification with respect to the nomenclature of Oregon feldspar.

Dr. Gübelin's main disagreement with the title of my Winter 1991 *G&G* article, "Sunstone Labradorite from the Ponderosa Mine, Oregon," seems to be that *sunstone* as a descriptive term is synonymous with *oligoclase* and, therefore, is misapplied to a *labradorite*. Instead, he recommends the use of *heliolite*, the term suggested by his contemporary, Dr. Pough, which is Greek for *sunstone*.

At the risk of being obvious, I would like to remind all readers that gemstones are just minerals, albeit very pure minerals, or sometimes rocks composed of minerals. Therefore, it seems reasonable that gemological nomenclature should conform to accepted mineralogical terminology and guidelines, when possible. The planet Earth's governing body for mineral names is the Commission on New Minerals and Mineral Names of the International Mineralogical Association (IMA). If a name gets their approval, then it is legitimate. If it does not, neither age nor acceptance by the gem community makes the name *scientifically* accurate.

The most blatant deviation from mineralogical terminology occurs in gem variety names, most of which are not sanctioned by the IMA. If a gem-industry name does not conform to IMA standards, then it is probably being driven by market forces. This is neither an indictment nor a condemnation; after all, most of us in the gem business are capitalists. Just because we take some portion of a geographic name and slap a bit of Greek on its backside does not turn the result into SCIENCE. Why can't we

METHODS FOR DETERMINING THE GOLD CONTENT OF JEWELRY METALS

By Meredith E. Mercer

Verifying the gold content of karat-gold jewelry is a problem for the entire industry. This study compares four widely available testing methods: density (measured by hydrostatic weighing), chemical reactivity (touchstone testing), capacitive decay (Tri-Electronics G-XL-18 Gold Tester), and X-ray fluorescence (Seiko Instruments SEA 2001 Jewelry Assay System). The latter three methods all proved useful within certain limitations; hydrostatic weighing was least suitable. None of these methods reliably determined gold content within the 3-ppt tolerance allowed by U.S. plumb laws.

I n jewelry, the integrity of the metal is as important as the identity and integrity of the gemstones (figure 1). The misrepresentation of gold content ("underkarating") has been a source of concern at all levels of the industry for literally hundreds of years. For the protection of retailers and consumers alike, a testing method that can verify the gold content of finished jewelry at point of sale is needed. Ideally, this method would be rapid, simple, reliable, inexpensive, nondestructive, and widely accepted by the jewelry industry. The study reported here was conducted to determine whether existing methods could meet these requirements. Four testing methods currently used in the trade—density, chemical reactivity, capacitive decay, and X-ray fluorescence—were applied to the same set of well-characterized reference standards and the results compared.

Gold-testing methods such as fire assay, touchstone testing, and hydrostatic weighing have been used since antiquity. Tests for plated material include cutting, heating, and ringing (Oddy, 1983; Revere, 1990). Much work has been done on the development of analyses to detect very small quantities of gold for mining (Young, 1980). Methods of analytical chemistry (such as X-ray transmission, Compton scattering, neutron activation analysis, inelastic scattering, atomic absorption, and particle-induced X-ray emission) can be quite accurate. However, these methods usually call for complex and expensive equipment, as well as destructive sample preparation (de Jesus, 1985; Kahn et al., 1981; Demortier, 1984). To the author's knowledge, no work evaluating techniques commonly used on jewelry metals in tests of carefully characterized karat gold alloys has been previously published.

BACKGROUND

Underkarating is the practice of knowingly or unknowingly misrepresenting the gold content of a finished piece to be higher than it actually is. A Jewelers Vigilance Committee (JVC) study found that as much as 50%–70% of the untrade-

Figure 1. Karat weight is an important consideration in gold jewelry, for customer and retailer alike. There are also different alloy colors of gold. Illustrated here, clockwise from the upper right, are a 14k green gold bee-shaped pin set with pavé diamonds; an 18k green gold pin set with diamonds and a black opal; a 14k yellow gold chain; a 14k ring of red, white, and yellow gold; and a 24k gold Chinese tael. The "bee" pin, chain, and ring are courtesy of The Gold Rush, Northridge, California; the opal-set pin is by Silverhorn, Santa Barbara, California. Photo © GIA and Tino Hammid.

marked jewelry they tested was underkarated (i.e., contained less gold than its karat mark stated; Tolhurst, 1986). In contrast, JVC reported in the same article that they found no underkarating in a random sample of trademarked items that they checked. Court cases involving underkarating are currently pending in San Francisco and Honolulu ("Police beat," 1989; Badham, 1990). The fact that there may be only slight differences in visual appearance between golds of greatly different karat grades underscores the difficulty of detecting underkarating in daily commerce (figure 2).

United States law recognizes alloys containing at least 417 parts per thousand (ppt; 41.7% or 10k) gold as karat gold, and allows a tolerance of 3 ppt on unsoldered items (see Box A for an explanation of the relationship between parts-per-thousand, percent, and karat designations). A 7-ppt tolerance is allowed on items containing solder. Thus, a 14k (nominally, 583-ppt) gold item that has been made or repaired with solder may be as low as 576-ppt gold. Where a quality mark stating gold content appears, it must be accompanied by a manufacturer's trademark (Jewelers Vigilance Committee, 1987; Shor, 1988). Although this trademark has been legally required since 1906, it is largely unenforced.

The oldest institution charged with protecting the consumer from underkarating is the Worshipful Company of Goldsmiths in London. In 1300, King Edward I of England required that all gold and silver
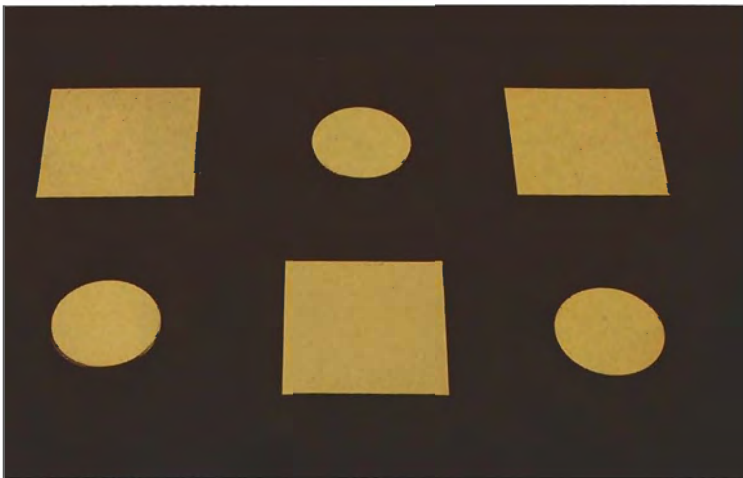
Figure 2. Although these karat-gold pieces are similar in color and appearance, they are actually 10k, 14k, and 18k (left to right). Gold courtesy of David H. Fell and Company, Inc., Los Angeles, California; photo by Maha Smith-DeMaggio.

wares be tested and marked by the goldsmith's guild, a precursor of the Worshipful Company (Johnson, 1980). Later, wares had to be sent to the guild hall for testing and marking (the probable origin of the English word *hallmark*; Hare, 1985).

Today, every item of gold, silver, or platinum sold in the United Kingdom must first be sent to one of four assay offices for hallmarking. Those that pass the assay are marked with four (or sometimes five) marks: (1) a maker's or sponsor's mark; (2) in certain cases, a symbol indicating the fineness of the item; (3) the fineness in parts per thousand; (4) the symbol of the office where testing was done; and (5) a letter in a particular typeface that indicates the year of marking. Not only does this information protect consumers, but it is also very valuable to jewelry historians. Unlike U.S. law, British law allows no negative tolerance (e.g., an item that is 749-ppt gold cannot be marked 18k, which is nominally 750 ppt; Assay Offices of Great Britain, 1988).

BOX A: THE NOMENCLATURE OF GOLD CONTENT

The gold content (also known as "fineness") of karat gold is described in several ways:

Percent (%) is simply the ratio of gold (by weight) to the total metal present, expressed as parts of 100. Thus, an alloy that is three parts gold and one part alloy metal is:

$$3/(3+1) = 3/4 = 75/100 = 75\% \text{ (by weight)}$$

Parts per thousand (ppt) is similar to percent, but compares the total metal (by weight) present to 1000, rather than 100, parts. This increases the expressed precision. Thus, an alloy containing seven parts fine gold and five parts alloy metal is:

$$7/(7+5) = 7/12 = 0.583 = 583 \text{ ppt (by weight)}$$

This could also be expressed as 58.3%. Legal tolerances and requirements are usually expressed in ppt.

Karat (k, also abbreviated kt) is perhaps the most widely known measure of gold content—as well as the least straightforward to calculate and envision. It is also based on the ratio of fine gold to total metal present (by weight), but it divides the total metal present into 24 parts. Thus, each karat is 1/24 (by weight) of the whole (4.17%, or 41.7 ppt). The 583-ppt gold alloy (seven parts gold and five

parts alloy metal) discussed above can be described in karats as:

$$7/(7+5) = 7/12 = 14/24 = 14k$$

This measure of gold content is spelled "karat" in the United States to help avoid confusion with "carat," the measure of weight commonly used for gemstones. In Great Britain and British Commonwealth countries, it is spelled "carat" for both applications.

Table A-1 correlates these three measures of gold content.

TABLE A-1. Comparison of expressions of gold content.

Karat (k)	Percent (wt. %)	Parts per thousand (ppt)
8	33.3	333
9	37.5	375
10	41.7	417
12	50	500
14	58.3	583
18	75	750
22	91.7	917
24	100[a]	1000[a]

[a] *Note: Most countries allow gold that is 99% (990 ppt) pure to be described as "24 karat," or "pure gold."*
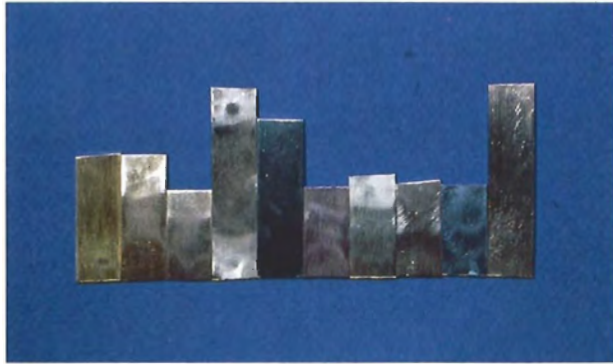
Figure 3. Ten karat-gold reference standards were used for this study (right to left): 8k yellow, 10k white, 10k yellow, 14k green, 14k red, 14k white, 14k yellow, 18k yellow, 22k yellow, and 24k. Photo by Maha Smith-DeMaggio.

International laws regarding karat standards vary widely. Seven European countries signed the 1972 "International Convention on the Control of Marking of Articles of Precious Metals," which established standards and authorized laboratories within member countries to apply a convention mark certifying gold content. This mark allows each member country to accept goods from other member countries without further verification. Today, hallmarking is compulsory in France, Ireland, Portugal, Spain, Holland, and Great Britain (P.V.A. Johnson, pers. comm., 1992); some other European countries have voluntary hallmarking programs. The effect of European economic unification on hallmarking laws is still being worked out (Johnson, 1992).

MATERIALS AND METHODS

Four methods for testing the gold content of karat golds were selected for this study: density, touchstone testing, capacitive decay, and X-ray fluorescence spectrometry. The criteria used in choosing these four methods were nondestructiveness, ease of operation, and, except for X-ray fluorescence, low cost and portability. The same 10 reference standards were tested by each method.

The reference standards in this study are karat golds commonly used in jewelry. They were custom cast, rolled, and given a brushed finish for GIA at Leach and Garner Technology, North Attleboro, Massachusetts. The standards range from 8k to 24k, and include yellow, white, red, and green golds (figure 3).

The composition of each reference standard was determined at Leach and Garner by fire assay and

directly coupled plasma spectroscopy, and then confirmed by fire assay and atomic-absorption spectroscopy at Goldsmith's Hall, London. The compositions found are shown in table 1.

Fire assay is one of the oldest methods known for testing gold content. The earliest written mention of the technique dates from 1380 B.C. (Wälchli and Vuillemier, 1987). In fire assay, the metal is oxidized at high temperature (cupelled) to separate base metals from noble metals. Any silver present is then removed from the residual metal by dissolution in nitric acid. The weight of the remaining fine gold is compared to the weight of the original sample to establish the metal's original gold content.

In atomic-absorption (AA) spectroscopy, the sample is dissolved in a liquid solution and then vaporized in a flame. The resulting gas absorbs light in proportion to its elemental composition, which can be measured to produce a quantitative chemical analysis.

TABLE 1. Compositions of karat-gold reference standards used for this study[a].

Reference standard	Composition (wt.%)				
	Au	Ag	Cu	Zn	Ni
24k yellow	99.99 ± 0.1 (99.99)	—[b] —	— —	—- —	— —
22k yellow	91.55 ± 0.2 (91.63)	2.85 ± 0.5 (3.07)	5.10 ± 0.5 (4.90)	0.50 ± 0.2 (0.50)	— —
18k yellow	75.00 ± 0.2 (75.03)	6.75 ± 0.5 (6.67)	15.35 ± 0.5 (15.34)	2.90 ± 0.5 (2.92)	— —
14k yellow	58.50 ± 0.2 (58.58)	3.95 ± 0.5 (3.74)	31.50 ± 0.5 (31.69)	6.05 ± 0.5 (5.94)	—- —
14k white	58.40 ± 0.2 (58.39)	—- —	22.70 ± 0.5 (22.66)	7.65 ± 0.5 (7.95)	11.25 ± 0.5 (11.00)
14k red	58.40 ± 0.2 (58.42)	— —	40.80 ± 0.5 (40.87)	0.80 ± 0.3 (0.76)	—-
14k green	58.40 ± 0.2 (58.42)	32.20 ± 0.5 (32.28)	9.20 ± 0.5 (9.17)	0.20 ± 0.1 (0.22)	—-
10k yellow	41.70 ± 0.2 (41.72)	5.80 ± 0.5 (5.62)	44.00 ± 0.5 (44.21)	8.50 ± 0.5 (8.42)	— —-
10k white	41.60 ± 0.2 (41.63)	—- —	33.45 ± 0.5 (32.66)	8.45 ± 0.5 (8.80)	16.50 (16.93)
8k yellow	33.40 ± 0.2 (33.40)	6.90 ± 0.5 (6.95)	49.95 ± 0.5 (49.87)	9.75 ± 0.5 (9.78)	— —

[a] Reference standards cast and analyzed (fire assay and DC plasma) by Leach and Garner Technology, North Attleboro, MA; uncertainty in measured value (±) varies with alloy content and method of measurement. Values in parentheses are from the Worshipful Company of Goldsmiths Assay Office, London, UK; analysis by fire assay and atomic absorption.
[b] — not detected.

For gold, silver, copper, tin, and cadmium, AA has very high sensitivity (approximately 1 atomic part per million [ppm—"parts per million atoms," not to be confused with ppt]; Veillon and Skogerboe, 1987). The disadvantages of AA include the fact that it can analyze for only one element at a time, and the possibility that error could be introduced when the sample is diluted to the low concentration necessary (Willard et al., 1981, p. 141).

Directly coupled plasma (DCP) spectroscopy, which is the technique used by the metallurgical laboratory that prepared the standards for this study, is similar to atomic absorption. As with AA, the sample is placed in a liquid solution, but it is then excited by high-temperature plasma—a gas ionized by highly concentrated electromagnetic energy—rather than by light. This excitation causes the emission of light (i.e., photons) with wavelengths that are characteristic of the sample's composition. The advantages of DCP are that it can analyze several elements at once and that it can handle solutions in high concentrations (up to 25%), which increases the accuracy that can be obtained for jewelry metals. Like AA, it is sensitive to approximately 1 ppm for most metals commonly found in jewelry. The primary disadvantage of DCP is its unsuitability to automated operation (Willard et al., 1981, p. 163). A related method, inductively coupled plasma (ICP) spectroscopy, is also frequently used, with similar results.

These three analytical methods, while more accurate and repeatable than the four methods examined in this study, are also much more complex and expensive. Therefore, they are not suitable for general use by most gemologists.

TESTS AND RESULTS

This study was conducted to examine the performance of each of the four testing methods on a set of well-characterized reference standards. Only the 10 reference standards were tested. No metals other than karat gold, no plated items or finished jewelry, were examined. Other shapes and finishes would probably produce somewhat different results.

Each method tested has unique advantages and limitations, and direct comparison between methods is difficult. The purpose of this work is not a competitive comparison of methods, but an individual evaluation of each.

Density. Common alloying elements (such as nickel, copper, zinc, and silver) have significantly lower den-

Figure 4. A Mettler balance with hydrostatic-weighing accessories was used to test the specific gravities of the karat-gold reference samples. Photo by Maha Smith-DeMaggio.

sities than gold. Density is often expressed as specific gravity (S.G.), a numerical comparison of the density of a substance to that of water. Hydrostatic weighing works on the principle that density can be measured by the buoyant force acting on an object immersed in a fluid.

According to legend, the ancient Greek scientist Archimedes (c. 287–212 B.C.) discovered this principle in response to a gold-testing problem (van den Waerden and Heath, 1983). King Heiron II of Syracuse asked Archimedes if there was a way to determine, without damaging the item, whether his new crown was made of the fine gold he had specified or of the adulterated alloy he suspected had been used.

Archimedes puzzled over the problem one day while visiting the public baths. Stepping into a tub, he watched water run out over the top—and realized that an immersed object displaces fluid in a way dependent only on its volume, and irrespective of its weight. Thus, he could find the volume of the crown by immersing it in a vessel filled completely with water, measuring the overflow, and comparing the volume of the overflow to the volume of an amount of pure gold that weighed precisely the same as the crown. If

the crown were pure gold, the two volumes would be the same; but if the crown were gold alloyed with a lighter metal, such as silver or copper, the same weight of alloy must have a greater volume than pure gold. Because gold is denser, that is, has a higher specific gravity, it displaces less water than an equal weight of silver or copper.

This idea struck Archimedes so strongly that he leaped up and, forgetting his clothing, ran home through the streets shouting "Eureka, Eureka!" ("I have found it!").

Method. The reader is referred to any of a number of books on gemological testing for description of the technique of hydrostatic weighing (e.g., Webster, 1983; Liddicoat, 1990) and to Sinkankas (1986) for an in-depth historical review of the use of this technique in gemology. Weighings for this study were performed on the equipment shown in figure 4.

Each standard was weighed in air and water four times (except the 14k green and 8k yellow samples, which were weighed only three times each). Densities were calculated according to the following equation:

density = (weight in air)/(weight in air – weight in water)

The means and ranges for the densities determined for each standard are shown in figure 5. In addition, density was calculated for each reference standard according to its known composition (as determined by fire assay, DCP, and AA spectroscopy) and is shown for comparison in figure 5. Calculated density is based on the measured concentration of each element in an alloy, multiplied by the known density of that element.

Results. As figure 5 shows, most of the mean measured data do not match the calculated densities (dashed lines). In eight of 10 cases, the hydrostatic results indicate less gold than is actually present. The 3-ppt tolerance allowed by U.S. plumb law is too small to show on this chart. For example, the 6-ppt (±3ppt) plumb range for the 14k yellow sample corresponds to a density range from 14.96 g/cm^3 to 14.88 g/cm^3. In contrast, the mean measured value is 13.0 g/cm^3.

Evaluation. Although theoretically straightforward, hydrostatic weighing presents practical difficulties. The balance pan must be weighed first, and its weight subtracted from the final water weight. Air bubbles clinging to the test piece will falsely decrease weight, while any water droplets on the wires holding the

weighing tray will falsely increase weight. The accuracy of the density method could be improved by making a greater number of measurements per sample, but the time required to do so would make this method impractical for most jewelry applications. Moreover, only objects without stones can be tested. This method also cannot detect gold-plated items filled with a metal (such as lead) that has a density similar to that of gold.

Figure 5. Densities determined by hydrostatic weighing are compared to densities calculated from the analytically measured contents of the 10 reference standards. The mean result of four weighings is shown for each sample. Y, W, R, G indicate yellow, white, red, and green golds, respectively. Note that the densities calculated apply only to the karat-gold samples used for this study; different karat golds of the same color and gold content may have different densities.

Chemical Reactivity. The property that sets gold apart from most other metals is its relative inertness to chemical reaction, which makes it highly resistant to corrosion. This property can be used to test jewelry metals, because the gold in the alloy will react much more slowly when exposed to acid than will the other metals. In addition, the more alloying metal present in proportion to gold, the greater will be the magnitude of the reaction to the acid. This type of testing is commonly known as "touchstone testing."

Corrosion is a property that occurs only in metals. Thus, to understand why and how corrosion occurs, one must first understand that metals as a group are unique among chemical elements. Their electrons are not rigidly bound in place, but are free to move about. In addition, electrons in different elements have different intrinsic energy levels, like different natural bodies of water at different altitudes. For example, when two different metals are placed in electrical contact, electrons flow from the metal with the higher energy level (e.g., copper) to the one with the lower energy level (e.g., gold), as water flows downhill. The removal of negatively charged electrons must be balanced by the removal of positively charged ions (atoms missing one or more electrons) from the same

piece of metal. The changes in color and texture of metals that we commonly associate with corrosion result from this loss of material. (It is this flow of electrons that also produces current in simple batteries, and it is this eventual depletion of material that causes batteries to "go dead"). The higher the energy level of a given metal, the more it will react in this way. Thus, we may judge these energy levels by observing chemical reactivity.

Touchstone testing for gold content, which exploits this chemical reactivity in metals, is the origin of the phrase *acid test*. Touchstone testing is done by visually comparing the reactions of a test metal and the reactions of metals of known gold content to the same acids simultaneously. References to the comparison of uncorroded metal streaks can be found as early as 600 B.C. (Wälchli and Vuillemier, 1985). The use of acid to measure the chemical reactivity of the streaks dates to the 14th century. The acid reacts with the atoms of other metals (such as silver, copper, or zinc) in a gold alloy by creating the flow of electrons and ions described above between microscopic regions richer in these other metals and regions richer in gold. The resulting corrosion can be observed as a discoloration.

Figure 6. The following tools are needed to determine chemical reactivity by means of touchstone testing on an item believed to be 14k gold (clockwise from upper left): touch needles, 14k acid (43% nitric acid), 14k touch needle, and a basalt touchstone. Note the streaks with acid next to the test piece on the touchstone. Photo by Maha Smith-DeMaggio.

Method. In touchstone testing, the test piece is drawn carefully across the surface of a fine-grained black "touchstone" (commonly, a piece of basalt; figure 6), producing a streak on the stone. The streak is bracketed by streaks from "touch needles"—strips of karat gold of known gold content. A drop of acid is drawn across all the streaks, and their subsequent reaction is carefully watched. A judgment is then made as to which touch-needle reaction most closely matches that of the test piece. The test is repeated, with different acids or touch needles, as necessary. Nitric acid, hydrochloric acid, and aqua regia are the most commonly used acids. It is reported that accuracy to at least 10–20 ppt, and (with experience) as close as 5 ppt, can be made with this method, given the availability of touch needles that are graduated to this degree of fineness (Wälchli and Vuillemier, 1985).

Tests were performed by the author on the stone shown in figure 6 with 9k, 14k, 18k, and 22k yellow- and red-gold touch needles manufactured by Bergeon (No. 6675-9). The acids were mixed according to the formulations used at Goldsmith's Hall. They included 9k (24% aqueous HNO_3), 14k (43% aqueous HNO_3), 18k (43% aqueous HNO_3 with 0.06% NaCl), and 22k (43% aqueous HNO_3 with 1% NaCl). Note that these acids, while used in very small amounts, are

hazardous materials that must be handled properly.

Each sample was tested four times by drawing it across the stone to create an even, consistent metal streak. On one side, a similar streak was drawn from a touch needle of possibly equal or lower karat weight. (An educated guess is the best estimate initially.) On the other side, a streak was drawn from the next-higher-karat touch needle. A drop of the acid estimated to match the sample karatage was placed on the touchstone near the streaks. From this drop, a thin, even line of acid was pulled (with the acid dropper) across the sample and touch-needle streaks. At least two comparison touch-needle streaks and two different acid reactions were used to test each sample.

Reactions were observed as they took place, and the appearance of the various streaks was noted after the acid had been soaked up with filter paper, in combined fluorescent/incandescent lighting. Between tests, as needed, the touchstone was cleaned with 600-grit silicon carbide sandpaper lubricated with olive oil.

Goldsmith's Hall also tested all but the 18k sample (which was not available at the time). Four different operators performed one test each on the nine other samples, using acids mixed to the same formulas described above.

Results. The results of the author's tests and those done at Goldsmith's Hall are shown in figure 7. All of the data from tests performed at GIA lie within a statistically acceptable range of the known values, as do most of the results from Goldsmith's Hall. The exceptions are the data for the 10k yellow and 10k white samples obtained by Goldsmith's Hall. The 14k red samples and white samples showed a wide range of values, as did the 18k, 22k, and 24k (yellow) samples. As was the case with hydrostatic weighing, all of the ranges are outside the 3-ppt tolerance specified by U.S. plumb law.

Evaluation. Tests performed by a trained but inexperienced technician (the author) tended to be closer to assayed values than those obtained by highly skilled and experienced workers at Goldsmith's Hall. This is probably due to the difficulty of creating a truly blind test for the author, and indicates one bias inherent in this kind of testing. Especially notable are results for the two 10k alloys, which were almost unanimously reported as 9k in the Goldsmith's Hall trials. Ten-karat gold is almost unknown in Britain, where the

Figure 7. Gold content was measured by touchstone testing at GIA and at the London Assay Office of Goldsmith's Hall. The mean and range of four tests for each sample are shown (the 18k sample was not available for testing at the Assay Office). The horizontal gray bars indicate the 6-ppt (±3 ppt) range allowed by U.S. plumb laws.

most common karat gold is 9k (which, as noted earlier, is not legally defined as karat gold in the U.S.).

Because touchstone results depend heavily on the skill, experience, and bias of the observer, they tend to be subjective. Also, some precision is lost with high-karat golds because of the increasing similarity of the reactions. Again, note that the acids are hazardous materials that must be used with caution.

Figure 8. The components of the G-XL-18 Gold Tester, used for capacitive decay testing, include (from left to right): the G-XL-18 tester unit, an electrical hook-up with test piece and electrolyte gel, and a gel dispenser/probe wand. For this test, the operator positions the test piece in the clip and applies a drop of gel. With the probe touching the gel, the operator then presses the button that corresponds to the color of the test piece. The results are displayed on the tester unit. Photo by Maha Smith-DeMaggio.

Even so, measurement of chemical reactivity by the touchstone test can be relatively reliable if the operator is sufficiently skilled and free of bias.

An important advantage of this method is that it can be used to test jewelry of almost any shape, size, and finish, including stone-set pieces. In addition, plating can be detected by skillful observation of the inhomogeneous reaction pattern that occurs within the metal streak.

Capacitive Decay. This method was invented by Leonid Radomyshelsky, a Jewish emigré from the Soviet Union who had been trained as an electrical engineer. After Mr. Radomyshelsky opened a jewelry store in the U.S., he became concerned about verifying the gold content of the jewelry he sold. Using his engineering expertise, he devised an electronic method to measure the "nobility" of metals.

Method. The G-XL-18 Gold Tester (figure 8), made by Tri-Electronics Corp. of San Diego, California, operates by measuring the capacitive decay rate of the test piece. When a test piece is placed in electrical contact with the platinum cathode, the tester

builds up a type of electrical charge known as "capacitance" between an electrolyte gel and the cathode. This capacitance decays at a measurable rate that varies with the gold content of the test piece. The G-XL-18 tester measures the decay rate, compares it to an internal computer file, and displays the karatage that matches the measured decay rate most closely.

Two sets of tests were run on the Gold Tester, both on the same instrument. For the first set, performed by the author, nine trials were run on each sample. For the second set, performed by Mr. Radomyshelsky himself, five to seven trials (the number he recommends for this instrument) were run on each test piece.

Because the G-XL-18 is designed to test gold only in the range of 10k to 18k, we did not include results for samples over 18k. However, we did include the 8k sample, because 8k or 9k gold may be encountered both in underkarated 10k goods and in 8k or 9k goods that are legal in various parts of the world. It was understood, however, that while the tester is capable of operating outside its design range, the accuracy of the results might suffer.

Results. The data are presented in chart form in figure 9 (for statistical consistency, only seven of the GIA trials are represented). As might be expected, the means for the 8k sample are off by more than 1k, with a considerable range. Also interesting are the results for the 14k yellow gold, which consistently produced a 12k read-out in the GIA trials. Although all of the results fall within 2k of known values, this is still well outside the 3-ppt tolerance allowed by U.S. law.

Evaluation. The inaccuracy encountered with the 14k yellow sample was traced to a higher copper content in the test piece than in the yellow gold used to calibrate the instrument. When the 14k yellow sample was retested as a red gold, the mean of four tests came to 13.6k, with very little variability. This illustrates the risk inherent in directly comparing the chemistry of one karat-gold piece to another that, although of the same gold content, may have a very different alloy composition. The poor results for the 8k sample simply confirm the manufacturer's stated limitations of the instrument.

One disadvantage of the G-XL-18 is that the presence of plating can only be detected by testing a small area from which the plating has been removed. Also, the curved surfaces of most chains, prong settings, and other small, highly curved items will interfere
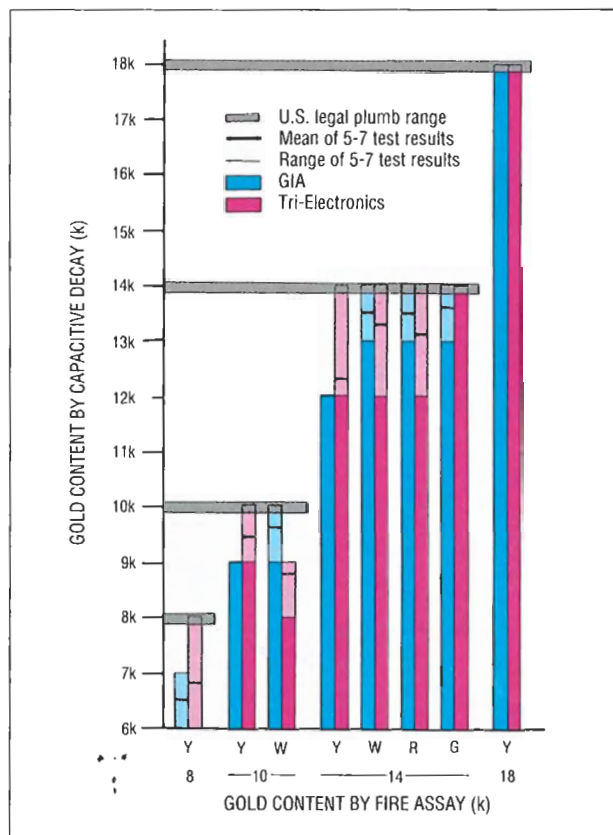
Figure 9. Capacitive decay testing was performed by GIA and Tri-Electronics using the G-XL-18 Gold Tester. The means and ranges of five to seven tests by Tri-Electronics, and seven tests by GIA, are presented in comparison to the 6-ppt (±3ppt) range allowed by U.S. plumb law. Although tests were not conducted on samples above the G-XL-18's 10k-to-18k design range, the 8k sample was included to show how the tester responded to a piece that was below the U.S. legal limit for karat gold.

with the capacitive-decay reaction. Tri-Electronics does not recommend the G-XL-18 for testing such items. An advantage of this method is that it can be used to test jewelry of most other shapes and most finishes, as well as stone-set pieces.

X-ray Fluorescence. In 1913, it was discovered that exposure to high-energy radiation can cause atoms to emit X-rays that are characteristic of the source element's atomic number. In 1951, X-ray intensity was correlated to the quantitative chemical composition of the sample. Development in the late 1960s of the lithium-drifted silicon X-ray detector and sophisticated computer systems paved the way for rapid

and relatively accurate quantitative analyses by this method (Goldstein et al., 1981).

Method. When an X-ray strikes an atom, it may cause the atom to emit a secondary X-ray that has an energy unique to the element from which it is emitted. These secondary X-rays can be collected and analyzed for information on sample composition. This is called X-ray fluorescence (XRF) analysis, because atoms in the sample respond to the original, incoming X-rays by fluorescing (emitting) characteristic secondary X-rays.

Tests were performed by the author at Seiko Instruments, Torrance, California, on their SEA 2001 Jewelry Assay System, an XRF system with sophisticated software developed specifically for testing karat gold (see figure 10). One test was run for each reference sample, with the instrument first calibrated to comparable standards when available. Standards were not available for the 24k and 22k yellow, and 14k green, test pieces.

Technicians at Goldsmith's Hall performed a second set of tests (one for each sample, except the 18k yellow) using the same-model instrument, also calibrated to comparable standards.

Figure 10. The SEA 2001 Jewelry Assay System for X-ray fluorescence analysis was the most sophisticated method used in this study. The components of this unit are (clockwise from top right): the liquid-nitrogen reservoir that contains the X-ray detector, the sample chamber (on top of the console), a computer, and a monitor (here displaying a typical spectrum). Photo courtesy of Seiko Instruments Corp.

Results. Figure 11 shows that 80% of the results from tests performed by the author with the Seiko instrument were within 3 ppt of assayed values. The fact that the 24k sample was 11 ppt below, and the 14k green 15 ppt below, their assayed values reflects the lack of calibration standards noted above. The testing at Goldsmith's Hall produced results that fell outside 3 ppt for the 14k green (14 ppt below), the 14k white (5 ppt above), and the 8k yellow (4 ppt below) samples.

Evaluation. The results of XRF analysis are promising, but several caveats must be made. Secondary X-rays travel only very short distances through metal. Therefore, the X-rays available for XRF analysis come from only the first few microns (millionths of a meter) below the sample surface. Thus, only a very small area is tested, which would not represent the bulk of a sample that was plated or otherwise internally inhomogeneous. This surface sensitivity also causes a strong dependence on shape and finish. Results for convex surfaces, unusual finishes, or relief work are generally unreliable.

Moreover, the XRF system must be calibrated to an alloy of similar composition for reliable and accurate quantitative results to be obtained. Seiko Instruments calibrated their tester with standards very similar to the reference standards used in this study. Both alloy sets were obtained from the same supplier. These results, therefore, may not represent practical testing of a variety of alloys from different suppliers. The greater variation in the data from the Goldsmith's Hall tests supports this concern.

The greatest disadvantage of XRF for most in the jewelry industry is that the system is considerably more expensive than the other methods described here, and it requires substantial technical skill both to operate the equipment and to interpret the results.

Despite these limitations, X-ray fluorescence testing can be relatively accurate if the test piece is flat and homogeneous, and the instrument is properly calibrated to a standard of similar shape, finish, and composition.

CONCLUSIONS

From this limited examination of 10 standard reference materials of normal gold-alloy composition ranging from 8k to 24k, the following preliminary conclusions can be drawn:

1. Hydrostatic weighing appears to be unsuitable for karatage determinations, as results are likely to be unreliable.

Figure 11. X-ray fluorescence testing was conducted independently by both GIA and the London Assay Office of Goldsmith's Hall. One test of each sample was made (the 18k sample was not available for Assay Office testing). Several, but not all, of the results lie within the gray bar that marks the 6-ppt (±3ppt) range allowed by U.S. plumb law.

2. Measurement of chemical reactivity by the touchstone test can be reasonably accurate if the operator is sufficiently skilled and free of bias. Plating can be detected by a skilled and observant operator, and the test is useful on jewelry of most shapes and finishes, as well as on stone-set pieces.

3. Instruments that use the principle of capacitive energy decay give results accurate to 2k in the

range below 18k and above 8k. This method can be used on pieces of many shapes and sizes, and on stone-set pieces, but not on some chains, prong settings, and other small, highly curved items. Plating may not be detected.

4. X-ray fluorescence testing can be accurate to within 15 ppt of gold content if the test piece is flat and homogeneous, and the instrument is calibrated to an alloy of similar composition.

None of the test methods examined here will solve the underkarating problem. In fact, none gave reliable readings that fell completely within the ±3-ppt plumb range allowed by U.S. law. However, some of these methods may be of limited use in the retail setting to identify larger discrepancies in gold content.

Most of the errors found in this study were in the form of erroneously low values. Although these would not result in underkarating if they were used by manufacturers and sellers to create and mark their jewelry, buyers might be mistakenly led to believe an item

had been underkarated. Moreover, some values were high, which could lead to unintentional underkarating. Regardless, it is risky to rely on a testing method that produces large errors in any direction.

A great deal more research is needed, both on the evaluation of sophisticated instrumentation that may be able to make the close determinations required by plumb laws, and on the development of methods that are more useful for the retail jeweler. An important limitation of this study is that it does not address actual jewelry in all of its shapes, finishes, and alloy combinations. In addition, no plated metals were tested. Note, however, that a rhodium flash on white gold would not be expected to substantially affect the accuracy of any of these methods, with the possible exception of X-ray fluorescence.

Underkarating is a problem that has existed throughout the history of "precious" metals. It will continue to be a problem until and unless an inexpensive, accurate, reliable, and easily operable testing method is developed.

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DIAMOND SOURCES AND PRODUCTION: PAST, PRESENT, AND FUTURE

By Alfred A. Levinson, John J. Gurney, and Melissa B. Kirkley

Africa was the major source of diamonds for most of the 20th century, but Australia and Sakha (of the Russian Federation) now produce about half of the world's supply. Also, most of the production today comes from primary sources (kimberlites and lamproite), whereas secondary (alluvial) sources dominated as recently as the early 1970s. Although the annual production of rough more than doubled in the 1980s, the production of rough yielding good-quality polished gems has not increased appreciably. The economic potential of a kimberlite or lamproite occurrence depends on the tonnage and grade of the ore, as well as on the quality of the diamonds it contains. The authors predict that the early 21st century will see the Russian Federation as an even more important source of diamonds and Canada as a major producer.

As it has over the last 100 years, the demand for fine-quality diamonds will inevitably increase in the long term. Today, as markets in Europe, the United States, and Japan mature, the industry can look toward the prospect of new markets in emerging nations in Eastern Europe and Asia (Rothschild, 1992). Yet the remaining life expectancy of a number of important primary producers is thought to be less than 25 years (e.g., Mir in Sakha/Yakutia, of the Russian Federation; Koffiefontein and the three mines still operating in Kimberley, South Africa; the Mwadui mine in Tanzania), and the significant secondary alluvial deposits on shore in South Africa and Namibia approach depletion. Thus, to ensure an adequate supply of fine-quality diamonds from the mine to the marketplace (figure 1), it is necessary to locate new diamond deposits as older ones become exhausted.

This article addresses future diamond sources by first reviewing past and present localities, and examining production figures and trends. Next, we summarize the geologic constraints on the occurrence of diamonds and the various economic factors that must be considered in determining whether a newly discovered pipe could become a viable mine. On the basis of these critical factors, we predict what the major sources of diamonds are likely to be well into the next century, including the Russian Federation, Canada, and possibly even Antarctica.

DIAMOND PRODUCTION: PAST AND PRESENT

A review of historic diamond sources shows that whereas there were only two significant localities before the first South African discoveries in 1867, about 20 additional producing countries have been identified since then (table 1). The impact on world production of these additional sources is phenomenal: from only about 300,000 ct in 1870 to 3,000,000 ct in 1920, to 42,000,000 ct in 1970, and over 100,000,000 ct in 1990 (figure 2). If the impact of unreported, illicit mining is fac-

Figure 1. Although production of rough diamonds is at its highest level ever, the deposits at many major localities will be depleted within the next few decades. In addition, good-quality gems represent a very small portion of the diamonds mined at most of the new localities. Thus, there is a continuing need to identify and evaluate potential deposits to maintain the production of fine "colorless" and colored diamonds such as those shown here. Photo courtesy of Christie's New York; © Tino Hammid.

tored in, figures since 1940 could actually be as much as 20% higher for some countries in Africa and South America (G. T. Austin, pers. comm., 1992).* Johnson et al. (1989) estimate that the production of diamonds in the year 2000 will be about 113,000,000 ct.

Of particular interest for the purposes of this article is the fact that as recently as 1960 more than 80%

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*For more on illicit diamond mining, see Green (1981), Greenhalgh (1985), Miller (1987), and Johnson et al. (1989). In the cases of China and Russia (now the Russian Federation), precise production data have not been released because diamonds are considered strategic commodities (Miller, 1987), so the U.S. Bureau of Mines figures for these countries are only estimates. It is also recognized that other tabulations may vary, sometimes considerably, from those in table 1.

of diamonds by weight were from secondary alluvial deposits; by 1990, only about 25% were secondary. This is another trend that is expected to continue with improvements in the technology used to identify and mine new primary deposits.

Total Diamond Production (Antiquity–1990). By combining all the production of all the diamond-producing countries listed in table 1, we estimated that the total production of diamonds, both gem and industrial, from antiquity through 1990 is 2,213,875,000 ct (table 2), which is conservatively rounded up (in recognition of the unreported illicit production) to 2,250,000,000 ct. This is the equivalent of 450 metric tons (mt; 1 mt = 1.1 U.S. ton).

TABLE 1. Estimated world rough diamond production in carats, by country, for the first year in each decade, 1870–1990[a], plus other historical data (year diamonds discovered, year significant production began, production from secondary deposits).

Country (older names in parentheses)	Year diamonds discovered[b]	Year significant production began[c]	% of total production from secondary deposits[d]	1870	1880	1890	1900	1910	1920	1930	1940
INDIA	Antiquity	Antiquity	100	2,000	nr	nr	nr	147	nr	nr	nr
BRAZIL	1725	1730	100	200,000	nr	nr	nr	nr	nr	115,000	325,000
SOUTH AFRICA	1867	1870	10–20	102,500	3,140,000	2,504,726	2,113,000	4,807,056	2,533,896	3,163,590	543,474
NAMIBIA (German Southwest Africa)	1908	1909	100					891,307	295,831	415,047	30,017
GUYANA (British Guiana)	1890	1921	100					3,808	39,362	110,042	26,764
ZAIRE (Belgian Congo)	1907	1917	90						315,000	2,519,300	9,603,000
ANGOLA	1912	1921	100							329,823	784,270
GHANA (Gold Coast)	1919	1925	100							861,119	825,000
TANZANIA (Tanganyika)	1910	1945	0							13,107	6,222
CENTRAL AFRICAN REPUBLIC (French Equatorial Africa)	1914	1947	100								16,000
GUINEA (French West Africa)	1932	1950	100								75,000
SIERRA LEONE	1930	1935	100								750,000
VENEZUELA	1901	1955	100								14,525
IVORY COAST	1929	1960	100								
LIBERIA	1930	1958	100								
BOTSWANA	1966	1970	0								
LESOTHO	1958	—	0								
RUSSIA (USSR)	1829	1960	0								
INDONESIA (Borneo)	Antiquity	—	100								
AUSTRALIA[e]	1851	1981	5								
CHINA[f]	1955	?	?								
SWAZILAND	1973	—	0								
OTHERS										3,000	17,225
YEAR'S TOTAL				304,500	3,140,000	2,504,726	2,113,000	5,702,318	3,184,089	7,530,028	13,016,497

[a] Data for 1870–1900: Bauer (1904, pp. 179, 204), Lenzen (1970, pp. 122, 159). Data for 1910: U.S. Geological Survey (1911) for India, South Africa, and Guyana; Lenzen (1970, p. 160) for Namibia. Data for 1920: Roush (1922). Data for 1930–1990: U.S. Bureau of Mines (1930–1991). Yearly production figures are constantly being revised as new data are received, so the final revised yearly production figures may be many years in coming. The following years (in parentheses) are the publication years in U.S. Bureau of Mines (1930–1991) in which the final revised publication figures presented in this table may be found: 1930 (1935); 1940 (1944); 1950 (1953); 1960 (1961); 1970 (1972); 1980 (1984); and 1990 (1991). These are official figures only, and in most cases do not include illicit production, which has historically been a problem in Zaire and Angola (as well as elsewhere in Africa and in South America). Note that most of the reported production for Liberia consists of illicit diamonds smuggled from other parts of West Africa. In this table, "nr" indicates production not reported in the above references.

[b] "Year diamonds discovered" sources: Bauer (1904) for India, Brazil, South Africa, Guyana, Russia, Indonesia, and Australia; Lenzen (1970) for Namibia; Webster

(1983) for Ghana, Tanzania, Sierra Leone, Lesotho, and China; Maillard (1980) for Zaire, Angola, Central African Republic, and Guinea; Wilson (1982) for Venezuela, Liberia, Ivory Coast, Botswana, and Swaziland. Other dates reported: Keller and Guo-dong (1986, p. 16) and Miller (1987, p. 74) both report "the late 1940s" for China; Webster (1983) for Guyana 1887, Zaire 1910, Guinea 1933, and Botswana 1955; Wilson (1982) for Angola 1916, Guinea 1936, and Botswana 1967; Miller (1987) for Angola 1917; Strnad (1991) for Russia 1735 and a reference dating back to 1375.

[c] "Year significant production began" refers to the first year in which 100,000 ct were mined, except for Brazil which produced 20,000 ct in 1730—a significant figure for that time. A dash indicates that 100,000 ct were never produced in any one year. Sources: Bauer (1904) for India, Brazil, and South Africa; Lenzen (1970) for Namibia; Lee (1981) for Guyana; Roush (1922) for Zaire; Imperial Mineral Resources Bureau (1924) for Angola; Kesse (1985) for Ghana; U.S. Bureau of Mines (1930–1991) for all other countries.

[d] "% of total production from secondary deposits" is approximate in the case of:

About 22% of this *total* was produced in the five-year period 1986–1990, largely as a result of the Argyle mine in Australia, which by the end of 1990 was responsible for about 8% of all diamonds ever produced and one-third of those mined for that year. The present annual production from the Argyle mine is essentially identical to the total world production from India and Brazil from antiquity to 1869, that is, about 35,000,000 ct.

In fact, about 94% of the world's total production of natural diamonds in 1990 originated from only

five countries (in decreasing order): Australia, Zaire, Botswana, Russia, and South Africa.

Notwithstanding the number of carats produced, when the *value* of the rough is considered, the sequence changes significantly ("World diamond mining," 1991). In decreasing order, the ranking of the same five countries for 1990 based on estimated (U.S.) dollar value is: Russia ($1.6 billion), Botswana ($1.4 billion), South Africa ($550–$650 million), Australia ($320 million), and Zaire ($225 million). The value of the 1990 production from Namibia and Angola,

1950	1960	1970	1980	1990	Country
nr	nr	20,000	14,000	15,000	INDIA
200,000	350,000	300,000	667,000	1,500,000	BRAZIL
1,747,868	3,146,000	8,112,000	8,520,000	8,708,000	SOUTH AFRICA
488,422	935,000	1,865,000	1,560,000	761,000	NAMIBIA
37,462	101,000	61,000	10,000	8,000	GUYANA
10,147,471	13,453,000	14,087,000	10,235,000	19,427,000	ZAIRE
538,867	1,058,000	2,396,000	1,480,000	1,300,000	ANGOLA
950,000	3,273,000	2,550,000	1,258,000	637,000	GHANA
164,996	537,000	708,000	274,000	85,000	TANZANIA
111,407	80,000	482,000	342,000	381,000	CENTRAL AFRICAN REPUBLIC
126,346	1,117,000	74,000	38,000	135,000	GUINEA
655,474	1,962,000	1,955,000	592,000	78,000	SIERRA LEONE
60,389	71,000	509,000	721,000	333,000	VENEZUELA
	200,000	213,000	nr	12,000	IVORY COAST
	977,000	812,000	298,000	100,000	LIBERIA
		464,000	5,101,000	17,352,000	BOTSWANA
		17,000	54,000	nr	LESOTHO
		7,850,000	10,850,000	15,000,000	RUSSIA
		20,000	15,000	30,000	INDONESIA
			48,000	34,662,000	AUSTRALIA
			900,000	1,000,000	CHINA
				42,000	SWAZILAND
3,000	420,000[g]	nr	nr	nr	OTHERS
15,231,702	27,680,000	42,495,000	42,977,000	101,566,000	YEAR'S TOTAL

India (some production, e.g., about 15,000–18,000 ct per year since the 1970s, has come from pipes—Maillard, 1980; Bliss, 1992); South Africa (where during certain unusual periods, e.g., 1933 and 1941–1942, most or all production was from alluvials); Zaire (where alluvials or eluvials are close to, and overlie, kimberlite sources, and perhaps 10% of current production is from kimberlites); Angola (where minor production in the past was from kimberlites); and Russia (where significant alluvial mining has been noted, particularly from the Vilyui River, but no figures are given—see Miller, 1987; Johnson et al., 1989; Meyer, 1990; "World diamond mining," 1991).

[e] Australia had a recorded production of about 202,000 ct between 1852 and 1922 from several alluvial deposits in New South Wales, but in no one year did production exceed 100,000 ct (MacNevin, 1977); this production is not shown in this table.

[f] Miller (1987) and Johnson et al. (1989) estimated the annual production for the late 1980s at 200,000–250,000 ct and 200,000–300,000 ct, respectively.

[g] Most of this production is probably from Russia and predates reporting of official figures.
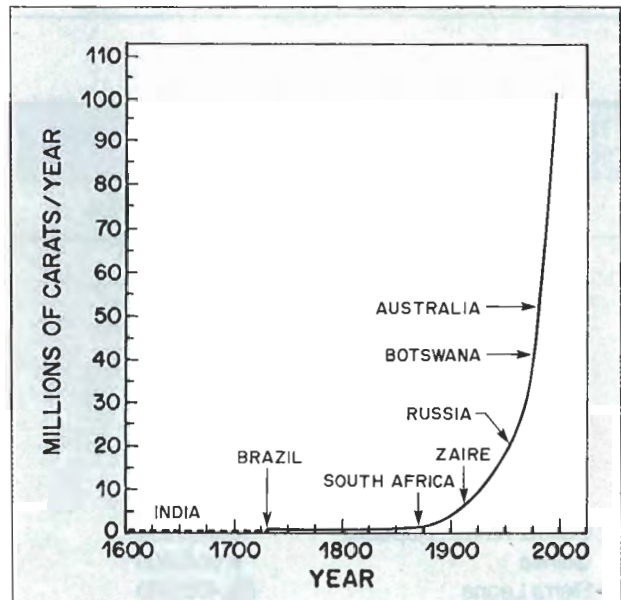

Figure 2. Using the data provided in table 1, this generalized graph shows the increase in total annual world production of rough diamonds (gem and industrial) from 1600 through 1990. The arrows mark the approximate years when each of the major sources noted began significant production.

Whereas historically the percentage of diamonds that are gem quality has been estimated at 20%–30% (e.g., Maillard, 1980; Atkinson, 1989), during 1985–1990 the percentage of diamonds classified by the U.S. Bureau of Mines as gem quality rose to an average of 46%. This is because, starting in 1983, the figures for "gem" included qualities of lower color, clarity, and shape that are commonly referred to as "near gem." Johnson et al. (1989) estimated that, on a worldwide basis, gem diamonds have a per-carat value that is roughly 10 times near gems, and near gems have a per-carat value roughly 10 times that of industrial diamonds. One source classified mine output for 1990 as 15% gem, 39% near gem, and 46% industrial ("World market trends," 1991).

Several factors are responsible for this change in the traditional classification of diamonds over the last decade, including: (1) the growth of the manufacturing industry in India, and its ability to fashion small diamonds economically from rough previously classified as industrial; (2) competition from synthetic diamonds that has kept prices for natural industrial diamonds low, enhancing the value of those industrial diamonds that could be reclassified as near gem; and (3) increased consumer demand for more affordable jewelry.

Today, it is no longer appropriate to consider diamonds in terms of "gem" and "industrial," but rather

both about $250 million, exceeded that of Zaire, yet each produced less than one-tenth as many carats of diamonds as did Zaire (see table 1).

The Changing Concept of Diamond Value. The lower value of the Australian and Zairean production results from their high proportion (>90%) of industrial or near-gem material. In recent years, industrial diamonds have represented only about 10%–15% of the total value of all the diamonds mined annually (Johnson et al., 1989).

TABLE 2. Estimated total production of rough diamonds from antiquity through 1990, by country.[a]

Country	Total production (ct)
India[b]	21,000,000
Brazil[c]	47,101,000
South Africa[d]	446,856,000
Namibia[e]	63,288,000
Guyana[f]	4,131,000
Zaire[g]	718,117,000
Angola[h]	59,800,000
Ghana[i]	100,785,000
Tanzania	18,590,000
Central African Republic	13,829,000
Guinea	8,865,000
Sierra Leone	52,405,000
Venezuela[j]	13,834,000
Ivory Coast[k]	5,743,000
Liberia	18,117,000
Botswana	151,747,000
Lesotho	412,000
Russia	271,850,000
Indonesia[l]	1,000,000
Australia[m]	184,061,000
China	10,850,000
Swaziland	327,000
Others	1,167,000
WORLD TOTAL	2,213,875,000

[a] All production figures are based on data in U.S. Bureau of Mines (1930–1991) for both gem and industrial diamonds for the years 1930–1990, except as noted below. Where data for isolated years are missing, production has been estimated based on reported production for the preceding and following years.

[b] India: The figure of 21,000,000 ct is an average of the estimates of 12,000,000 ct and 30,000,000 ct, given by Blakey (1977, p. 72) and Maillard (1980, p. 26), respectively.

[c] Brazil: For 1725–1850, Bauer (1904, p. 179); for 1851–1869, Lenzen (1970, p. 122); for 1870–1929, an average annual production of 200,000 ct was assumed based on estimates of Lenzen (1970, p. 122) and Rich (1990, p. 34).

[d] South Africa: For 1867–1912, Wagner (1914, pp. 338–339); for 1913–1921, Roush (1922, p. 587); for 1922–1923, estimated at 2,000,000 ct per year based on average production of previous and following years; for 1924–1929, Lenzen (1970, p. 177).

[e] Namibia: For 1909–1929, Williams (1932, Vol. 2, p. 562).

[f] Guyana: For 1902–1929, Lee (1981).

[g] Zaire: For 1913–1929, U.S. Bureau of Mines (1955, p. 489).

[h] Angola: For 1919–1921, Imperial Mineral Resources Bureau (1924); for 1922–1929, estimated at 200,000 ct per year based on production before and after this period.

[i] Ghana: For 1920–1946, Kesse (1985, Appendix 3A).

[j] Venezuela: For 1913–1939, Themelis (1987).

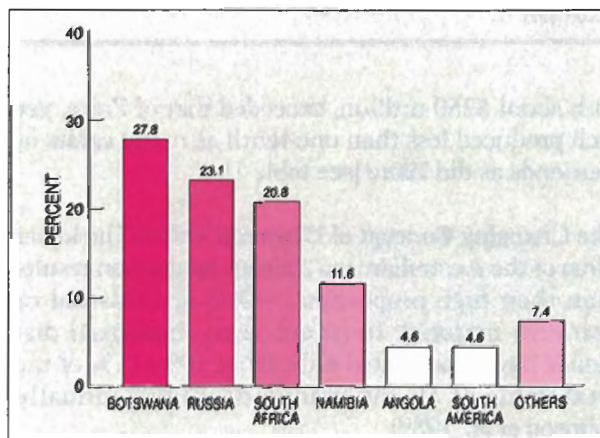[k] Ivory Coast: For 1945–1959, Greenhalgh (1985, p. 4).

[l] Indonesia: In the period 1966–1990, 489,000 ct were produced. Earlier production figures are intermittent and unreliable (Spencer et al., 1988). The figure of 1,000,000 ct given in this table as the total production since antiquity is an estimate, and it is in relative proportion to the significant historical production from India.

[m] Australia: For 1852–1922, 202,000 ct of alluvial production reported by MacNevin (1977) is included.

in terms of "cuttable" and "industrial." *Cuttable* describes any natural diamond, regardless of quality, where all or part of the rough is suitable for manufacturing into jewelry. According to the Central Selling Organisation in London, about 50% of the world's diamond production today is considered cuttable, but only about 12% (by weight) of the diamonds mined in 1990 will eventually be set into jewelry as faceted stones. This is because near-gem material has a yield of only about 15%–25%, compared to about 45% for material traditionally classified as gems (Johnson et al., 1989).

Gemological Rarity. Even though 50% of the world's rough diamonds are now classified as cuttable, and the annual supply of rough more than doubled in the period 1980–1990, the total amount of available rough yielding good-quality polished stones (D–H color and Fl–SI$_2$ clarity) of 0.5 ct or larger has not changed appreciably in the last decade and, in fact, may have decreased (Moyersoen, 1989). The Argyle mine, which is responsible for much of the recent increase in world diamond production, for the most part produces small stones, of which only about 5% are gem quality (Boyajian, 1988); many of these are browns and most are difficult to cut. Near gems account for 40%–45% of the production. The estimated current annual supply of rough diamonds worldwide that yield polished

Figure 3. Although the current annual production of rough diamonds exceeds 100,000,000 ct, only about 2,000,000–2,500,000 ct yield good-quality (D–H color, Fl–SI$_2$ clarity) stones 1 ct or larger. Five countries, as noted here, are responsible for almost 90% of this production. Based on data in Moyersoen (1989).
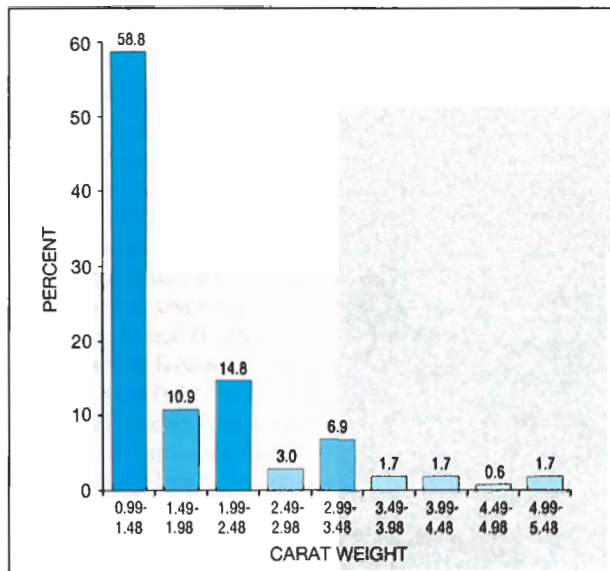
Figure 4. The relatively small proportion of cut stones 1.49 ct and above in the total population of gem diamonds is evident in this chart of the distribution, by carat weight, of a random sample of 9,000 good-quality (D–M color; Fl–SI₂ clarity) polished diamonds submitted to the GIA Gem Trade Laboratory, Inc., for grade analysis (1,000 each from the years 1982–1990). Data provided by D. V. Manson; courtesy of the GIA Gem Trade Laboratory, Inc.
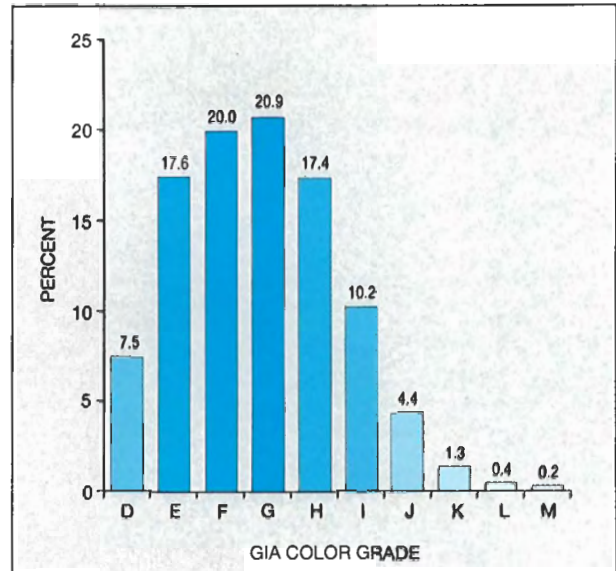

Figure 5. Of the random sample of 9,000 cut diamonds (D–M color, Fl–SI₂ clarity) described in figure 4, only 7.5% in the size range 0.99–1.98 ct were graded D-color. The decreasing proportion of stones graded H–M reflects the fact that stones of lower quality are less likely to be submitted for grade analysis. Data provided by D. V. Manson; courtesy of the GIA Gem Trade Laboratory, Inc.

gems of 1 ct or more amounts to about 2.0–2.5 million carats (Moyersoen, 1989). Assuming an average 55% weight loss during cutting for good-quality stones, the annual supply of polished gems in this category is about 900,000–1,100,000 ct.

The main countries that produce rough good-quality stones of 1 ct or larger are shown in figure 3. Both Australia and Zaire have had only a minor effect on the availability of such stones. Both countries are included in "Others" in figure 3.

The current annual production of polished stones 0.5 ct or larger with D–H color and Fl–VS₂ (not to be confused with the broader, to SI₂, range given above) clarity is only about 300,000 (± 50,000 ct). No more than three 1 to 2 ct polished D-flawless stones are produced each day. Further, fewer than 5,000 cut stones of D-color, 0.5 ct or larger, in all clarity grades are produced annually (Moyersoen, 1989).

Similar conclusions can be drawn for diamonds examined at the Gemological Institute of America. Figure 4 presents the size distribution, by carat weight, of a random sample of 9,000 diamonds (1,000 from each year, 1982–1990) from all diamonds submitted to the GIA Gem Trade Laboratory, Inc., during that period. Represented are stones ranging from D to M in col-

or (which differs from the D–H color range given above) and Fl–SI₂ clarity. This figure clearly shows the significantly lower proportion of stones 1.49 ct and above. The desirability of certain weights (i.e., 2.0 and 3.0 ct), and cutting to those weights, is apparent in the fact that there are larger proportions of stones in the 1.99–2.48 ct and 2.99–3.48 ct categories than in the categories that immediately precede them.

Figure 5 shows the distribution of D–M color stones in the 0.99–1.98 ct range within these same 9,000 diamonds, which confirms the rarity of D-color stones. The decreasing proportion of stones graded H–M is a reflection of the fact that stones of lower quality are less likely to be sent for grade analysis.

From the above discussion, it can be seen that rough diamonds that yield good-quality polished gems, especially 0.5 ct or larger, are not common, and that stones over 1.48 ct are particularly rare. Depending on the characteristics of the mine, on the order of 100,000 tons of kimberlite or secondary material may have to be processed to produce a single piece of rough from which a 1-ct D-flawless diamond can be cut.

GEOLOGIC FACTORS

In the last decade, vast amounts of new information have become available on the origin of diamonds,

Figure 6. Presently, the Finsch mine is the largest producer of diamonds in South Africa, with production in 1990 of 4,177,572 ct (De Beers Consolidated Mines, 1992), although the rough averaged only 0.03 ct per stone. When the pipe was discovered in 1960, an estimated 1400 m of kimberlite had already been eroded away and the outcrop at the surface was 44.2 acres (17.9 ha). This photo, taken in September 1990, reflects the cone shape characteristic of kimberlite pipes and that the mine is pinching out at depth (present depth approximately 600 m). Note that the area shown here is larger than the original pipe because of the requirements of open-pit mining.

such as when they were formed and how and where they reached the earth's surface. General reviews of these topics may be found in Gurney (1989), Atkinson (1989), Kirkley et al. (1991), and Mitchell (1991).

Secondary deposits historically have been the easiest to find because they often cover large areas; for example, the alluvial diamond deposits in Zaire are spread over about 150,000 km^2 (Johnson et al., 1989), although only certain sections are economically viable. By comparison, economic primary deposits (kimberlite or lamproite pipes) are small; they have a median surface (outcrop) area of only about 30 acres (12 hectares [ha]) and only rarely exceed 250 acres (Bliss, 1992). This is one explanation for the fact that alluvial diamonds have been known for at least 2,000 years, but the first primary source was not discovered until approximately 1869, in the Kimberley region of South Africa (Janse, 1984). As mentioned above, after 1960, with the discovery of the major primary deposits in Russia, Botswana, and Australia added to the South African deposits, production from primary deposits grew until it accounted for about 75% of the total world production in 1990.

Primary Deposits. Most diamonds form deep within the earth, usually at depths of 150–200 km, in peri-

dotite or eclogite source rocks. The diamonds are transported to the surface by kimberlite or lamproite. Although as many as 1,000 kimberlites occurrences are known to contain diamonds (Kirkley et al., 1991), as well as seven lamproites, only 50–60 kimberlites and one lamproite (Argyle) worldwide have ever been economic.

An uneroded kimberlite pipe consists of three zones: root, diatreme, and crater. The root zone, at the bottom of the pipe, has a vertical extent of about 0.5 km and is found about 2–3 km below the surface. The diatreme zone usually contains the bulk of the kimberlite ore and, therefore, most of the diamonds. Its vertical extent in a medium to large kimberlite pipe is 1–2 km. The crater zone occupies the upper parts of the pipe and is represented on the surface by an eruptive (volcanic) crater. Kimberlite pipes are rarely found complete; rather, most are partly eroded (figure 6). With increasing depth, the root zones narrow and merge into feeder dikes, usually about 60 cm (2 ft.) wide, which will contain diamonds if the pipe itself does. However, these may not be economic because of the high cost of mining such narrow zones.

Economic kimberlites are concentrated in those portions of cratons that are of Archean age (older than 2,500 My [million years]—for example, Kirkley et al.,

1991; Janse, 1992). Cratons are parts of the earth's crust that have attained stability and have been little deformed for a very long period of time, generally more than 1,500 My.

Janse (1984, 1992) defined the following three major portions of cratons, each representing a different age of formation, to facilitate their comparison and the preliminary evaluation of their economic potential: (1) *archons*—Archean, older than 2,500 My; (2) *protons*—early to middle Proterozoic, 2,500–1,600 My; and (3) *tectons*—late Proterozoic, 1,600–800 My (figure 7).

Although at this time, all economic *kimberlite* pipes (and dikes) worldwide occur on archons, some noneconomic kimberlites (e.g., the State Line Group, Colorado-Wyoming) and lamproites (e.g., the Prairie Creek lamproite pipe, Arkansas), as well as the highly productive Argyle lamproite pipe, occur on protons. Thus, protons may have considerable economic potential for diamonds, particularly in lamproites. No economic primary diamond deposit has yet been found on a tecton (or in any younger primary environment).
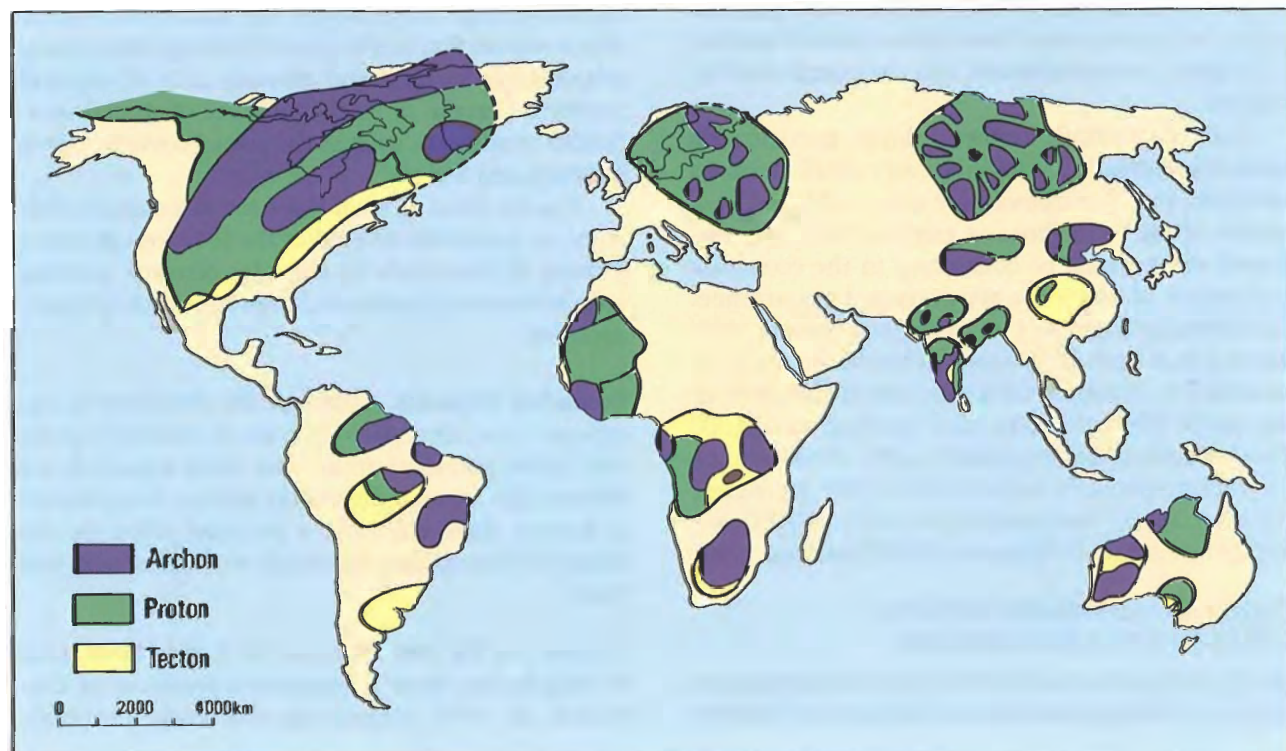
Numerous other geologic and geophysical factors (e.g., geothermal gradient, thickness of the craton) are also taken into account during modern exploration programs for primary diamond deposits. The reader is referred to Atkinson (1989) and Helmstaedt and Gurney (1992) for further information on these subjects, which are beyond the scope of this article.

Some cratons have been actively explored for over 100 years with ever-increasing sophistication, but with an ever-decreasing success rate; the Kaapvaal craton in South Africa is a case in point. In the 90 years since the Premier deposit was discovered in 1903, the only large and significant finds in South Africa have been those now worked as the Finsch and Venetia mines. Although the latter is scheduled for full production in 1993, with a projected annual output of 5,900,000 ct (Anglo American Corp., 1992), this craton is now considered at the mature stage (i.e., approaching its ultimate potential), from the point of view of diamond exploration.

Secondary Deposits. The moment a kimberlite pipe reaches the surface, it is subjected to weathering and erosion. Given a worldwide average erosion rate of 1 m every 30,000 years, a typical kimberlite pipe 2.3 km deep could be completely eroded away (except

Figure 7. This generalized world map shows known cratonic areas. The major portions of each craton (here referred to as archons, protons, and tectons) are indicated. To date, economic diamond-bearing kimberlites have been found only in archons, those portions of a craton that are older that 2,500 My. After Janse (1992).

for the root zone and feeder dikes) in 69 My (Kirkley et al., 1991).

Diamonds can be transported great distances and subsequently concentrated into a variety of secondary deposits amenable to mining. In close proximity to the primary diamondiferous kimberlite or lamproite deposits, diamonds may be found in economic eluvial or colluvial (i.e., those not involving stream transport) concentrations. With increasing distance, and where river transport and mechanical processes of concentration are involved, alluvial placers may form. If the diamond is carried to the marine environment either onshore (i.e., beach, beach terrace, dune) or offshore (i.e., marine shelf, sea-floor), marine processes such as wave action may form economic secondary deposits (Gurney et al., 1991). In general, alluvial deposits have a higher percentage of gem-quality diamonds than do primary deposits. However, there are exceptions, most notably Zaire, where only about 5% of the large alluvial production is fine-quality gems. The presence of alluvial deposits also implies the possible existence of kimberlite or lamproite pipes upstream in the drainage area.

ECONOMIC EVALUATION OF PRIMARY DEPOSITS

The major factors in determining whether a newly discovered kimberlite or lamproite pipe will be economically viable are its tonnage (size) and grade (concentration of diamonds), as well as the value (size and quality) of its diamonds. Other factors include location of the pipe, tax environment, and environmental legislation.

Even in economic kimberlite pipes, gem/cuttable diamonds typically are found in very small amounts and sizes, and in extremely variable qualities. These factors, along with those of gemological rarity discussed above, must be considered in the economic evaluation of any primary diamond occurrence. Consulting geologist A. J. A. Janse (pers. comm., 1992) states that at least 10,000 tons of kimberlite must be processed to obtain a valid estimate of the grade of any single kimberlite pipe, and as much as 100,000 tons for a complete feasibility study. To determine the average per-carat value of the stones recovered, at least 5,000 ct—and possibly as many as 10,000 ct— should be evaluated (Atkinson, 1989; Jennings, 1990).

MAJOR DIAMOND-PRODUCING AREAS IN THE 21ST CENTURY

The information presented in the preceding pages can help in predicting what diamond deposits are likely to be important in the future, as well as where new ones are likely to be discovered, what types they will be, and what factors should be considered in evaluating their economic potential.

Although many secondary deposits continue to be important and cannot be ignored, their overall role in diamond production is declining. Marine deposits would seem to have great potential, but first the technological difficulties of exploration and mining offshore must be overcome.

We predict that in the next century, most new major diamond deposits will be of the primary type, which are particularly attractive exploration targets. Such deposits, when economic, are likely to be long lived and amenable to large-scale mining, as well as to deterring illicit mining. For example, two-thirds (about 66,000,000 ct) of the total world production of diamonds in 1990 came from just eight primary mines (Argyle in Australia; Orapa, Letlhakane, and Jwaneng in Botswana; Mir and Udachnaya in Russia; and Finsch and Premier in South Africa [figure 8]). Most of these will have had a mine life of at least 30 years (some, like the Premier, possibly over 100 years) before they are exhausted of diamonds.

Given the current and projected decline in the discovery of new deposits on some cratons now commercially exploited for diamonds, the greatest potential for new, large, and economically important primary diamond deposits will be in those cratonic areas with large archons (and, less favorably, protons) where exploration to this point has been hampered by inhospitable location and climate, as in Siberia and northern Canada, or by the presence of special overburden conditions, such as the glacial cover in North America and Siberia.

On the basis of what has been discussed to this point, it is possible to predict the locations of major sources of diamonds for the 21st century, starting with secondary deposits and then turning to primary deposits.

Secondary Deposits. Although the discovery of significant new secondary deposits is unlikely, given that most potential areas have been explored, we believe that increased production from two presently known areas will have a profound effect on the supply of fine-quality diamonds within the next few years.

Angola. For the past 70 years, the Lunda Norte area of Angola has been a consistent producer of diamonds. In 1990, Angola was the world's seventh

largest producer by weight, with most coming from the Cuango River Valley (figures 8 and 9). In marked contrast to the predominantly industrial production in nearby Zaire (East Kasai province), that in Angola is reportedly 70% gem quality, with an average value of about $185 per carat; 15% of these are stones of 2 ct or more ("World diamond mining," 1991; "World market trends," 1991). Illicit trade traditionally has been a major problem (e.g., Miller, 1987; Johnson et al., 1989), and it is widely believed that in 1992 the value of smuggled stones will have well surpassed Angola's official diamond exports of about $200,000,000 (Contreras, 1992).

Angola has significant reserves of both alluvial diamonds and, it appears, primary deposits. Alluvial production at Lucapa is estimated at 400,000 ct annually, with additional operations further northeast, in the Andrada region ("World diamond mining," 1991). In addition geologists have identified more than 300 kimberlite pipes. However, present political instability in this region makes it difficult to assess the long-term impact of these reserves.

Marine Deposits. Meyer (1991) and Gurney et al. (1991) reported on the vast resource of diamonds (estimated to be at least 1.5 billion ct) that may exist off the west coasts of South Africa and Namibia (again, see figure 8). It is estimated that 90%–95% of these are gem quality. These diamonds were released from weathered diamond-bearing kimberlites in the ancient and present Orange River (and probably other) drainage basins, and were then transported to the west coast where they were deposited in the marine environment. Raised marine deposits now on land have yielded almost 100,000,000 ct, but similar deposits still in the marine environment have yet to be fully prospected.

In 1990, about 75,000 ct of diamonds were recovered from the offshore Namibian waters, with another 128,000 ct offshore of South Africa (Gurney et al., 1991). Offshore Namibian production almost tripled in 1991, to about 212,000 ct, with 170,744 ct produced by De Beers Marine alone (De Beers Centenary AG, 1992; Namibia, 1992). Although production is difficult and expensive at present, the west coast off southern Africa should be an even more important source of fine-quality diamonds by the early 21st century. Possible future opportunities also include marine diamonds associated with the Argyle field (i.e., off the northwest coast of Australia), the Russian Federation deposits (in the Arctic Ocean, near the mouths of

Figure 8. For most of this century, Africa has supplied the vast majority of diamonds to the world market. The three Botswana mines and South Africa's Finsch and Premier mines are still among the most productive. However, all of the primary South African operations shown here—with the exception of the newly opened Venetia mine—are mature operations that will probably be depleted in the early 21st century. Although the proportion of diamonds produced from secondary deposits worldwide has decreased greatly over the last three decades, the secondary occurrences noted here—alluvial deposits in Angola and marine deposits offshore Namibia and South Africa— are likely to be of increasing importance in the future.

north-flowing rivers like the Lena), and even off the north coast of Canada (in Coronation Gulf).

Primary Deposits. We believe that the cratons of the Russian Federation and North America have

Figure 9. Extensive alluvial deposits are being worked in Angola, with a significant production (1,300,000 ct reported in 1990) of rough that is reportedly 70% gem quality. Angola appears to have major reserves that could last well into the future once the problems of political instability and irregular production are resolved. Here, illegal miners work one of the many active areas in the country. Photo © Paul Lowe–Network/Matrix.

the greatest potential for producing major amounts of diamonds in the near and intermediate (i.e., 10–25 years) future. In the very distant future, perhaps in 100 years, Antarctica could be a major producer.

The Russian Federation. The eastern Siberian republic of Sakha (formerly known as Yakutia), in the Russian Federation, C.I.S., already is a major diamond-producing region. Mining activity has progressed rapidly since the discovery in 1953 of the first diamond in the Malaya Botuobiya River, a tributary to the Vilyui River, and the discovery of the first kimberlite (Zarnitsa) in 1954 (figure 10). The desirability of prospecting for diamonds in these Archean areas was first noted by Russian academician Vladimir S. Sobolev. In the late 1930s, he realized that similarities between the geologic structure of the central Siberian shield and the interior plateau area of southern Africa suggested the possibility of great diamond riches in Siberia.

Prospecting on the basis of this relationship started in 1947.

In 1955, the richly diamondiferous Mir pipe (17 acres [6.9 ha]) was located; only 10 days later, the Udachnaya pipe, 400 km to the north and about 20 km south of the Arctic Circle, was found (again, see figure 10). By 1956, the number of known pipes had risen to 40. To date, the Amakhinsky Exploration Team has found more than 500 kimberlite occurrences. These kimberlites lie in clusters that straddle the Arctic Circle to 400 km north. The diamond contents of the kimberlites range from zero to highly economic (e.g., Meyer, 1990). The first mining started, at Mir, in 1957. Augmented by the mining of alluvial deposits in the nearby Vilyui River, total annual production had risen to an estimated 5,200,000 ct by 1965. The smaller Internationalaya pipe was opened next, followed by Aikhal to the north, the larger Udachnaya pipe 60 km away (about 49 acres [20 ha]), and Sytykanskaya halfway between. (For more on diamond mining in this region, see Meyer, 1990.)
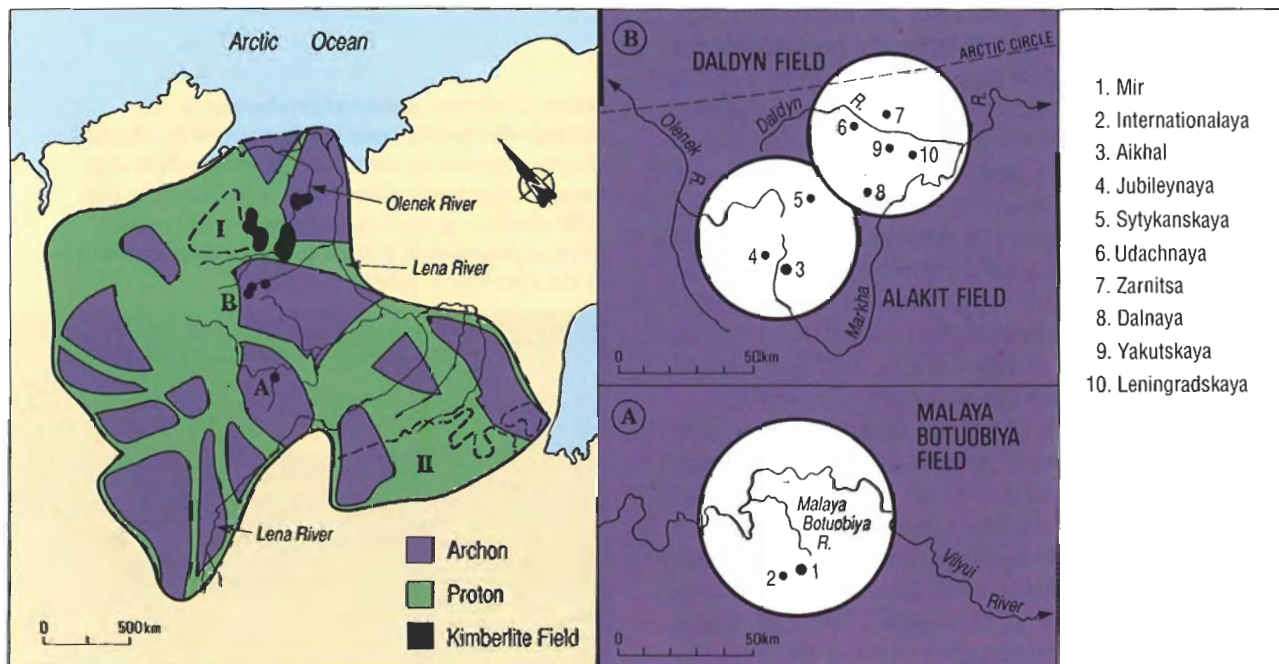
Internationalaya has now reached the end of its working life as an open-pit operation. Underground mining of the root zones of the pipe is hampered by the presence of saline water containing hydrogen sulfide and sometimes by the acid conditions in the Devonian sediments above the archon in which the pipe is emplaced. Currently, there is no active mining of kimberlite at Mir, though production from stockpiled ore continues. The main current mining activity is at the Udachnaya open pit. However, it is now a mature mine (figure 11). Production in this area is augmented by that from Aikhal and Sytykanskaya. A new major deposit, the Jubileynaya, is scheduled for full production in 1994/95. This very large pipe, nearly the size of Orapa (262 acres [106 ha]), was concealed by an overlying diabase sill that has been stripped away to allow open-pit mining (Meyer, 1990).

The five older kimberlite mines (Mir, Internationalaya, Aikhal, Udachnaya, and Sytykanskaya) and their associated alluvials have provided the more than 270,000,000 ct of diamonds estimated to have been produced from the Yakutia region since 1960.

Figure 11. The Udachnaya kimberlite is currently the most important diamond-mining operation in Sakha. It is about 49 acres (20 ha; Johnson et al., 1989) in surface area. Large dump trucks remove the kimberlite and waste rock at a rate of about 1,000 metric tons per hour. The mine operates 24 hours a day and throughout most of the year.

Figure 10. The Yakutian craton of eastern Siberia (again, see figure 7) is presently one of the most productive diamond-bearing cratons in the world. The mines shown here are located in the republic of Sakha (formerly Yakutia) in the Russian Federation (C.I.S.). The craton, on the left, has two exposed portions: the Anabar Shield in the north (I), and the Aldan Shield in the south (II). Note the elaborate pattern of archons surrounded by protons. The main producing kimberlite areas are shown in black and marked by A and B. The maps on the right show the important diamond-bearing kimberlite pipes in the Malaya Botuobiya field (A) and the Alakit and Daldyn fields (B).
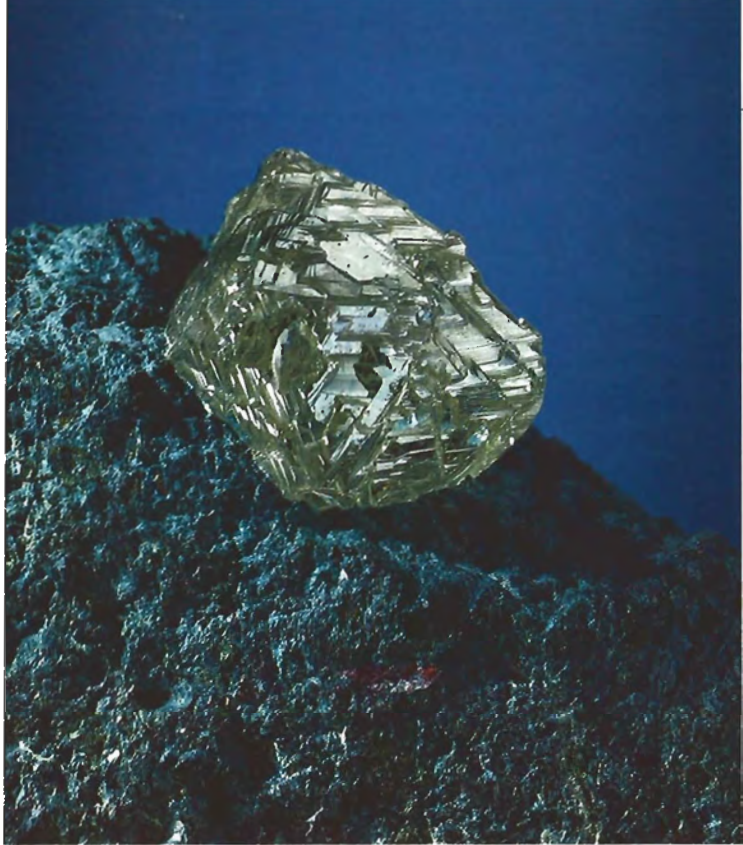
Figure 12. The diamonds of the Sakha region, in eastern Siberia, are noted for their excellent color, clarity, and shape. This 2-cm crystal in kimberlite is from the Mir mine. Courtesy of the Houston Museum of Natural Science; photo © Harold & Erica Van Pelt.

Unfortunately, official data for diamond grades and value, tonnage mined, total production, and future reserves—such as are routinely published by many mining companies—are completely unavailable for this region. At the Mir pipe, grades of up to 4 ct/mt have been reported, along with 2 ct/m^3 in high-grade gravels dredged from the Vilyui River. Aikhal is also extremely high grade, and some of the diamonds out of Udachnaya have been described as being of exceptional clarity and color. In general, diamonds from the two producing regions are noted for their excellent shape for cutting, since a high proportion are extremely regular, sharp-edged, flat-faced octahedra. Exceptionally large stones are rare, but well-formed crystals over 20 ct are not uncommon (figure 12).

Despite the lack of official data, the apparently high grade of kimberlite pipes in this region is important in attempting to assess its impact on the diamond industry into the 21st century. There are many known diamondiferous kimberlites, some of considerable size (e.g., Zarnitsa, at 53 acres [21.5 ha], is larger than the Finsch mine, 44.2 acres [17.9 ha], in South Africa), in Sakha and in other parts of the Russian

Federation that are not currently exploited. In the past, Siberian kimberlites with less than 0.5 ct/mt of diamond were considered barren, and economic grade was greater than 2 ct/mt. Elsewhere in the world, the Argyle lamproite is the only primary deposit that consistently meets this criterion! Therefore, the possibility exists that kimberlites found but not previously worked will prove viable in the future.

The relatively recent discovery and sampling of diamondiferous kimberlites on the Baltic Shield near Arkhangelsk (on the White Sea, in the province of Oblast, near the border with Finland) gives added potential to the future supply of diamonds from the Russian Federation. It has been speculated that mines could be established on at least one kimberlite, the Lomonosovskaya, and perhaps on as many as five kimberlites. Like those in Sakha and other localities, this new kimberlite province lies close to the Arctic Circle.

One concern regarding future production is that the superb quality of many of the diamonds from Sakha is not matched by diamonds from kimberlites elsewhere in the region; in these latter kimberlites, resorbed diamonds and those that are colored, including yellows and browns, are more abundant. This may translate into a lower average value per carat for the diamonds. In addition, the fact that many deposits lie well within the Arctic Circle, some in low-lying, waterlogged ground, and in regions where there is absolutely no infrastructure (figure 13), signifies logistical problems that will take time to overcome.

Figure 13. Future diamond production in the Russian Federation could be hampered by the lack of infrastructure in the remote regions where diamondiferous kimberlites have been found. In this 1990 photo, a special exploration vehicle (with tracked propulsion) is used to ford a river en route to the Zarnitsa kimberlite in Sakha.
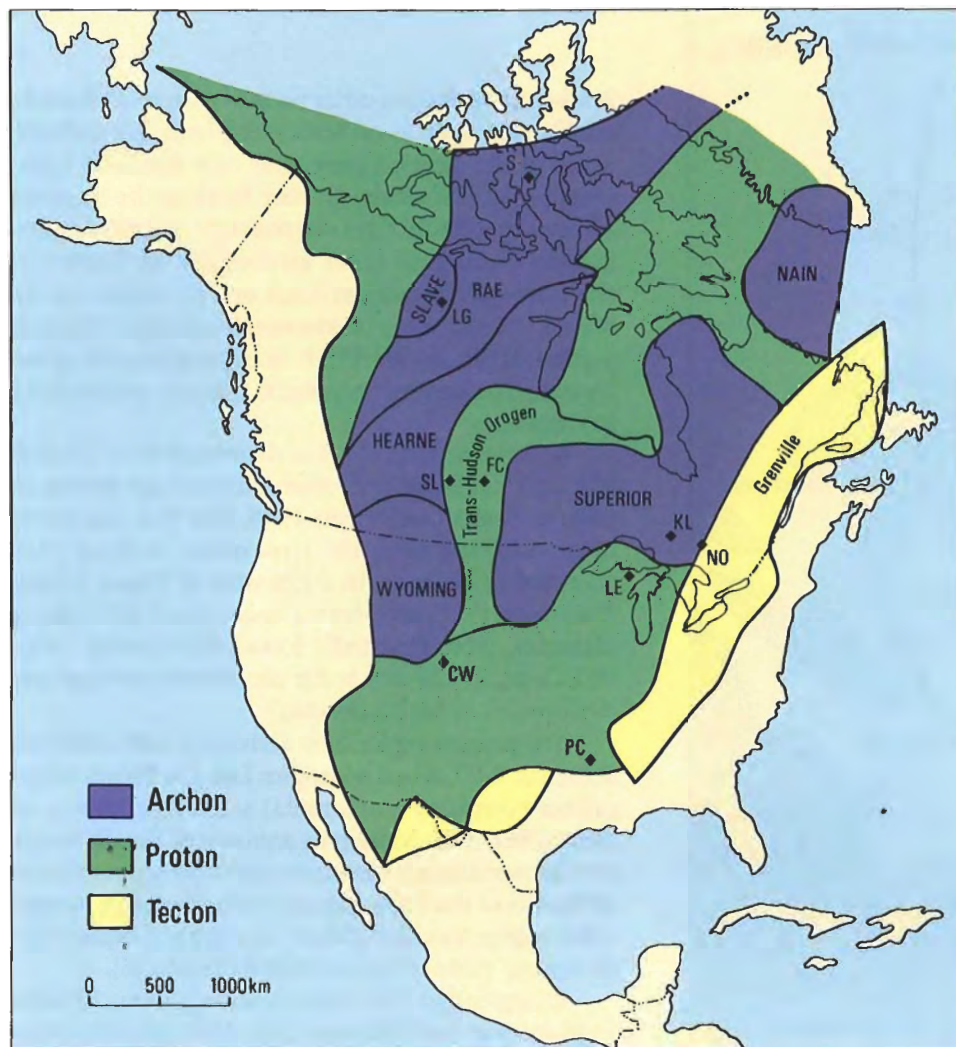
Figure 14. North America contains the largest known craton in the world (again, see figure 7), shown here with the three age-based divisions identified (after Hoffman, 1988; Janse, 1992). Archons (Slave, Rae, Hearne, etc.) are the most favorable areas for economic diamondiferous kimberlite pipes. Although no economic kimberlites have been found thus far on a proton, diamonds have been found in kimberlite pipes in the Trans-Hudson Orogen. Kimberlites have also been found in the Grenville tecton, at least one with traces of diamonds. Specific diamond-bearing occurrences noted are: CW—Colorado-Wyoming; FC—Fort à la Corne; KL—Kirkland Lake; LE—Lake Ellen; LG—Lac de Gras; NO—Noranda; PC–Prairie Creek; SI—Somerset Island; SL—Sturgeon Lake.

Canada. There has never been a profitable diamond mine in North America. Although the occurrence at Prairie Creek (Crater of Diamonds State Park, near Murfreesboro, Arkansas) produced an estimated 100,000+ ct during the period 1907–1933 (Waldman and Meyer, 1992), it was not economic. The diamondiferous kimberlites found subsequently—for example, in clusters in the State Line district of Colorado and Wyoming, in the Lake Ellen group near Crystal Falls, Michigan, and at scattered localities elsewhere in the United States and eastern Canada (Janse, 1992; Waldman and Meyer, 1992)—have also been noneconomic. However, the United States is situated mostly on geologically less favorable protons and tectons (figure 14), whereas Canada has some of the largest areas of the world that are underlain by archons. Recent exploration activity in Canada has revealed the existence of several diamondiferous kimberlites that may prove to

be economic. On the basis of this favorable geology and the intensity of the current exploration, we predict that Canada will be a major producer of diamonds by the second decade of the 21st century.

Isolated discoveries of diamonds were reported in the *United States* as early as the 1840s, in North Carolina, Georgia, and California (e.g., see Kopf et al., 1990). The most significant, from the point of view of exploration, were the diamonds found in glacial drift in Ontario and the Great Lakes states as early as 1863. Almost a century ago, Hobbs (1899) concluded that the diamonds had been transported by glaciers, and that the apex of the fan along which they traveled indicated that the source was located in the James Bay Lowlands (figure 15).

Exploration was particularly intense in this area of *eastern Canada* during the late 1970s and early 1980s, but no kimberlites were reported (Brummer, 1984; Janse et al., 1989; and Reed and Sinclair, 1991).

Figure 15. Early evidence of possible diamond-bearing kimberlites in North America are the diamonds found in glacial deposits in the Great Lakes states. The diamonds are believed to have originated from the James Bay Lowlands of Ontario. This map of the region shows the limits of Pleistocene glaciation and the last glacial advance, the known diamond occurrences in glacial deposits, the total number of diamonds found in each state (e.g., Indiana, 34), and the paths that the diamonds may have taken from their presumed source(s) in the James Bay Lowlands. Note that of the more than 80 diamonds that have been found in glacial deposits thus far, only two were in Canada: the 0.25-ct South Porcupine and the 33-ct Peterborough. After Hobbs (1899) and Brummer (1984).

A few kimberlites in other parts of eastern and northern Canada, such as on Somerset Island (Rae archon), north of the Arctic Circle, and near Kirkland Lake, Ontario, and Noranda, Quebec (both in the Superior archon), reportedly have uneconomic amounts of diamonds. Numerous other kimberlites are known in the Grenville tecton, at least one of which—at Ile Bizard, 15 km west of Montreal—yielded 10 small diamonds (Brummer, 1984). Some exploration activity continues today in eastern Canada, particularly in Ontario.

In *western Canada*, five diamonds were allegedly found in glacial drift near Cumberland House in eastern Saskatchewan in 1948, but this has never been substantiated; the first major staking rush occurred in 1961, about 6 km west of Prince Albert. Two diamonds, each about a quarter inch (0.64 cm) in diameter, were reportedly found. (See Strnad, 1991, and Gent, 1992a and b, for the history of diamond exploration in Saskatchewan.)

The present exploration activity in Saskatchewan started in 1987, when Monopros Ltd. (De Beers's exploration company in Canada) staked property; in November 1988, Monopros announced the discovery of a diamondiferous kimberlite about 30 km northwest of the site of the 1961 staking. Soon thereafter, several other companies filed claims for diamond exploration in various parts of Saskatchewan (figure 16).

In September 1989, joint-venture partners Uranerz Exploration and Mining Ltd. and Cameco Corp. announced the discovery of seven kimberlite pipes in the Fort à la Corne area (figure 17). They subsequently announced the recovery first of microdiamonds (<0.5 mm in diameter) and then of four larger diamonds. Two years later, clusters of kimberlite pipes were discovered under a 100-m-thick glacial overburden; all of the 15 sites (out of 70 potential) that were drilled proved to be diamondiferous. To date, Uranerz and Cameco have reported the recovery of 160 small diamonds, weighing a total of 7 ct; the average stone is 0.04 ct, and the largest is about 0.5 ct. There has been no official report of the quality of these stones. The best preliminary grade reported for any kimberlite tested is low, about 0.1 ct/mt, but the average grades of these pipes are typically much lower (0.01–0.02 ct/mt). However, because of the thick overburden, the large-scale bulk testing that is necessary for meaningful evaluation has not been completed.

In 1992, kimberlite-specific garnets and chrome diopside were identified in glacial-till samples taken in the southwestern part of Saskatchewan close to

Figure 16. Since 1987, more than 50,000,000 acres have been staked or claimed for diamond exploration in western Canada. This map shows the locations staked as of mid-December 1992. Most of the exploration activity is for kimberlites, although that in the vicinity of Dubawnt Lake is for lamproites. The dashed line in southwestern Saskatchewan, in the vicinity of Val Marie–East Poplar, encompasses an area of many small claims.

the Montana border (Swanson and Gent, 1992), but no kimberlite pipes have yet been announced. Geologically, this area is within the favorable Wyoming archon. As of December 7, 1992, approximately 1,794,000 acres (726,000 ha; 2,800 sq. mi.) had been staked in Saskatchewan for diamond exploration (M. R. Gent, pers. comm., 1992).

In British Columbia, Alberta, and the western part of the Northwest Territories, intermittent exploration for diamonds has been in progress for as much as 20 years by major mining companies such as Cominco, BP Minerals, Lac Minerals, De Beers oper-

ating via Diapros and Monopros, Falconbridge Exploration, and Corona (Godwin and Price, 1986; Dummett et al., 1987).

Of particular importance in this exploration has been the identification of certain characteristic heavy minerals, referred to as indicator minerals (specifically, pyrope garnet, ilmenite, chrome diopside, and chromite), that are associated with kimberlites. The dispersion of these minerals into secondary concentrations such as alluvials has been used in diamond exploration since the 1870s in South Africa and elsewhere (Dummett et al., 1987; Atkinson, 1989;

Figure 17. This drilling operation is designed to recover ore from buried kimberlite that has been identified in the Fort à la Corne area of Saskatchewan by geophysical techniques. Note the many meters of drill pipe on the bed of the truck.

Jennings, 1990). Although indicator minerals do not provide conclusive evidence that a kimberlite is diamondiferous, they (rather than diamonds) are typically used to locate kimberlites because they are more abundant than diamonds and more recognizable. Thus, they are more likely to be found in any reasonably sized sample.

In western Canada, various types of glacial deposits, such as eskers (long, narrow, sinuous ridges of material deposited by a stream flowing under a glacier), perform the same function as rivers in dispersing minerals from a kimberlite. Although more difficult to follow and interpret than an alluvial trail, a glacial trail should lead to the primary source of a dispersed mineral (the same concept used by Hobbs in the Great Lakes region; again, see figure 15). Folinsbee (1955) did the first thorough geological study, including the use of heavy minerals, of the Point Lake–Lac de Gras area of the Northwest Territories (again, see figure 16). Years later, such a trail of heavy indicator minerals eventually led one exploration company—Dia Met Minerals Ltd.—back to the Lac de Gras area in search of diamonds (Richards, 1992; Walsh, 1992).

Beginning in 1989, Dia Met Minerals began to acquire ground in the area, eventually staking 1,500,000 acres (606,000 ha). In April 1990, a geologic structure was discovered under Point Lake (figure 18) that indicator minerals and geophysical surveys strongly suggested was a kimberlite pipe.

In August 1990, Dia Met entered into a joint venture with BHP-Utah (now known as BHP Minerals), the North American arm of the major Australian mining company Broken Hill Proprietary Ltd. About a year later, the presence of diamondiferous kimberlite was confirmed when a hole drilled at an angle from the shore penetrated this rock under Point lake. Eighty-one small diamonds, all less than 2 mm in diameter, some reportedly gem quality, were subsequently recovered from 141 m of drill core weighing 59 kg. Early in 1992, 160 tons (still a relatively small sample) of kimberlite were obtained, from which 101 ct of diamonds were recovered (0.63 ct/ton). Twenty-five percent of these were reported to be "gem quality" (excluding near-gems); a few were in the 1–3 ct range. In September 1992, it was announced that nine additional kimberlite pipes had been discovered in the same general area, all containing diamonds in variable proportions. Although the grade of the Point Lake deposit, 0.63 ct/ton, is very good by average world standards for primary deposits, and approximately 80 million tons of kimberlite have already been delineated, there has been no clear statement or independent confirmation as to the actual quality of those stones categorized to this point only as "gems."

The discovery of the Point Lake and nearby kimberlites (now known as the Lac de Gras kimberlite field) has resulted in the largest and most exciting staking rush in Canadian mining history. In the Northwest Territories, as of December 14, 1992, at least 19,365,000 acres (7,840,000 ha) had been staked by

Dia Met, Monopros, and at least 50 other companies and individuals (again, see figure 16). It is anticipated that the entire Slave archon will be staked by the end of January, 1993.

Staking is now proceeding eastward (near Dubawnt Lake) to the Rae archon, portions of which contain the largest geologic province of lamproitic rocks in the world (Peterson, 1992). Similar rocks are found as far south as southern Alberta. It is significant that of the only 25–30 lamproite occurrences known worldwide, seven of these contain diamonds.

In Alberta, intermittent and very secretive diamond exploration has been in progress for at least 15 years, much of it also based on heavy-mineral sampling in conjunction with geophysical surveys. In 1990, Monopros acquired 1,680,000 acres (680,000 ha) in the Peace River area. Several small diamonds now have been reported from various locations in glacial till and other alluvial materials in Alberta, but none yet from any kimberlite occurrence. However, the province is underlain by parts of several archons, so there is good geologic potential for kimberlite pipes. Further, the infrastructure and climate are certainly more conducive to efficient exploration than is the case in the Northwest Territories, and the province recently enacted legislation that encourages exploration for minerals. As of December 11, 1992, about 28,400,000 acres (11,500,000 ha) had been staked for diamond exploration in Alberta (again, see figure 16).

From the above discussion, it is clear that North America, in general, and western Canada, in particular, has good long-term potential as an economic source of diamonds. Reasons include: (1) it has the largest craton in the world, including six major archons; (2) it is underexplored relative to South Africa and many other cratonic areas of the world; (3) good-quality diamonds, some over 15 ct (Hobbs, 1899; Brummer, 1984) have been found in the glacial deposits; and (4) the infrastructure and political situation are among the best in the world.

Antarctica. Any discussion of future sources of diamonds would be incomplete without at least mention of Antarctica because of its favorable geology and geologic relationship to other diamond-producing areas.

The continent of Antarctica encompasses about 14,250,000 km^2 (the United States, including Alaska, covers 9,372,000 km^2), of which about 98% is permanently covered by a continental ice sheet averaging 2,000 m in thickness. Geologic knowledge is based on limited rock exposures on the edge of the continent, or those projected through the ice sheet, in addition to geophysical data (e.g., aeromagnetic surveys). Geologically speaking, Antarctica is the last frontier.

Antarctica today is divided into East and West Antarctica (figure 19) by the Transantarctic Mountains, which extend about 4,500 km from the Ross Sea to the Weddell Sea, reaching heights of 4,000 m (Dalziel, 1992).

The larger of the two, East Antarctica, has the greatest potential for diamonds because geologically it is a craton. Although more than 99% of its surface is covered by ice, four archons have been identified. The present East Antarctic craton formed 1.0–1.3 billion years ago, and became part of an ancient supercontinent that eventually broke up more than 570 My ago. Starting in the Cambrian and until middle Jurassic time, an interval of about 350 My, Antarctica formed the core of a second supercontinent known as Gondwanaland. Over the next 160 My, Gondwanaland

Figure 18. Evidence of the first kimberlite pipe in the Northwest Territories was discovered in April 1990 by C. E. Fipke, of Dia Met Minerals, under Point Lake (in foreground, looking northeast toward Lac du Sauvage at the top of the photo). The surface of the kimberlite lies about 50 m (150 ft.) below the surface of the lake, which is 600 m across. The white objects on the northeast shore are trailers. A drilling rig may be seen on the shore about 100 m to the left of the trailers. From this position, an angle hole was drilled under the lake in September 1991, which confirmed the presence of diamond-bearing kimberlite. Photo taken in late July, 1992; courtesy of B. T. Evans, Tyler Resources, Inc., Calgary, Alberta.
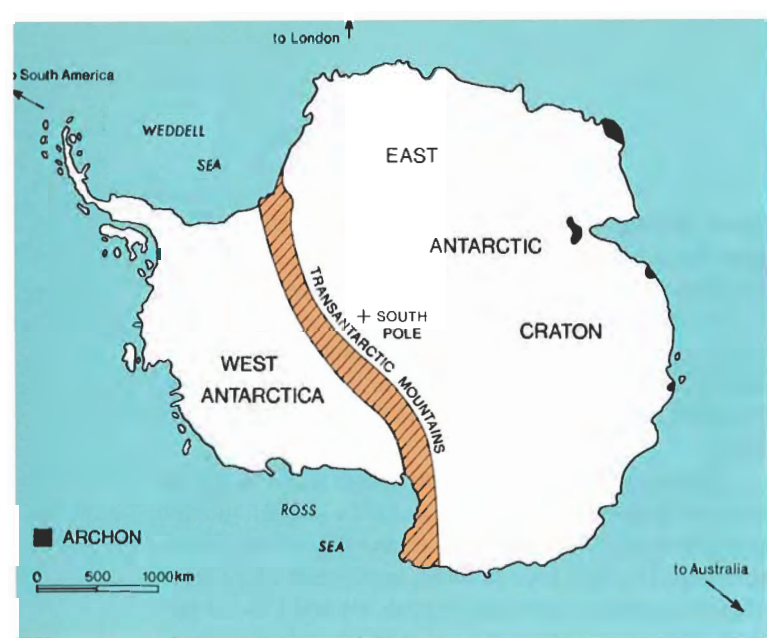
Figure 19. On the basis of what little is known about the geology of this remote region, Antarctica may have great potential as a source of diamonds. The East Antarctic craton is probably the second largest in the world (after North America). Four archons, not covered by the ice cap, have been identified on the east side of the continent.

broke up to form South America, Africa, India, Australia, and Antarctica (see Tingey, 1991, and Dalziel, 1992). Thus, all the present diamond-producing regions of the southern hemisphere, as well as in India, have a common geologic history. Johnson et al. (1989) list Antarctica as one of several favorable regions for large, as yet undiscovered, kimberlite provinces.

At this time, consideration of Antarctica as a source of diamonds is academic, if for no other reason than international agreement forbids any mining. Further, legislation recently passed in the United States (Antarctic Protection Act of 1990; 101st Congress) prohibits U.S. nationals and companies from engaging in any type of mineral-resource activities in Antarctica (Molnia, 1991). Nevertheless, the fact remains that the East Antarctic craton is huge, and it contains archons. If scientific advances in the next century match those of the last 100 years, it is conceivable that diamonds could be mined economically, and in an environmentally acceptable manner, by the end of the 21st century.

CONCLUSIONS

A study of diamond production over the past 120 years shows that although most rough has come from Africa, this situation is rapidly changing. There is also a steady geologic shift toward increased production from primary sources (kimberlite and lamproite pipes) at the expense of secondary sources, mainly alluvial deposits.

The growth of the near-gem market, especially since 1980, has resulted in rough now being classified as cuttable and industrial. The explosion in diamond production during this period, however, has had little impact on the availability of good-quality gems; such cut stones 0.5 ct and larger still constitute only a very small percentage of the diamonds produced annually. At the same time, with the greater economic freedom in once-"closed" areas of Eastern Europe and Asia, major new markets are poised to develop.

Thus, the need for steady sources of good-quality diamonds continues. The most significant long-term deposits are those that occur offshore, such as the marine deposits off of southern Africa, and those primary deposits with significant reserves of ore. Although marine deposits have great long-term potential, they are restricted by the technological challenges of exploration and mining in deep seas. On the other hand, once the economic value of a primary kimberlite or lamproite deposit has been established, it is much easier to mine.

The most likely major source for greatly increased production from primary deposits within the next 10 years is Sakha and elsewhere in the Russian Federation, because the locations of potentially economic kimberlite pipes are known. Canada is likely to be a major producer of diamonds 10–25 years from now, but it is doubtful that significant production could start before the end of this century, owing to the long time it takes to evaluate a pipe and then bring it into production. A hundred years from now, the ecological environment permitting, technological developments might well provide for mining beneath the ice cap in Antarctica, probably the last great terrestrial source of diamonds.

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SAPPHIRES FROM CHANGLE IN SHANDONG PROVINCE, CHINA

By Jingfeng Guo, Fuquan Wang, and Gerry Yakoumelos

Sapphires were recently found in alluvial deposits and in situ in basaltic rocks near Wutu, Changle County, in central Shandong Province. The fact that significant amounts of sapphire have been found in situ at Changle makes it unique among sapphire deposits in basaltic terrains around the world. (Sapphires have been found in situ elsewhere, but never in such abundance in basalt.) Changle sapphires occur in a range of colors (dark blue, blue, greenish blue, and yellow), but they are predominantly dark blue. Fe, Ga, Ti, Co, and V are the most abundant trace elements present. The gemological properties of Changle sapphires are consistent with those from similar alkalic basalt environments.

The sapphire potential of the People's Republic of China (PRC) was recognized several years ago, following the discovery of alluvial deposits of this gem material in several provinces. Previous reports in English on Chinese sapphires include the survey of the PRC's gem resources by Keller and Wang (1986), the description of the Mingxi deposit in Fujian Province

by Keller and Keller (1986), and the report on the Wenchang deposit in Hainan Province (formerly Hainan Island) by Wang (1988). In all three articles, the authors speculated that the sapphires obtained from these alluvial deposits were derived from surrounding Cenozoic basalts; however, no locality-specific studies were available to corroborate this hypothesis.

More recently, in the late 1980s, local farmers discovered alluvial sapphires near the township of Wutu, Changle County (henceforth, Changle), in central Shandong Province. These sapphires are characterized by their large size, dark color, and absence of fractures (figure 1). Some show distinctive zonation (figure 2). Follow-up geologic surveys were conducted by the 7th Geological Brigade of the Shandong Bureau of Geology and Mineral Resources. Subsequently, large quantities of sapphire were discovered in Tertiary alkalic basalt lava flows, where they occur *in situ* as "megacrysts" (a general term for large crystals, without any implication with respect to origin). Although the only mining thus far has been by local workers digging in the alluvium, officials at the Shandong Bureau of Geology and Mineral Resources estimate that more than 50,000 carats of rough from the Changle deposits

were exported to Hong Kong, Thailand, Australia, and the United States in the period 1988–1991.

To date, however, no studies have been published on the Changle deposits. The object of this report, which is based on information obtained during the authors' early-1989 visit to Changle and from discussions with senior geologists of the 7th Geological Brigade, is to briefly describe the Changle deposits and present information with respect to the geologic occurrence and origin of the sapphires.

Figure 1. Dark blue sapphires are being recovered from alluvial deposits in Changle County, Shandong Province, China. Sapphires have also been found in situ *in the basalt. These two Changle sapphires each weigh approximately 3 ct.*

LOCATION AND ACCESS

Wutu is situated about 8 km southeast of the town of Changle, which is about 150 km east of Jinan, the capital of Shandong Province (figure 3). Modern highways and a railway make Changle easily accessible year-round. Changle is an agricultural region, and foreign visitors can obtain access to the area by contacting the local Changle County government.

The sapphires are found within a roughly 5 km radius of Wutu (see figure 3). At the time of our 1989 visit, the "mining operation" was represented by sporadic holes in the ground, without any organization. Mechanized operations by joint ventures between the government and foreign companies (e.g., Shandong Leyang Pty. Ltd.) are now under way to explore the sapphire-producing potential of the area more fully.
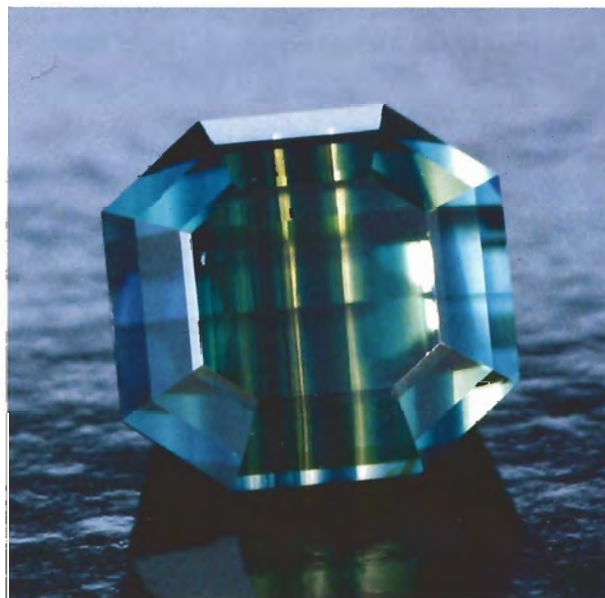
GEOLOGY AND OCCURRENCE

The first discovery of sapphire near Wutu was in alluvial sediments filling the topographically long and narrow gully at Xinwang (figure 4). In 1988, geologists from the 7th Geological Brigade discovered sapphires *in situ* in basaltic rocks at two localities in the vicinity of Wutu: Fangshan and Qiujiahe (again, see figure 3). From field observations, it appears that the basalts at Fangshan occur stratigraphically somewhere near the top of the Niushan Group or the bottom of the Yaoshan Group (see table 1). Potassium-argon geochronologic ages determined for these basalts are 16–17 My (lower Miocene; Chen et al., 1985), which places them geologically in the Niushan Group. The basalts at Qiujiahe also are within the Niushan Group, but at a different stratigraphic position. However, the occurrence of sapphires at these two localities differs: At Fangshan (figures 5 and 6), the sapphires are concentrated in a layer at least 2 m thick that contains abundant ultramafic "xenoliths" (foreign inclusions in an igneous rock) within a massive basalt flow; at Qiujiahe, the sapphires occur in a layer 0.3–0.6 m thick within a different basalt flow that does not have xenoliths.

At the Fangshan locality, there is a positive correlation between the abundance of xenoliths and of sapphires; that is, the greater the number of xenoliths (which may reach 30%–40% of the basalt by volume) present, the greater the number of sapphire megacrysts found within the basalt. The xenoliths have been deeply weathered, and the sapphires remain embed-

Figure 2. Distinctive zoning is seen in some Changle sapphires like that evident in this 0.70-ct stone. Photo © GIA and Tino Hammid.
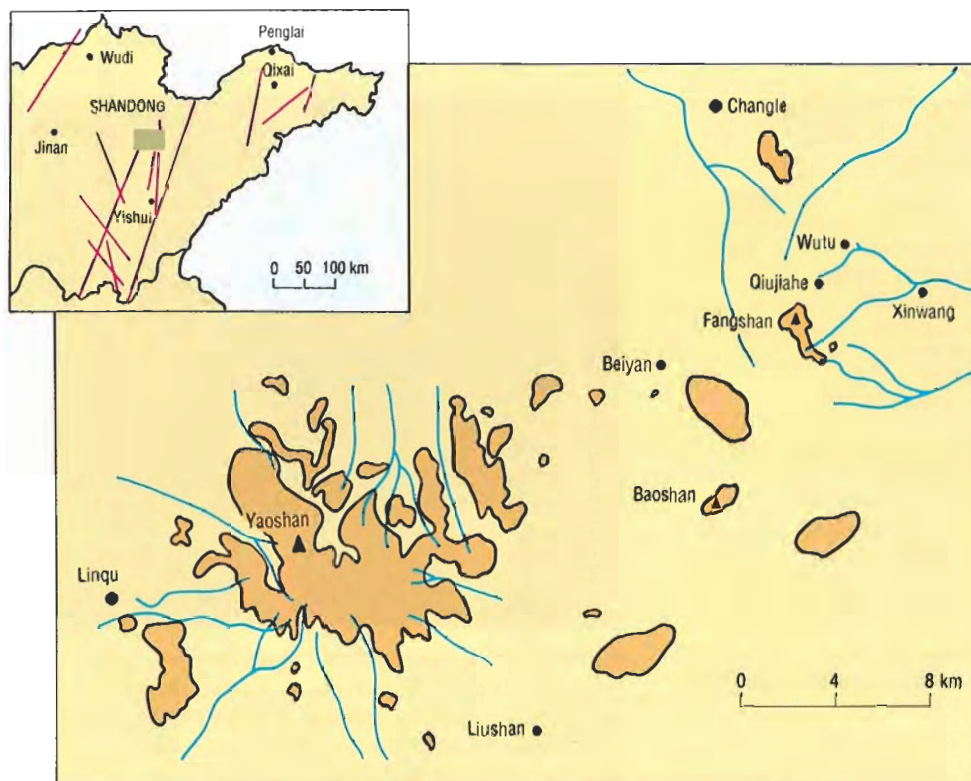
Figure 3. This map shows the location and distribution of Cenozoic basalts in the Linqu-Changle region, Shandong Province. The shaded areas represent the exposed basaltic rocks. Local hills are indicated by solid triangles; circles represent cities and towns. The major drainage patterns, through which alluvial stones might travel, are also shown. The inset at the upper left shows the location of regional faults which provide channels for volcanic eruption, across Shandong Province.

ded in the basaltic matrix (figure 7). Similar occurrences of sapphire in basalt are known from the Inverell-Glen Innes region of New South Wales and the Anakie-Rubyvale region of Queensland, Australia (MacNevin, 1972; Stephenson, 1976, 1990), as well as from other localities, but the abundance of sapphires in the Changle deposits is much greater than it is in these other localities.

The basalts in Shandong Province, which are part of the Cenozoic (less than 65 My) Basalt Belt of northeastern China, are extensive. Most basalts in this area are Miocene in age and range from 9 to 21.5 My; only minor amounts were extruded during the Pliocene age. In general, the basalts are alkalic in composition (i.e., high in sodium and potassium). The ultramafic xenoliths characteristic of the Fangshan sapphire deposits are derived from the Earth's mantle (i.e., below the crust and above the core). They are found throughout the volcanic sequence in varying amounts. Sapphires, however, occur only in specific situations and are particularly abundant in basalts with an age of 16–17 My, as at Fangshan. Two major regional fault trends, extending northeast and northwest, respectively, may have played an important role in controlling volcanic activity in the region (again, see figure 3).

MINING
The horizon that contains the alluvial sapphires lies about 4 to 5 m below the surface. To date, most of the sapphires recovered have been picked by hand from the

Figure 4. The sapphire-bearing gravels are found in a largely agricultural area at Xinwang, near Wutu in Changle County. Only a portion of the long, narrow gully is visible from this angle.

Time scale	Stratigraphic unit	Description[b]	Sapphires
Pliocene	Yaoshan Group	Basalt lavas (15 m) Interbedded clay-coal layer Conglomerate (30 m)	Yes
Upper Miocene	Shanwang Group	Basalt lavas (10 m) Thin coal layer Basalt lavas Sandy conglomerate (54 m) Clay, shales	No
Lower Miocene	Niushan Group	Partially exposed basaltic lavas interbedded with pyroclastics (total >143 m)	Yes
Archean	Taishan Formation	Highly deformed amphibolites and feldspathic gneisses	No

[a] *Information from the 7th Geological Brigade, Zhu et al. (1985), and Wang and Jin (1986).*

[b] *The thickness of each layer is given where available.*

Figure 6. At the digging site at Fangshan (see figure 5), sapphires are concentrated in a xenolith-rich band of unknown thickness (2 m is visible) within the basalt. This was the only in situ operation at the time of the authors' 1989 visit, and was exploited solely for mineral specimens of sapphire in basalt. Mr. Shao Zhixin, a local resident, is shown looking for such specimens.

alluvium (again, see figure 4), although the joint ventures mentioned earlier are to bring in heavy equipment, presumably for an open-pit operation. Only relatively large crystals are recovered by hand picking, but the daily yield can be significant, as well as quite variable. There was no processing plant at the time of our visit, but we understand that such plants will be part of the mechanized operations planned.

Figure 5. Sapphires have been found in situ in basalt in this hill at Fangshan. The arrow points to the in situ digging site near the top of the hill.

At the time of our visit, there was no organized mining of the *in situ* deposits, although we know that a few people have extracted sapphire-basalt specimens (again, see figures 6 and 7). A detailed exploration program is presently being carried out by the 7th Geological Brigade to assess the economic potential of the sapphire deposits in the entire region. The joint ventures were formed in 1991 to bring organized exploration, mining, processing, treatment, cutting, and distribution to the Changle deposits. As yet, no details are available of the results of these ventures. Such operations are under the authority of the Bureau of Mineral Resources of the Changle County government, which can be contacted for further information.

THE CHANGLE SAPPHIRES

Sapphires recovered from this area range from blue to greenish blue to yellow, and they are sometimes strongly zoned (again, see figure 2). Most of the blue sapphires are dark (again, see figure 1), like those from the Anakie Field, in Queensland, Australia. In diaphaneity, they range from transparent to translucent (silky). The rough sapphires are relatively large, 5–20 mm on average, with exceptional crystals up to

10 cm along the c-axis. Blue sapphires smaller than 5 mm can be cut in their natural state. However, those larger than 10 mm are usually too dark and may require heat treatment before being marketed. None of the material we have encountered would produce asterism.

We examined a random sample of more than a hundred individual sapphire grains, some of which were extracted directly from the basalts. The crystals are typically barrel shaped, pseudo-hexagonal, and terminated at both ends (again, see figure 7). Many of the grains are broken fragments, but most of these show one or two original crystal faces. Those sapphires that have their natural surfaces preserved show extensive etch features, the result of interaction with the basalt magma in which they were carried to the surface. Typically, they do not exhibit distinct dichroism. Specific gravity was determined by the hydrostatic method to range from about 3.98 to 4.09.

Further studies on these sapphire samples were carried out at Macquarie University, Sydney, Australia. The minor and trace elements were determined using energy-dispersive particle-induced X-ray emission (PIXE) analysis. Fe, Ga, Ti, Co, and V were found to be among the most abundant elements present (table 2). Ti contents of the yellow sapphires were lower than those of the blue varieties, resulting in higher Fe/Ti ratios for the yellow sapphires. We noted that the deeper the blue color of the sapphires was, the lower the Fe/Ti ratios were.

Results of quantitative chemical analysis by electron microprobe revealed the following mineral inclu-

Figure 7. A dark blue sapphire megacryst is seen here embedded in its basalt matrix, as recovered from Fangshan in Changle County. The yellow fragments adjacent to the sapphire are weathered ultramafic xenoliths.

sions: uranium-and-thorium-rich zircon, titanium-rich columbite, sodium feldspar, apatite, ilmenite, and magnesium-iron spinel. This combination is similar to that found in sapphires from other basaltic areas such as Hainan Island, China, and the Inverell-Glen Innes, Anakie-Rubyvale, and Lava Plains regions in eastern Australia. The zircon inclusions are orange-red in color and can be as large as 1 mm; the columbite

TABLE 2. Minor- and trace-element contents in dark blue, blue, and yellow Changle sapphires.[a]

Element (ppm)	Sample (color)[b]							
	SD12 (d.blue)	SD14 (d.blue)	SD19 (d.blue)	SD13 (blue)	SD17 (blue)	SD18 (blue)	SD15 (yellow)	SD17 (yellow)
Fe	7188	7868	7245	7642	9046	9593	7629	8800
Ga	207	190	194	222	275	211	249	250
Ti	330	276	125	173	161	190	65	79
Co	31	35	33	34	35	35	28	30
V	28	15	17	19	21	13	19	21
Cr	9	29	11	5	<3	<3	<3	46
Mn	5	7	6	7	5	11	7	5
Cu	<3	<3	4	<3	4	4	<3	<3
Zn	<3	<3	<3	<3	<3	<3	<3	<3
Fe/Ti	22	29	58	44	56	50	117	111

[a] Sapphire samples were analyzed using the proton microprobe at the CSIRO Division of Exploration Geoscience, North Ryde, NSW, Australia, with the assistance of Dr. W. L. Griffin.

[b] d.blue = dark blue. Note that sample SD17 is a particolored crystal; separate analyses were done on blue and yellow sections of this crystal.

inclusions are typically black, with metallic luster, and also range from several hundred microns to 1 mm. Columbite was found to be one of the most common mineral inclusions in sapphires from basaltic terrains. U-Pb dating of the zircon inclusions gave the same age (16 My) as the host Fangshan basalt (16.3–16.4 My). The implications of these data are beyond the scope of this report and are the topic of a separate paper (Guo, in preparation).

CONCLUSION

The occurrence of sapphires *in situ* in basalts at Changle confirms the relationship between gem-quality sapphires and basalts, which has been recognized but not always proved at other, similar sapphire deposits throughout the world, such as Thailand, Australia, and elsewhere in China. Sapphires found in basaltic terrains were clearly brought to the surface by the rapidly ascending alkalic basaltic magmas along with other heavy materials (e.g., mantle xenoliths). However, the genesis of the sapphires at depth remains a mystery, because the data at hand are inadequate to determine whether the sapphire crystals formed directly from the basalt magma (i.e., they are phenocrysts) or crystallized elsewhere and were merely transported to the surface as xenocrysts (i.e., crystals that are for-

eign to the rock in which they occur). One way of approaching this problem is to study the mineral and fluid inclusions within the sapphires. This type of study is currently in progress (e.g., Guo et al., 1992; Guo, in preparation). Preliminary indications are that sapphires have no direct genetic linkage with their host basalts; that is, they are not phenocrysts of basalt magmas, but rather they are the product of complex magma-mixing processes.

Although gemstone resources in China have been neglected for years, these newly discovered sapphire deposits have attracted the attention of the international gem community. Preliminary exploration in the vicinity of the Wutu district alone has revealed that the sapphire reserve is large, on the order of tons (7th Geological Brigade, pers. comm., 1992). At present, the recovery of sapphires from this area is negligible in comparison to the estimated reserve.

However, it is possible within the near future that cooperation already established between Chinese government agencies and foreign gem companies will make sufficient foreign capital available to bring this deposit into full-scale production using modern mining methods. Considering the vast area in eastern China that is covered by similar alkalic basalt rocks, the long-term prognosis for economic sapphire deposits is good.

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DIAMOND

With Etched Dislocation Channels

Some unusual inclusions in a 2.04-ct light pink pear-shaped diamond were illustrated in the Fall 1992 Lab Notes section (p. 194). Subsequently, we were shown a 1.28-ct fancy pink diamond, reportedly from Australia, with similar inclusions: rectangular hollow channels (figure 1), some of which "zigzagged" for quite a distance (figure 2).

Emmanuel Fritsch, of GIA Research, informed us that X-ray topographers use the term *zigzag disloca-*

Figure 2. At 63× magnification, one can see the extent of the "zigzagging" in one of the inclusions shown in figure 1.

Figure 1. The surface-reaching inclusions in this 1.28-ct light pink diamond are actually rectangular hollow tubes. Magnified 33×.
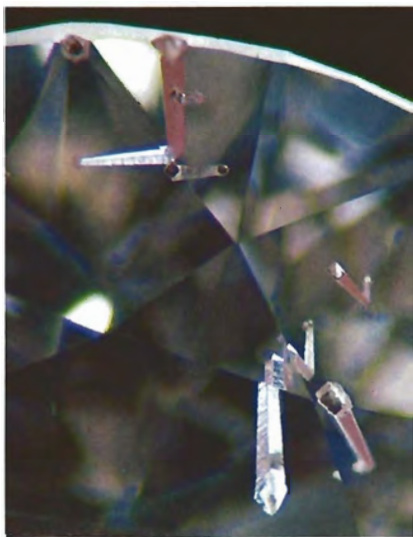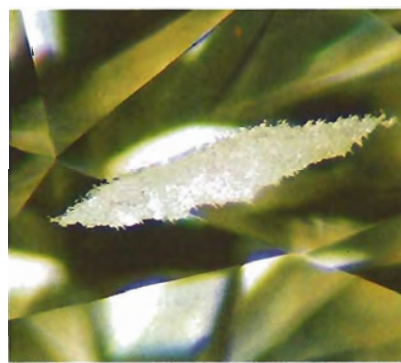
tions for features of similar geometry seen with X-radiography (the phenomenon is not limited to diamond). The dislocations represent zones of weakness in the crystal structure. Under certain geologic conditions, the dislocations may become etched, in which case they are called *etched dislocation channels.*

The channels that we observed in the two diamonds mentioned above would appear to be related to the various etch phenomena noted by Hofer in his article on pink diamonds from Australia (*Gems & Gemology*, Fall 1985, pp. 147–155). Although Hofer describes these etch phenomena as typical of Argyle pink diamonds, we also

noted an open cleavage that had been etched in a 0.87-ct fancy yellow diamond (figure 3) that was reportedly from Argyle.

It is possible that the series of long, blade-like, nearly parallel inclusions observed in still another, 0.75-ct diamond could also be evidence of etched dislocation channels. When the round brilliant was viewed faceup, these inclusions were reflected in other facets, so that the whole stone resembled a kaleidoscope (figure 4). Of necessity, many jewelers have been forced to handle dia-

Figure 3. This etch feature, typically associated with pink diamonds from Argyle, was seen in a 0.87-ct fancy yellow stone, also reportedly from that locality. Magnified 45×.

Figure 4. These long, blade-like inclusions produce a kaleido-scopic effect when this 0.75-ct. diamond is viewed faceup. Magnified 16×.

monds with lower clarity grades than they had been accustomed to handling in the past. It is interesting that these inclusions were first observed while our client was examining stones for evidence of fracture filling, turning what might have been a chore into an opportunity to discover heretofore unappreciated beauty in the inclusions themselves. *GRC*

Colored Diamond Crystal Set in a "Renaissance Ring"

The increasing popularity of fancy-color diamonds is also often associated with the Argyle deposit, because of the many brown and pink diamonds it produces (see, e.g., *Modern Jeweler*, April 1987). Consumer awareness has been heightened recently by jewelry manufacturers' promotions of finished pieces that incorporate these colored diamonds.

The ring shown in figure 5 was sent to the East Coast laboratory for identification of the stone and, if it proved to be a diamond, whether the color was natural or treated. The dark brown octahedron was, without a doubt, a diamond. It measured 5.00 × 4.85 mm wide where mounted into the bezel; the closed-back setting prevented measurement of its height. Using the microscope and diffused lighting, we observed pronounced brown graining. This, together with the absence of sharp absorption bands in the hand

Figure 5. The ring in which this dark brown diamond octahedron is set reportedly dates from the Renaissance period.

spectroscope and the weak yellow flourescence to long-wave ultraviolet radiation, confirmed that the color was natural.

This ring is very similar in style to a ring from the Renaissance period in Europe that is featured on page 97 of *Gems and Jewels: A Connoisseur's Guide*, by Benjamin Zucker (Thames and Hudson, New York, 1984). Although old styles are often reproduced, empirical evidence such as the purity and the patina of the gold, along with the burnished effect on the bezel that occurs with wear, indicates that this is an original antique. The intricate workmanship, and the fact that the ring is very well preserved, suggests that colored diamonds have been desirable for centuries. Also, the apparent age of the ring leads us to believe that the diamond is of Indian origin.

TM

SYNTHETIC EMERALD Overgrowth on Faceted Beryls Used in Jewelry

One of the earlier commercial synthetic emerald products consists of a pre-

faceted colorless or pale-colored natural beryl over which a layer of synthetic emerald has been grown by the hydrothermal method. Although the synthetic emerald layer is typically very thin, comprising only a small percentage of the entire gem, the faceup color is generally a uniform, medium to medium-dark green. Because this product was developed by Johann Lechleitner, it is commonly referred to by gemologists as "Lechleitner synthetic emerald overgrowth."

We rarely see these synthetic emerald overgrowths in the GIA Gem Trade Laboratory; when we do, it is generally as individual, loose stones. It was thus unusual for the West Coast lab to receive for examination the white metal pin shown in figure 6. Gemological testing proved that all four of the large (up to 11.7 × 9.5 × 7.7 mm) green emerald cuts are examples of synthetic emerald overgrowth on natural beryl. Typical features, noted with magnification, included a "crazed layer," consisting of many fine, intersecting fractures at the interface of the synthetic emerald layer and the beryl core. Growth features on several facets of each specimen

Figure 6. The four green stones in this pin, which range from approximately 8.2 × 6.1 × 3.8 mm to 11.7 × 9.5 × 7.7 mm, are synthetic emerald overgrowths on natural beryl.

proved that little or no repolishing had been done after the overgrowth process.

SFM and R. C. Kammerling

Pink Hydrogrossular GARNET

Although we regularly receive for identification a wide variety of transparent, single-crystal garnets, only infrequently do we examine nontransparent aggregate types (see, e.g., the entry on a massive grossularite garnet carving in the Winter 1991 Lab Notes section). It was thus a pleasant surprise for the West Coast lab to receive the translucent, orange-pink 8.57-ct pear-shaped cabochon shown in figure 7.

The stone produced an "aggregate" reaction in the polariscope and a spot R.I. reading of 1.69. The specific gravity, determined hydrostatically, was 3.30. Although the R.I. and S.G. values are within the published ranges for hydrogrossular garnet, they are somewhat lower than what we have encountered in the past and could make this a difficult identification for some gemologists. X-ray powder diffraction analysis, however, proved that the stone was hydrogrossular garnet. Energy-dispersive X-ray fluorescence (EDXRF), per-

formed by GIA Research, revealed the presence of manganese, which is believed to be responsible for the gem's color.

SFM and R. C. Kammerling

Black OPAL

In the trade, the term *black opal* is used to describe solid (i.e., unassembled) opals that display their play-of-color against a dark, essentially opaque background when viewed with overhead lighting. However, there does not appear to be a consensus as to what "dark background" means. Because black opal is so desirable, there is a tendency to use the term for materials with backgrounds that are dark brown or dark gray rather than black. Some traders use the term even more loosely, describing stones with only light gray backgrounds as black opal. (For more on opal description and valuation, refer to *Opal Identification and Value*, by Paul B. Downing [Majestic Press, Tallahassee, Florida, 1992].)

Regardless of how the term is defined, opals with a truly black background are uncommon, so the West Coast laboratory appreciated the oppor-

Figure 8. This 7.37-ct stone (19.8 × 11.8 × 4.7 mm) is a fine example of opal with a truly black background.

tunity to examine the 7.37-ct oval cabochon seen in figure 8. Against its black background, this stone exhibited large, vivid patches of color, mainly red and orange, but with some blue, green, and violet as well. When viewed from some angles, the opal displayed orange play-of-color across more than two-thirds of its surface.

Because this cabochon contains two thin seams of dark potch (i.e., common opal), an unwary gemologist might mistake it for an assembled stone. Therefore, a note was added to the conclusion on the GIA-GTL report that this opal is not assembled.

SFM and R. C. Kammerling

Freshwater Natural PEARL from Alabama

In their classic work, *The Book of the Pearl* (Century Co., New York, 1908), Kunz and Stevenson discuss natural pearls formed in bivalve mollusks that live in freshwater rivers and lakes. In America, pearls are primarily found in mollusks from the family *Unionidae*, which live in the Mississippi and Tennessee Rivers and their tributaries,
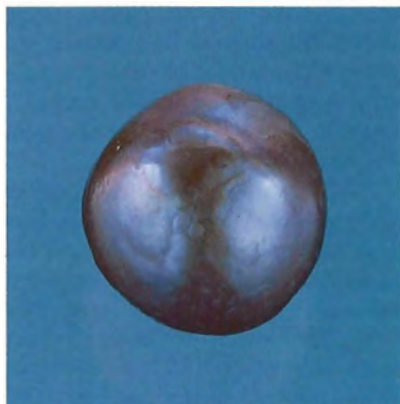
Figure 7. The R.I. and S.G. values of this 8.57-ct hydrogrossular garnet (20.7 × 7.3 × 6.1 mm) are at the low end of the range for this gem species.

Figure 9. The Chattahoochee River in Alabama is the source of this 12-mm natural pearl.

as well as in the Colorado River. The West Coast laboratory has just learned that some natural pearls were found recently in Alabama, a lesser-known pearl source.

The attractive pinkish purple pearl in figure 9 was found in the Chattahoochee River near Dothan, Alabama. The slightly off-round pearl measured approximately 12 mm in diameter and weighed about 52 grains (13 ct). The X-radiograph showed the very dense structure and thin conchiolin layers commonly seen in freshwater natural pearls. Because of the fairly dark tone and coloration of this pearl, X-ray luminescence was only moderately strong. The pearl fluoresced greenish yellow to long-wave ultraviolet radiation. Unfortunately, it is not known which species produced this lovely pearl.

KH

Synthetic Green QUARTZ

The laboratory periodically receives amethyst for identification, primarily to determine whether it is natural or synthetic. Amethyst, however, is not the only variety of quartz that is synthesized by the hydrothermal process.

Recently, two separate clients submitted to the West Coast laboratory faceted specimens of a transparent, dark green gem material that visually resembled tourmaline (see, e.g., figure 10). In both cases, the material had been represented to our clients as a new type of natural green quartz from Brazil.

Gemological testing revealed properties consistent with quartz, both natural and synthetic. When the stones were immersed in water and examined with a polariscope, they proved to be untwinned, with a "bull's-eye" interference figure. Magnification revealed parallel green color banding, similar to that seen in a synthetic green quartz reference stone of Russian origin (see the Gem News section, Spring 1992). We also noted some angular brown color zoning running perpendicular to the green banding, a feature we have seen in other colors of hydrothermal synthetic quartz, but not in the natural counterpart. One specimen also contained numerous tiny white pinpoint inclusions.

EDXRF analysis in GIA Research detected the presence of silicon, potassium, and iron. This differed only slightly from the chemistry of our reference sample, which also contained minor amounts of chromium.

On the basis of these results, we identified the specimens from both clients as synthetic green quartz. The iron may be responsible for the green coloration of these stones, as it is in natural green quartz and in "greened amethyst" (produced by the heat treatment of some natural amethyst). It is important to note that, while green

Figure 10. This 12.30-ct synthetic green quartz had been misrepresented to our client as a new type of natural quartz from Brazil.

quartz (sometimes referred to by the trade name "praseolite") does occur naturally, such material is typically light in tone. To our knowledge, there are no reports of natural green quartz with this darkness of tone.

SFM and R. C. Kammerling

SAPPHIRE

Color-Zoned Sapphire

Some of the most interesting sapphires we encounter are those that exhibit distinct color zoning, such as the stones reported in the Spring 1986 and Fall

Figure 11. While the faceup color of this 3.51-ct sapphire is primarily orangy pink with purple overtones, the stone has distinct orange and pink color zones.

1989 Gem News sections. The West Coast laboratory recently examined an unusual sapphire that exhibited distinct orange and pink zones. In the faceup position, most of this 3.51-ct stone took on an orangy pink color with purple overtones, although distinct areas were more orange (figure 11).

This stone reminded us of an exceptional 1,126-ct sapphire crystal from the Ratnapura area of Sri Lanka illustrated in the Spring 1983 *Gems & Gemology* ("Padparadscha: What's in a Name?," by Robert Crowningshield), with a follow-up entry in the Spring 1986 Lab Notes column. That crystal also exhibited color zoning in predominantly pink and orange hues. It is pos-

sible that the stone described here was cut from a similar crystal.

SFM and R. C. Kammerling

Durability of Diffusion-Treated Sapphire

An item in the Summer 1992 Lab Notes section reported unusual wear of the crown facets on a diffusion-treated blue sapphire. In that item, we surmised that repeated heating of some diffusion-treated sapphires may have produced a lower resistance to wear. However, the appearance of another diffusion-treated stone with badly abraded crown facets suggests that something more than just heating may be involved. An approximately 4-ct stone, set in a ring with side diamonds (figure 12), was submitted to the East Coast lab for identification. The lack of any evidence of wear to the setting leads us to believe that it could not have been worn for a long time. Yet, "micro-chipping" at the edge of the table (figure 13) resembles the damage seen on a heat-treated zircon that has been worn for years. Thus, we are forced to consider the possibility that the surface layer of at least some diffusion-treated sapphires is just not as durable as the surface of an ordinary heat-treated sapphire.

Figure 12. Abraded table facet junctions are readily seen on this approximately 4-ct diffusion-treated sapphire which has been set in a ring with diamonds.

Figure 13. At 35× magnification, the full extent of the abrasion damage to the table facet junctions of the stone shown in figure 12 is apparent.

We do not know how prevalent this problem is, given the many thousands of carats of blue diffusion-treated sapphires that have entered the trade in recent years. It appears, however, that some diffusion-treated sapphires are as prone to wear as heat-treated zircons.   *GRC*

Yellow Sapphire with Unusual Fluorescence

Reaction to ultraviolet radiation is often a useful gemological test. One specific application is to determine if corundum gems have been subjected to heat treatment. For example, blue heat-treated "geuda" stones from Sri Lanka often fluoresce a chalky bluish white to greenish yellow to short-wave U.V. radiation. Occasionally, we have also seen rubies that showed a patchy bluish fluorescence to short-wave U.V. (see, e.g., the Summer 1984 Lab Notes section).

Recently, the West Coast lab was asked to issue an identification report on an 8.27-ct transparent, light yellow, oval mixed cut. Gemological testing proved the stone to be a natural sapphire. Magnification revealed small discoid fractures around the included crystals, clear evidence that the stone had been heat treated.

The moderate orange fluorescence to long-wave U.V. radiation has been seen before in both heat-treated and untreated yellow sapphires. However, we were surprised to see an atypical overall yellow fluorescence to short-wave U.V. Examination of the stone with a microscope that had been modified for use with U.V. radiation sources revealed the cause of the yellow appearance: Most of the stone fluoresced orange to short-wave U.V., but some areas fluoresced a chalky bluish white. These areas corresponded to light blue color zones that might have developed during the heat treatment. It appears that the areas of chalky bluish white fluorescence combine with the underlying orange fluorescence to produce an overall yellow appearance to short-wave U.V. radiation.

SFM and R. C. Kammerling

SYNTHETIC STAR SAPPHIRE of Unusual Color

Synthetic star corundums are produced by the flame-fusion method in a great variety of colors. One of the most prevalent colors mimics the appearance of ruby. In our experience, synthetic star stones tend to be semitranslucent to almost opaque, because of the high concentration of acicular synthetic rutile inclusions responsible for the asterism. These synthetic rutile needles not only lower the transparency of the synthetic stones, but they also contribute a strong purple appearance that is due to scattering of light. It is because of this effect of rutile on the overall color appearance (of natural as well as synthetic stones) that the laboratory allows more leeway in making the distinction between ruby and purple sapphire in star stones.

On rare occasions, we see synthetic star rubies that contain lower concentrations of the needle-like inclusions. Such stones invariably have a more natural appearance. They not only exhib-

Figure 14. The combination of a high degree of transparency and a reddish purple body color makes this 7.08-ct synthetic star sapphire unusual.

it slightly less distinct stars, but they also are semitransparent with a less purple, more red body color. Even more unusual, in our experience, is the 7.08-ct synthetic star sapphire shown in figure 14, which was recently examined in the West Coast laboratory. Although this stone exhibited the high degree of transparency associated with lower concentrations of rutile, the dark reddish purple body color resulted in it being identified as a synthetic star sapphire rather than a synthetic star ruby.

SFM and R. C. Kammerling

Unusual Bicolor ZOISITE

The blue to violet variety of zoisite known as tanzanite, which is produced primarily in the Merelani Hills of Tanzania, first entered the gem market in the 1960s. Much more recently—in 1991—commercial quantities of a transparent green zoisite were also discovered in the Merelani Hills (see "Gem-Quality Green Zoisite," by N. R. Barot and W. Boehm, in the Spring 1992 Gems & Gemology).

In our experience, both tanzanite and the newer transparent green zoisite tend to have quite uniform color distribution throughout the stone. Staff gemologists in the West Coast lab were therefore surprised to receive for identification the 2.52-ct emerald cut illustrated in figure 15. This zoisite is very unusual in that it is distinctly bicolored, displaying violetish blue in one half and yellowish green in the other.

Standard gemological testing confirmed that the stone was zoisite. Ultraviolet-visible spectroscopy and EDXRF chemical analysis were performed in GIA Research to explore the difference in color between the two zones. A qualitative EDXRF analysis showed that both the violetish blue and yellowish green sectors contain, besides zoisite's normal components, traces of strontium, vanadium, and possibly chromium. However, the blue sector was found to have significantly more vanadium than the green sector, but none of the titanium that was present as an additional impurity in the green sector. No iron was found in the crystal, in either color sector. In their article, Barot and Boehm also noted the presence of strontium and the absence of iron in both the green and the blue
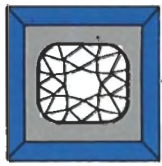
samples, although no ultraviolet-visible absorption spectra were provided. They identified Cr as the primary chromogen responsible for the green color, versus the established chromogen V in the blue material. Their blue and green samples all contained comparable amounts of Ti.

Unpolarized absorption spectra, taken in the same orientation in both the blue and green zones, show identical features, with the exception of an additional absorption in the green zone that has a "two-humped" broad band with apparent maxima at about 445 and 466 nm. A band at about 444 nm has in the past been tentatively attributed by Faye and Nickel (Canadian Mineralogist, Vol. 10, No. 5, 1971, pp. 812–821) to Ti^{3+} in zoisite. However, this interpretation poses some problems that remain unresolved. For example, this absorption may be related to titanium in a more indirect manner, such as a charge transfer with some other ion; there are no previously known absorptions around 466 nm. Therefore, the color difference between the two zones of this zoisite is not clearly understood at this time.

R. C. Kammerling
and Emmanuel Fritsch

Figure 15. This 2.52-ct zoisite (10.3 × 5.5 × 4.6 mm) is unusual in that it is distinctly bicolored. The green portion is actually greener in the stone than it appears in this photograph.

GemNews

JOHN I. KOIVULA, ROBERT C. KAMMERLING AND EMMANUEL FRITSCH, EDITORS

DIAMONDS

Indicators of additional diamond pipes in Australia.
Centenary International Mining Ltd. of Australia has announced the discovery of a potentially diamondiferous pipe zone at Giralia, north of Lake MacLeod in Western Australia. The joint-venture lease area is about 1,600 km (1,000 mi.) southwest of Argyle. Preliminary exploration revealed the presence of chrome spinels that, theoretically, could only come from a primary deposit similar to the Argyle pipe. Follow-up work will include detailed sampling of previously detected magnetic anomalies, as well as aeromagnetic, ground magnetic, and stream sediment sampling of the remainder of the lease area. (*Diamond International*, July/August 1992, pp. 33, 35)

"Presidential" diamond cavity. Anthony de Goutière, a gemologist and jeweler from Victoria, British Columbia, brought to the editors' attention a 0.33-ct round-brilliant-cut diamond with an exceptionally deep surface-reaching cavity. The cavity was open at the pavilion and, when viewed down its length, showed distinct trigons on its inner surfaces as well as a square cross-sectional outline. When viewed through the stone's crown, the cavity proved to be exceptionally deep (with an approximately four-to-one length-to-width ratio). Also evident was the remarkable resemblance of the cavity to a statue of the 16th president of the United States, Abraham Lincoln (figure 1). The exact cause of the cavity is not known. Similar features, however, have been described previously as "etched dislocation channels" (see Gem Trade Lab Notes, this issue).

An update on diamond research. In early September 1992, one of the editors (EF) attended the "Diamond 1992" conference in Heidelberg, Germany. He prepared the following report on recent progress made in diamond research.

Most research activity in the low-pressure growth of synthetic diamond (essentially chemical vapor deposition—or CVD—synthetic diamond) appears to be concentrating on refining current processes to achieve higher growth rates or fit specific applications. To demonstrate progress made in the growth of large (for this technique) gem-quality crystals by microwave CVD, Prof. Andresz Badzian of Pennsylvania State University exhibited a 2-mm-high pyramidal single crystal of synthetic diamond that, to the unaided eye, appeared to be transparent and colorless.
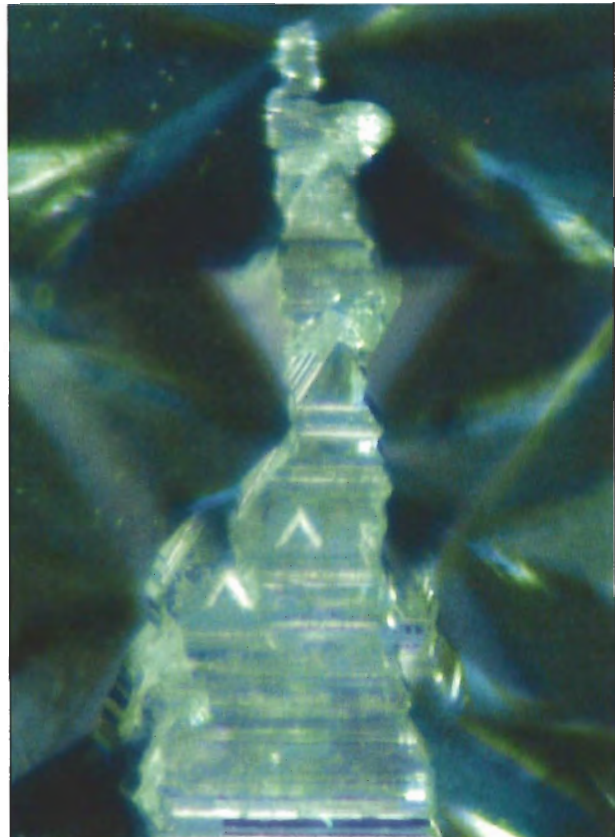

Figure 1. Viewed through the crown, this cavity in a diamond resembles a statue of 19th-century U.S. president Abraham Lincoln standing on a pedestal. Photomicrograph by Anthony de Goutière; magnified 18×.

As a result of research on high-temperature, high-pressure synthesis of diamond, Dr. Hisao Kanda, of the National Institute of Research on Inorganic Material in Japan, has produced yellow synthetic diamonds that contain A nitrogen aggregates (type IaA diamond) by treating type Ib yellow synthetic diamonds at high pressure. All of the synthetic yellow diamonds reported previously contained only dispersed (type Ib) nitrogen. The presence of nitrogen aggregates may dramatically affect the gemological properties of the stones

and would have important implications should they ever be made commercially available.

Dr. Alexander P. Yelisseyev, of the Institute of Mineralogy and Petrography in Novosibirsk, Russia, showed typical cubo-octahedral yellow gem-quality synthetic diamonds grown in Novosibirsk. These diamonds were grown at high pressures and temperatures in what is called a split-sphere apparatus, a technique that, Dr. Yelisseyev maintains, is less expensive than the classic belt method used by all other producers of high-pressure synthetic diamonds. It is interesting to note that some of these diamonds had been heat treated at high pressure, which resulted in a lighter, greener color. According to Dr. Yelisseyev, this green color is caused by nickel-related color centers formed during the treatment. The nickel impurity comes from the molten metal flux in which the synthetic diamond is grown.

The Drukker International booth in the industrial exhibit area featured a display of hundreds of large (0.5 to 8 ct) De Beers synthetic yellow diamond crystals. According to a Drukker representative, De Beers Industrial Diamond Division sells thin slabs (about 1 mm) of such synthetic diamonds for use as heat dissipaters. However, some slabs had fairly large surface areas (about 1 cm on an edge).

During an enlightening lecture on the geologic origins of diamonds, Dr. Jeff Harris, of Glasgow University in Scotland, reported that recent inclusion research has proved that some diamonds may form at much greater depths than previously thought. Most diamonds are now believed to have formed at depths between 180 and 450 km, but some rare crystals might have grown at a depth of about 670 km.

More exploration in Tanzania. The Tanzanian government has signed a number of exploration agreements with private firms. One such agreement, between the Tanzanian Ministry of Energy and Minerals and the firm Reunion Mining, is for diamond exploration in the Lake Victoria region. There is also reportedly some interest in prospecting for gems in the Tabora region. (*Mining Journal,* July 31, 1992, p. 72)

Zimbabwe diamond find. Australia-based Auridiam Consolidated reports that three months of test work at its pilot processing plant in Zimbabwe has yielded 5,000 ct of diamonds, including one 17-ct cutting-quality stone. The ore from which these stones were processed was recovered from the firm's River Ranch concession, located near the Limpopo River in the south of the country. Plans call for the plant to begin processing 200,000 m³ of ore per year. (*Mining Journal,* October 2, 1992, p. 233)

COLORED STONES

Agate and amethyst from Uruguay. Although Brazil is well known as a source of many varieties of quartz, neighboring Uruguay also has large, commercial deposits of, specifically, agate and amethyst. These are found in the northernmost department of Artigas. According to the August 14, 1992,

Country Supplement to *Mining Journal* (p. 7), annual production is approximately 150 tons of agate and 80 tons of amethyst, with a significant amount of the latter being shipped to Germany.

Amber from the Dominican Republic and the Baltic region. At the June 1992 Vicenzaoro trade fair in Vicenza, Italy, two of the editors (EF and RCK) noted the large amount of fine-quality amber on display. One dealer, Dr. Salvatore Greco, devoted a significant portion of his display area exclusively to rare blue amber from the Dominican Republic. Strong luminescence to visible light is said to produce the blue appearance of this material.

Sarunas Davainis—representing the firms Galeria No. 44, Gdansk, Poland, and Amber Ltd., Vilnius, Lithuania—provided an update on the amber industry in the Baltic region. He estimated that this region—specifically, Lithuania, Russia, and Poland—produces approximately 10 metric tons annually. The different types of deposits require different mining methods. In Russia and Lithuania, the amber-containing strata lie beneath 25–40 m of overburden. Explosives used in the recovery process damage the amber, producing a yield in finished goods of only 7% to 10% by weight. In Poland, however, the amber is closer to the surface, under roughly 12 m of overburden. Here, miners use the "floating" method: They inject saline solutions into the soils, thereby drawing the amber toward the surface. Near the city of Gdansk, Poland, some—usually top quality—amber is still found along the coast. Mr. Davainis indicated that he is exploring the possibility of "pumping" amber directly from the seabed. In a first experiment in the summer of 1991, he recovered some 160 kg of amber from the submerged former shoreline.

Unusual aragonite. Pectolite from the Dominican Republic is a visually distinctive material; it typically has a greenish blue body color and displays finely fibrous spheroidal aggregates in cabochons and polished slabs (for more information, see Woodruff and Fritsch, "Blue Pectolite from the Dominican Republic," *Gems & Gemology,* Winter 1989, pp. 216–225). Until recently, the editors knew of only one material that might be confused with pectolite, an artificial glass marketed under the names: "Imori Stone" and "Victoria Stone."

At the February 1992 Tucson Show, the editors saw for the first time another gem material with a striking resemblance to some Dominican pectolite (figure 2). Marketed under the trade name "Victorite" (after Victor Herrera, a friend of the mine owner, according to Eugene Mueller of The Gem Shop, Cedarburg, Wisconsin), this material comes from a copper-mining area approximately 3,000 to 4,000 m above sea level in the Department of Moquegua of southern Peru. Recovery is primarily from small seams, although the material mined to date ranges from a few grams to over 1 kg.
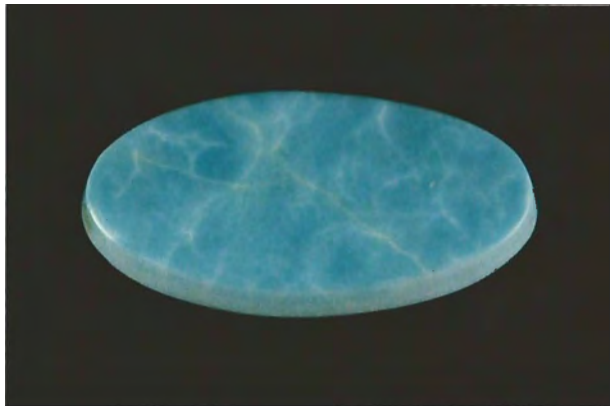
Figure 2. This 9.36-ct tablet (22.51 × 11.06 × 4.10 mm) is an impure form of aragonite from Peru. Photo by Maha Smith-DeMaggio.

We subsequently obtained three specimens of "Victorite," including a large unpolished piece donated by Mr. Mueller. Detailed testing on the 9.36-ct oval tablet shown in figure 2 revealed the following properties: color—variegated greenish blue and white; diaphaneity—semi-translucent; spot R.I.—1.52 to 1.66, with a strong "birefringence blink" indicating high birefringence (approximately 0.140). The material was inert to both long- and short-wave U.V. radiation, although two large fractures luminesced a weak, dull brownish orange. The tablet appeared green through the Chelsea color filter, showed no distinct absorption features when examined with a desk-model prism spectroscope, and had a specific gravity of 2.75, as determined by hydrostatic weighing. Magnification revealed a coarse microcrystalline structure.

Energy-dispersive X-ray fluorescence (EDXRF) analysis, performed by GIA Research, revealed the presence of calcium, copper, and strontium. X-ray powder diffraction analysis, carried out by Gus Calderon of the GIA Gem Trade Laboratory, produced a match with a standard pattern for aragonite. Although the S.G. is lower than that reported in the literature for aragonite (2.94+), the presence of impurities and/or cavities could account for the discrepancy.

On the basis of this information, the "Victorite" was identified as an impure form of aragonite. The blue coloration of this material (like blue pectolite) may also be due to copper. Although this aragonite may resemble pectolite, the much stronger birefringence of aragonite will easily separate the two. Note, too, that aragonite is not as durable as pectolite.

Color-change burbankite-related mineral from Mont St. Hilaire, Quebec. As reported in the Spring 1992 Gem News section, an unusual color-change gem, stated to be burbankite, was discovered in 1991 not far from Montreal at the Poudrette quarry, Mont St. Hilaire, province of Quebec,

Canada. Some good-size gem-quality crystals were found, and faceted stones as large as 6.62 ct have been cut. Burbankite [$(Na,Ca)_3(Sr,Ba,Ce)_3(CO_3)_5$] is a hexagonal carbonate.

Recently, the editors examined a 3.18-ct cut-corner rectangular modified brilliant faceted from this material, which was loaned to GIA by Art Grant of Martville, New York. This stone exhibited a color change from very slightly greenish yellow in fluorescent lighting to slightly yellowish orange in incandescent illumination (figure 3). Gemological properties were determined by Gus Calderon and Shane McClure of the GIA Gem Trade Laboratory (GIA-GTL). Refractive indices of 1.630 and 1.632 yielded a birefringence of only 0.002, which is exceptionally low for a carbonate and also quite different from the published values for burbankite of 1.615 and 1.627. The stone showed no significant pleochroism, and the optic figure was pseudo-uniaxial. The specific gravity, determined by averaging three hydrostatic measurements, was 3.53 (as compared to 3.50 for burbankite). Microscopic examination revealed several narrow parallel growth tubes across the width of the stone. This stone proved inert to both long- and short-wave U.V. radiation, and showed no reaction (i.e., appeared green) through the Chelsea color filter. A handheld-type prism spectroscope revealed total absorption up to about 420 nm, with several sharp bands characteristic of a rare-earth spectrum; the strongest features were at approximately 452, 514 (strong doublet), 522, and 575 nm (several strong lines coalesced together).

EDXRF analysis performed by GIA Research identified strontium and calcium as major elements, with minor sodium, potassium, lanthanum, and cerium. Neodymium was also detected in trace amounts. This represented a departure from typical burbankite chemistry. In particular, no barium was detected, although lanthanum, neodymium, and potassium were also found in the specimens used for the original description of burbankite (Pecora and Kerr, *American Mineralogist*, Vol. 38, 1952, pp. 1169–1183). Subsequent X-ray diffraction and microprobe analyses on reportedly identical material (but not on this specimen) at the Canadian Museum of Nature in Ottawa, Ontario, identified their material as remondite-(Ce), a new mineral related to burbankite (and first described by Cesbron, Gilles, Pelisson, and Saugues in 1988, with the crystal structure determined by Ginderow, 1989; see *American Mineralogist*, Vol. 75, No. 3–4, 1990, p. 433). On the basis of this information and what we gathered, we believe the cut stone we examined is also remondite-(Ce).

To understand the color-change behavior seen in this gem, we recorded its ultraviolet-visible transmission spectrum. This revealed sharp lines at approximately 444, 488, 510, 522, and 578 nm, plus others at 626, 678, 740, 800, and 874 nm, as well as a series of broader absorption bands in the near infrared. We attributed the cutoff toward the ultraviolet to absorption by cerium (Ce^{4+}) and the sharp bands to neodymium (Nd^{3+}). Our own research has shown that Nd^{3+} produces a moderate bluish purple to reddish

Figure 3. This 3.18-ct stone is believed to be remondite-(Ce), a new rare-earth carbonate related to burbankite. It exhibits a color change from slightly greenish yellow in daylight (left) to yellowish orange in incandescent light (right). Photo © GIA and Tino Hammid.

purple or purplish pink color change in YAG and cubic zirconia. Therefore, we believe that the color change in this sample is due to Nd^{3+}; the colors seen are different from those observed in YAG and cubic zirconia because of the influence of the Ce^{4+} absorption. Mr. Grant informed us that not all specimens of this material that he has cut exhibit color change. We speculate that those that do not have little or no neodymium.

Dumortierite-in-quartz beads. The vast majority of the gem materials fashioned into beads are polished to produce a vitreous luster. Occasionally, however, we see beads on which the surface has intentionally been left rough to give a dull finish. At the Vicenzaoro trade fair this past June, two of the editors (EF and RCK) noticed some interesting beads at the booth of Gaetano Bazzi from Faenza, Italy. These large beads—roughly 18 mm in diameter—exhibited a violetish blue body color with mottled black veining (figure 4). The material had been represented to Mr. Bazzi as dumortierite from South Africa.
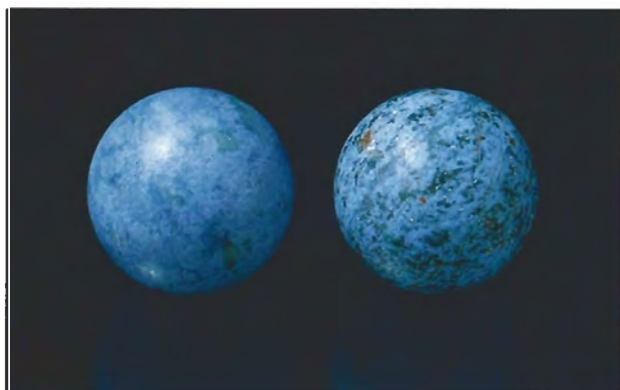
Two beads were donated to GIA for research. Subsequent testing revealed a vague spot R.I. of 1.55 and an S.G. of 2.95. The beads were inert to long-wave U.V. radiation, but the violetish blue areas luminesced a moderate, chalky whitish blue to short-wave U.V. (with the black areas remaining inert). Using a gemological microscope, we noted angular patches of a semitransparent, colorless mineral (probably quartz) interspersed with the violetish blue material. X-ray powder diffraction analysis produced a pattern matching a standard for dumortierite in quartz, that is, a superimposition of the patterns for both minerals.

Feldspar-and-amphibole gem from Egypt. The Sinai Peninsula of Egypt is well known as one of the earliest

sources of turquoise. In neighboring Israel, adjacent to the Sinai Peninsula, another semitranslucent to opaque, blue-to-green gem is found. Known in the trade as "Eilat stone," this mixture of chrysocolla and malachite, like turquoise, is colored by copper. It was thus with interest that in Cairo this past year, one of the editors (RCK) saw some unusual, mottled cabochons with major areas of greenish blue, similar to "Eilat stone." According to the vendor, small quantities of the material show up sporadically in the marketplace, having been collected by Bedouin tribespeople.

Two representative cabochons (a 7.05-ct pear shape and a 3.29-ct oval) were purchased and subsequently examined in detail. Both are semitranslucent and have a variegated, mottled appearance, with greenish blue and very dark green areas, the latter so dark in tone as to appear black in

Figure 4. These two rough-surfaced beads, approximately 18 mm in diameter, are dumortierite in quartz. Photo by Robert Weldon.

overhead illumination (see, e.g., figure 5). The greenish blue areas are highly fractured and veined; the dark green areas contain irregular inclusions with a metallic luster. We also noted small inclusions of a more saturated greenish blue color and lower diaphaneity, as well as areas of brownish red (limonitic?) staining.

Spot refractive-index determinations gave readings of 1.54. The stones appeared green through the Chelsea color filter. The more translucent areas fluoresced a faint yellowish green to long-wave U.V. radiation, but the stones were completely inert to short-wave U.V. Hydrostatic weighing produced specific-gravity values of 2.67 for the 7.05-ct pear-shaped cabochon and 2.74 for the 3.29-ct oval.

As the above data were inconclusive, X-ray powder diffraction analysis was performed on both the greenish blue and dark green areas. On the basis of the patterns produced, we determined that the greenish blue areas are a feldspar, whereas the dark green areas are an amphibole, although we could not determine the specific species. Therefore, we identified these stones as rocks consisting of feldspar and amphibole with possibly other, undetermined mineral components. EDXRF analysis revealed the presence of Al, Si, K, Ca, Ba, Mn, Fe, and Cu. We believe that the blue coloration is most likely due to the copper impurities.

Figure 5. Believed to be from the Sinai Peninsula of Egypt, this 7.05-ct cabochon consists primarily of greenish blue feldspar and an amphibole mineral. Photo by Maha Smith-DeMaggio.
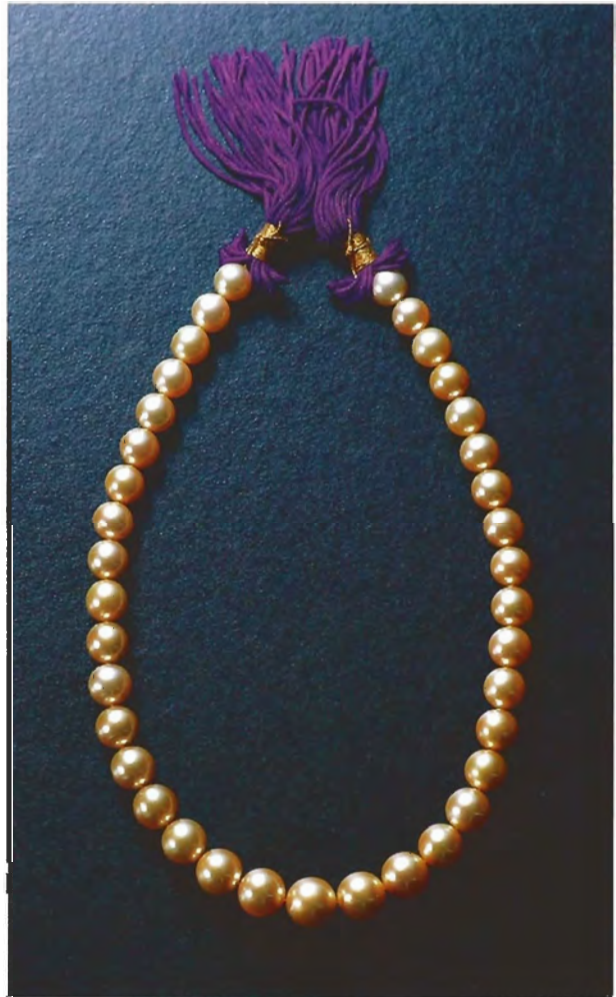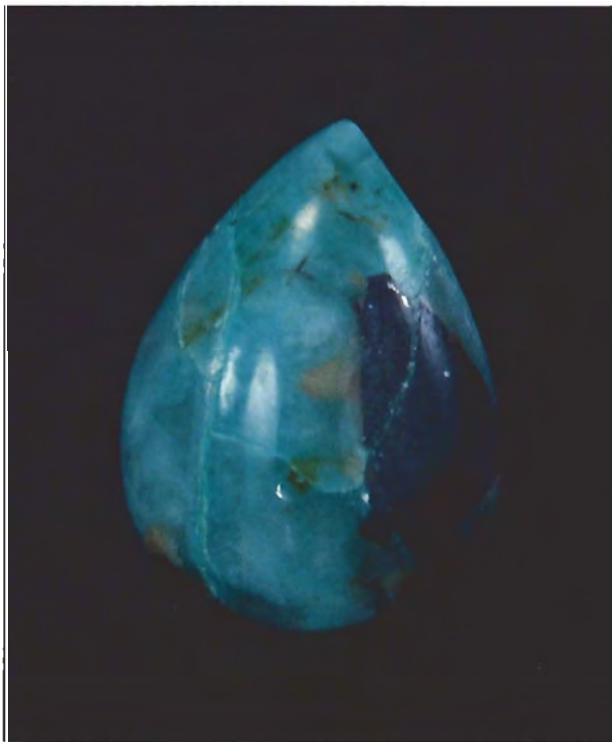

Figure 6. Okinawa is the reported source of this rare strand of 37 "golden" cultured South Sea pearls (11.2–14.1 mm in diameter), which are also notable for their high luster and absence of blemishes. Photo courtesy of René Hodel.

Update on golden cultured pearls. At the September 1992 Hong Kong Jewelry and Watch Fair, René Hodel of the firm Schoeffel in Hong Kong exhibited three strands of fine, rare "golden" cultured South Sea pearls, which ranged up to 18 mm in diameter (see, e.g., figure 6). Mr. Hodel reported that cultured South Sea pearls of this hue are actually accidents of the culturing process, representing a very small percentage of the harvest from the yellow- and white-lip oysters. According to Mr. Hodel, those with a "pure, dark gold" color are most valuable; any greenishness is considered detrimental.

The cultured pearls in these necklaces reportedly came from Okinawa, Japan. In the past, Burma (now Myanmar) was the principal source of golden cultured pearls. Today,

Figure 7. Small-scale mining operations continue in the Elahera gem field of Sri Lanka. This shallow circular pit is located along a tributary of the Mahaweli Ganga River. Photo by Shane F. McClure.

Indonesian pearl farms produce most of the golden cultured pearls in the marketplace, usually in sizes less than 15 mm in diameter. Top-quality larger (up to 18–19 mm) golden cultured pearls primarily come from Australia.

Sri Lanka: Current mining in Elahera. In August 1992, GIA-GTL's Shane McClure visited mining sites in Sri Lanka through the assistance of gem dealer M.H.S.M. Mahisukeen. One area visited was Elahera, in the center of this island nation (the subject of a Summer 1986 *Gems & Gemology* article by Gunawardene and Rupasinghe).

At the time of the visit, local inhabitants indicated that no large-scale mining had taken place for roughly four years. Individual miners, however, continue to operate in the area illegally and produce small quantities of sapphire, garnet, and various collector gems from the alluvial deposits. These operations are typically small pits dug into the banks of tributaries of the Mahaweli Ganga River (figure 7).

Sri Lanka: Update on gem production. Gordon Bleck of Radiance International, San Diego, California, has provided another update on gems and gem mining in Sri Lanka. He reports that a variety of factors have produced a general decline in gem production there. In the Okkampitiya area, one reason is the threat of terrorism by members of the Liberation Tigers of Tamil Elam. Also, this southeastern area of the country has been suffering through a drought so bad that drinking water has had to be trucked into some communities, so there has not been sufficient water to wash the gem gravels.

Good natural-color blue and yellow Sri Lankan sapphires are less plentiful than in previous years, although pink to purple sapphires appear to be slightly more available than in the past. Yellow sapphires of all qualities are reportedly being purchased in large quantities for heat or diffusion treatment. Mr. Bleck also noted the appearance on the market of a higher percentage of yellow sapphires that are unstable to daylight. Typically, sapphires turned yellow by exposure to X-rays fade to their original pale yellow or colorless state after a few hours in direct sunlight. Consequently, it is common practice for many buyers to expose yellow sapphires to daylight for one or two days prior to completing the purchase. According to Mr. Bleck, however, subjecting a sapphire to repeated irradiation and fading cycles may produce a color that will not discernibly fade for as long as 10 days in sunlight.

Similarly, some light pink sapphires are reportedly irradiated to produce a pinkish orange, "padparadscha" color. Because the yellow component of the color is unstable, the stones fade back to light pink after one to six hours' exposure to daylight. Therefore, it is strongly recommended that buyers expose "padparadscha" sapphires to direct sunlight for several hours to check color stability.

Some rare and unusual stones surfaced during the past year. One small pit in the Okkampitiya area has produced a surprising number of chatoyant kornerupines. Near Okkampitiya, in the small town of Passura, several chatoyant rutiles have been found. This material is very unusual (see also the entry in the Summer 1986 Gem Trade Lab Notes section, p. 111). Some of the almost two dozen cabo-

chons the editors examined (which ranged up to 3.5 ct) showed a very intense, sharp eye. Rutile from Karawita, near Ratnapura, has been faceted into small stones, in weights up to slightly over 1 ct. Most showed a very dark brown-red body color when illuminated with a strong light source, and were found (by EDXRF analysis in GIA Research) to contain impurities of iron, chromium, and niobium. One stone, however, a 1.08-ct oval shape, appeared dark violetish blue in the same lighting; it contained traces of niobium only, and displayed very strong electrical conductivity when tested with a gemological conductometer. Such conductivity behavior has been documented in blue synthetic rutile as due to a reduction of Ti^{4+} to Ti^{3+} (see, e.g., K. Nassau's *Gems Made by Man*, Chilton Book Co., Radnor, PA, 1980, p. 217). This reduction could have occurred in nature due to natural radiation, as many radioactive gemstones and other minerals are found in the same general area of Sri Lanka.

Mr. Bleck also showed us a remarkably large (114 ct; 38 × 28 × 12 mm), slightly waterworn twinned crystal of yellow chrysoberyl (figure 8). According to the State Gem Corporation, it is the largest chrysoberyl recovered from Sri Lanka in recent years.

A brownish yellow-green 3.71-ct oval chrysoberyl revealed some unusual properties. Most notable were the indices of refraction—1.763 and 1.777—which are significantly higher than the expected values of approximately 1.746 and 1.755. However, the stone's X-ray diffraction pattern matched GIA's standard pattern for chrysoberyl. Energy-dispersive X-ray fluorescence analysis identified traces of titanium and gallium, as well as a very intense signal for iron. This high iron concentration is probably the cause of the unusually high R.I.

Figure 8. This 114-ct twinned chrysoberyl crystal is reportedly the largest recovered in Sri Lanka in recent years. Photo by Maha Smith-DeMaggio.

Large taaffeite. At the September 1992 Hong Kong Jewelry and Watch Fair, one of the editors (EF) saw an exceptionally large taaffeite. The 33.33-ct oval mixed cut displayed numerous eye-visible included crystals that, from their morphology, were possibly apatite. Like many taaffeites that we have examined, this gem displayed a slight color change, appearing purple under fluorescent lighting and a more reddish purple under incandescent illumination.

New joint venture in Vietnam. A new joint-venture company, Vietnam Gems Technology Co. Ltd. (GemTec), has been formed to process and trade in rubies and other gems mined in Vietnam. The firm, formed between Australian businessman Raymond Eaton (chairman of the Bangkok-based Export Development Trading Corp.) and the Electronic and Optical Instruments Corp., a subsidiary of the National Center for Scientific Research, will buy, fashion, and market the rubies. To this end, a factory and trading house with a staff of 120, plus a small gemological laboratory, are to be set up in Hanoi.

Update on Vietnam gems. In November 1992, *Gems & Gemology* editor Alice S. Keller and one of the Gem News editors (RCK) visited a number of gem localities in Vietnam. The trip was arranged through Savitech, a joint-venture between FINGEMS (a Swiss firm) and the State Bank of Vietnam, to prepare an update to Kane et al.'s "Rubies and Fancy Sapphires from Vietnam" (*Gems & Gemology*, Fall 1991, pp. 136–155) with one of the coauthors of that article, Saverio Repetto. Following are some of the highlights of the new information they gathered.

Mining for rubies and pink sapphires has been reactivated and accelerated at the original Vietnamese source, Luc Yen, in Yen Bai Province. The largest operation, a joint venture between state-owned Vinagemco and the Thai firm B. H. Mining, is a heavily mechanized open-pit mine, with four electricity-powered water cannons and a six-jig sluice. Geologist Nguyen Duc Khai, senior expert with the Council of Ministers in Hanoi, explained that the joint venture has a 12-year lease to work the area, and plans to work five open-pit mines total, one after the other. The Vietnamese army is also involved in mining in the Luc Yen area. We saw only one "independent" (illicit) mining operation, but were told that most of the illegal operations in this area are conducted at night.

Mining has also accelerated greatly at Quy Chau and neighboring Quy Hop, in Nghe An Province. Four companies—three controlled by the provincial government and one by the national Ministry of Heavy Minerals (in conjunction with Thai investors)—are authorized to mine in the Quy Chau area. To date, all of the mining has been open pit, into the gem-bearing gravels. The operations range from some that are highly mechanized, using bulldozers, water cannons, and diesel-powered jigs (to separate the gems), to many that are simple hand digging, with miners using shovels to remove the overburden and baskets to wash the grav-

Figure 9. At Ba Dan, in Binh Thuan Province, hundreds of predominantly shallow pits have been dug to reach the sapphire-bearing gravels. Photo by Robert C. Kammerling.

els. We saw significantly more independent mining in the Quy Chau area than in Luc Yen, although both areas had a strong police presence. Prof. Dr. Phan Truong Thi, chairman of the Vietnam Mineralogical Association, reported that a "good" 54-ct ruby had recently been found at Quy Chau. Most of the stones we saw at Quy Chau were small and highly fractured, with the characteristic blue zones in the pink to red material. We also saw significant amounts of what appeared to be flame-fusion synthetic rubies in both Luc Yen and Quy Chau, primarily in the provincial capitals of Yen Bai and Vinh and at some of the mining areas in Quy Chau.

Although fine blue sapphires have been known to come from the marble-related deposits in the Luc Yen area, most of the blue sapphires currently mined in Vietnam originate from alkalic basalts in the south of the country, in Lam Dong, Dong Nai, and Binh Thuan Provinces. We visited two localities in Binh Thuan Province: Da Ban and Ma Lain. Both were crude open-pit operations, where the miners dug into the alluvium (often less than a meter) to reach the gem gravels, which were then washed in nearby artificial ponds. At Ba Dan, hundreds of predominantly shallow pits appeared to have literally chewed up an area at least hundreds of meters long (figure 9). Reportedly, there had been as many as 3,000 people working this deposit in recent months, but the number was greatly reduced by government efforts to control the area and eventually systematize the mining. We saw more activity at Ma Lain, where we were told that approximately 400 people were still working the region, with an average yield of 100 stones per day. Most of these pits, too, were shallow, but we saw some as deep as 3 m. For the most part, the sapphires we observed from both localities were very dark blue to bluish green; most of the potentially gem-quality rough crystals were small, less than

3 ct. Mr. Nguyen Xuan An, general director of Vinagemco, indicated that lighter blue sapphires had been found at Lien Dam, near Di Linh, in neighboring Lam Dong Province.

Green zoisite from Pakistan. Recently, the editors examined two remarkably well-formed transparent crystals of green zoisite provided by Larry C. Winn of AJS Enterprises in Wheat Ridge, Colorado. Of great interest was the fact that the crystals (100.5 and 9.6 ct; figure 10), reportedly came from Skardu, Pakistan. At approximately the same time, we were also given two crystal fragments of green zoisite by Pierre Bariand, curator of the Sorbonne mineral collection in Paris, France. These, too, reportedly came from central Asia, although the exact source (Afghanistan or Pakistan) is not known. EDXRF and ultraviolet-visible spectroscopy showed that all four specimens, although not identical in appearance, had very similar spectra, which suggests a common origin.

When gemologically compared to the green zoisite recently described from Merelani Hills, Tanzania (Barot and Boehm, *Gems & Gemology*, Spring 1992), these new green zoisites have a slightly higher refractive index at 1.700–1.706. In addition, they show relatively strong absorption lines in the hand spectroscope, at 433 and 460 nm, and distinct pleochroism in bluish green, brownish orange, and yellow.

The two crystals obtained from Mr. Winn are slightly tapered prisms. The color seen through the two flatter prism faces is a medium dark, slightly greenish blue, whereas that seen through the other two prism faces is a slightly orangy brown. In addition to the constituents of zoisite detected (calcium, aluminum, and silicon), EDXRF analysis revealed traces of titanium; small amounts of vanadium, chromium, and strontium; and a comparatively large amount of

Figure 10. These two green zoisite crystals (100.5 and 9.6 ct) are reportedly from Pakistan, a new source for this material. Courtesy of AJS Enterprises; photo by Shane F. McClure.

iron. This is a significant difference from Tanzanian green zoisite, which has essentially no, or negligible, iron.

Ultraviolet-visible spectra taken in the orangy brown direction showed two intense, sharp bands at about 390 and 452 nm, with accessory peaks at 359 and 427 nm. These are typical of Fe^{3+} in octahedral coordination. In conjunction with a general increase of the absorption from the red toward the ultraviolet, they produce the orangy brown color seen in that direction. We also noted a weak, broad band with an apparent maximum at about 590 nm, very similar in shape and position to that responsible for the blue color of tanzanite; this has been correlated to vanadium (present only as a trace element in these specimens). In the near-infrared portion of the spectrum, we observed a broad band centered at about 1150 nm. Spectra taken in the "green" direction showed the same sharp bands at about 390 and 452 nm; in this direction, however, they were accompanied by a complex broad band causing absorption between approximately 600 and 850 nm, and the band at about 1150 nm was not present. These sharp and broad absorption features are also typical of Fe^{3+}. The pleochroism of these specimens

appears to be very similar to that observed in crystals of mixed epidote and clinozoïsite from Gilgit, Pakistan (G. R. Rossman, pers. comm., 1992).

To our knowledge, green zoisite from Pakistan has not been reported previously.

ENHANCEMENTS

Filled diamonds marketed under new name. In the more than five years since the fracture filling of diamonds to enhance apparent clarity was first introduced in the trade, there has been considerable debate concerning proper nomenclature to describe diamonds that have been treated in this fashion. One of the newest twists to this issue of disclosure was just brought to our attention by a jeweler in Western Australia, who sent us a flier being used to promote such treated stones in Perth. According to this flier, "a diamond of a clarity of say Piqué 1 or 2 can be enhanced to become a *Genesis II Diamond* [editors' emphasis] of at least S1 [sic] or VS clarity." Referring to such treated diamonds by this name, without also clearly indicating that they are treated stones, could easily result in confusion in the marketplace.

Fracture filling of rough diamonds reported. *Diamond Intelligence Briefs* (September 24, 1992, p. 926) has warned that rough diamonds apparently are being clarity enhanced and then shipped to one or more African nations for marketing. These efforts appear to be aimed at defrauding subsequent purchasers of the stones.

As pointed out in ICA Laboratory Alert No. 52 and in a follow-up entry in the Fall 1992 Gem Trade Lab Notes section of *Gems & Gemology*, this enhancement cannot withstand the heat generated in cutting and polishing. Such deceptive treatment of rough would therefore certainly be discovered on the cutting wheel. Those who buy rough diamonds outside established channels are advised to check their stones carefully for evidence of fracture filling, such as the flash effect, trapped bubbles, or flow structure seen with magnification (see, e.g., Koivula et al., "The characteristics and identification of filled diamonds," *Gems & Gemology*, Summer 1989, pp. 68–83).

More on irradiated "black" diamonds. The Summer 1992 Lab Notes section included an entry on a green irradiated diamond with a color so dark that the stone appeared black to the unaided eye. In the trade, such stones are often described as black.

At the Vicenzaoro trade fair in Vicenza, Italy, this past June, one of the editors (EF) was shown several such "black" diamonds by Eddy Vleeschdrager, a cutter from Antwerp. Although Mr. Vleeschdrager indicated that these stones were not radioactive, he confirmed that similarly treated stones that were radioactive had recently been seen in Antwerp and Germany. According to Mr. Vleeschdrager, radioactivity was no longer present in the stones seen in Germany after they were subjected to prolonged boiling in

acid. This would indicate that the radioactivity was related to metallic polishing residues that had collected in the numerous surface-reaching fractures in these low-clarity stones. Irradiation in a nuclear reactor apparently produced radionuclides in these polishing residues. Acid boiling the stones (to remove the residues) before they are submitted for irradiation would appear to solve this problem in the future.

Interesting treated ornamental sandstone. On a recent trip to Asia, Ms. Eddie Decsi, of GIA Education, visited a factory in the town of Hualien, on the east coast of Taiwan. Hualien is a center for fashioning ornamental gem materials, especially marble, which is mined locally. In addition to marble, Ms. Decsi saw an attractive ornamental sandstone that was being fashioned into objects such as small teapots. Whereas some of the objects were marketed in their natural, light to medium brown color, others were treated to produce darker tones. The editors found it interesting that the "dye" used on these teapots was *tea:* The fashioned items were boiled in tea until the desired depth of color was obtained.

Ms. Decsi purchased one of these "dyed" teapots and provided it to the editors for examination (figure 11). Although no dye appeared on an acetone-dipped cotton swab when it was rubbed on an inconspicuous part of the carving, similar testing with dilute (2%) nitric acid produced a tell-tale discoloration on the swab.

SYNTHETICS AND SIMULANTS

Update on crystal growth. In August 1992, one of the editors (EF) attended the tenth International Conference on Crystal Growth in San Diego, California. Presented at this conference were advances in crystal-growth techniques as well as descriptions of new synthetic materials.

Most of the crystal-growth research of potential relevance to the gem industry is being conducted in the fields of laser and optical materials. Very few such materials are still grown using a classic flux technique or hydrothermal method (a major exception to the latter is hydrothermal synthetic quartz). Instead, most such crystals are being grown by pulling techniques, such as the Czochralski method, which is already well established for the production of such materials as synthetic corundum and yttrium aluminum garnet (YAG), as well as other so-called synthetic "garnets."

In the past, such methods required that the material melt congruently, that is, that the composition of the crystal formed by freezing must be identical to that of the melt. As this technique reached its maturity, new pulling techniques were developed that are now commonly used. In one such method, the composition of the melt is constantly adjusted by the addition of raw materials during growth. This has led to the production, for example, of fluoride crystals over 100 kg, a size that would be impossible with the classic Czochralski pulling method. Another technique,

Figure 11. Tea was used to color enhance this sandstone teapot (14.7 × 9.2 × 6.8 cm). Photo by Maha Smith-DeMaggio.

called top-seeded solution growth, combines flux and pulling methods. A seed starts to grow in a solution (typically referred to in gemology as a flux), and then is slowly pulled up during growth. The thermal geometry of this arrangement will allow for controlled nucleation and ensure the growth of a single, larger crystal than would be possible with either method alone.

New types of crystals being developed are yttrium silicates (Y_2SiO_5, see entry below) and yttrium vanadates (YVO_4), as well as various types of apatite for laser applications. Colorful, rare-earth aluminates with perovskite structures, such as $LaAlO_3$, are also being grown for use as superconductor substrates. Neodymium (as Nd^{3+}) already has been reported to cause a pink-purple color change in materials such as YAG (Gem News, Spring 1992, p. 66) and cubic zirconia. Now, neodymium is being incorporated into a variety of color-change synthetic apatites, including fluorapatite and silicate-oxyapatites. A neodymium-doped fluorapatite grown by Dr. Bruce Chai, of the University of Central Florida Center for Research in Electro Optics and Lasers, exhibited a distinct color change, from blue in fluorescent lighting to violet in daylight and purple in incandescent illumination. EDXRF analysis by GIA Research revealed strontium as a constituent in the crystal.

Union Carbide, a well-known synthetics manufacturer, has shown interest in producing various crystals by the Czochralski method for the gem industry. Dr. Milan Kokta, from the firm's Washougal, Washington, facility, showed the editor a variety of corundum crystals doped with iron-titanium or cobalt (blue) and titanium (pink), as well as complex synthetic garnets with a beautiful green color. These crystals are grown specifically for the jewelry industry: Several nuances of blue color in synthetic corundum have been produced in response to market demands.

Attractive "gem construct." The term *assembled stone* is used in the trade to describe gems that have two or more
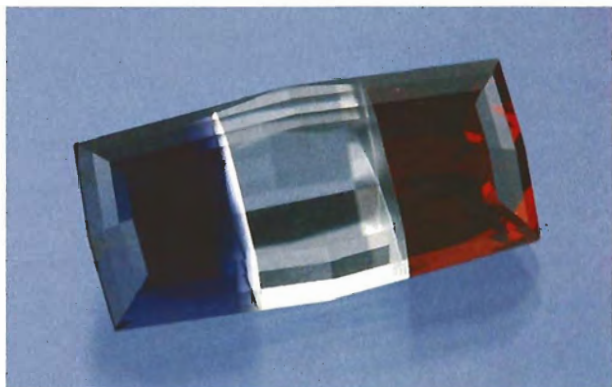
Figure 12. This 16.31-ct gem construct (22.26 × 10.65 × 7.32 mm) is composed of sections of rhodolite garnet, colorless topaz, and iolite. Photo by Maha Smith-DeMaggio.

components. Two pieces of material joined by a colorless cement are commonly referred to as *doublets*, whereas the term *triplet* is used to describe assemblages of three materials (or two sections joined by a colored cement, such as synthetic spinel triplets).

For the most part, assembled stones are produced either to imitate other gems or, as in the case of opal doublets and triplets, to use thin sections of a gem material that alone would lack sufficient durability for jewelry. In both cases, it is desirable that the assembled nature of the piece not be apparent. There is, however, another type of assembled stone that is less commonly seen in the trade, one that is constructed to accentuate the unique visual features of the components. One producer, Sid Berman, refers to these assembled stones as "gem constructs."

An attractive 16.31-ct "gem construct" was donated to GIA from the Josephine L. Scripps gem and mineral collection. The stone, which arrived in a container marked "Rhodiolopaz," has distinct dark purplish red, colorless, and dark violet sections of approximately equal size (figure 12). Gemological testing indicated that the name was not inappropriate, as the components were identified as rhodolite garnet, iolite, and colorless topaz.

Extremely small synthetic melee. In June 1992, at a trade show in Vicenza, Italy, two of the editors (EF and RCK) spoke with Mario Tiedemann, marketing director of Durafourg, a major producer and manufacturer of melt-grown synthetic gem materials that is based in Lausanne, Switzerland. Mr. Tiedemann noted that his firm produces large quantities of flame-fusion synthetic corundum and synthetic spinel each month, as well as very large quantities of cubic zirconia. Of particular interest is the small size of some of the stones fashioned in their cutting facilities. We were shown faceted CZs that weighed approximately 0.002 ct each, that is, almost 500 stones per carat.

Synthetics preset in findings by "automation." Also at the Vicenza trade show, we visited the booth of Bifra, a Vicenza-based firm that markets synthetic gem materials preset in various types of gold findings. The firm's Mr. David indicated that the findings with prong-set stones can be produced using virtually any stone shape and that the bezel-set stones include rounds, ovals, squares, and marquises.

Mr. David reported that the setting process is fully automated, with the findings machined from small blocks of gold rather than from gold tubes. About 3,000 pieces are produced per day. We were told that the product is particularly popular in Japan, which has high labor costs: Rather than set the stones individually, the jewelry manufacturer simply solders the gem-set finding onto the piece of jewelry being produced.

Large hydrothermal synthetic ruby. One of the most striking synthetic gem materials displayed at the International Conference on Crystal Growth (see summary entry above) was a 386-g (1,930-ct) hydrothermally grown synthetic ruby crystal (figure 13). This and smaller crystals, all exhibited by Dr. Roch Monchamp of Goleta, California, were grown about 1966, when synthetic ruby was the foremost laser material and the subject of much research. This large crystal, possibly the largest hydrothemal synthetic ruby ever produced, represents a failed attempt to synthesize a one-pound (2,268 ct) ruby.

According to Dr. Monchamp, the crystal was grown-with the necessary ruby constituents in a concentrated potassium-carbonate solution in a silver-lined vessel, at a pressure of 20,000 psi and a temperature of 540°C. Veils of fluid inclusions throughout the crystal are quite apparent to the unaided eye and form a roughly hexagonal honeycomb-

Figure 13. The hydrothermal method was used to synthesize this extremely large (1,930 ct; 95.30 × 55.05 × 19.78 mm) ruby crystal in the mid-1960s. Courtesy of Dr. Roch Monchamp; photo by Shane F. McClure.

like structure. Dr. Monchamp indicated that these veils and the corresponding structure (which the editors have seen in other pink-to-red synthetic corundum crystals produced around the same time) are typical of the rapid growth conditions. Although smaller crystals were grown with fewer such inclusions, these crystals tended to develop color banding due to uneven chromium distribution.

This large synthetic ruby crystal was subsequently loaned to GIA for characterization. The gemological properties were generally typical of synthetic ruby: R.I.—1.760–1.768; birefringence—0.008; red appearance through the Chelsea color filter; and an absorption spectrum typical of ruby, both natural and synthetic. When exposed to long-wave U.V. radiation, the crystal luminesced a very strong orangy red; the reaction to short-wave U.V. was a moderate purplish pink with a whitish surface luminescence. It was interesting to note that the fluid-filled cavities luminesced a moderate greenish yellow to long-wave U.V. and a weak greenish yellow to short-wave U.V.

Chemical analysis by EDXRF found (in addition to aluminum and chromium) impurities of iron, potassium, titanium, copper, and traces of chlorine, calcium, and arsenic. Quantitative measurements revealed approximately 0.04 wt.% Cr_2O_3 and roughly 0.01 wt.% each of TiO_2 and FeO.

Assembled imitation watermelon tourmaline. Recent Gem News entries have described a number of novel tourmaline imitations, including a glass imitation of indicolite (Summer 1992), a glass composite resembling watermelon tourmaline (Fall 1992), and a tourmaline-glass assemblage (also Fall 1992).

Bill Larson of Pala International, Fallbrook, California, has since brought to our attention the most complex tourmaline imitation we have seen to date. The large (667.74 ct; 65.3 × 42.2 × 37.7 cm) "crystal" section superficially resembled the watermelon variety (figure 14).

Detailed examination, however, revealed that the specimen was actually a complex assemblage. The outermost layer consisted primarily of a veneer of long, narrow slices of a gem material—two of which were dark blue, while the others were dark yellowish green. All of the slices appeared finely striated parallel to the length of the "crystal." Although the striations made refractometer testing very difficult, a spot R.I. reading taken on one yellowish green section produced a value of 1.63 and a weak "birefringence blink." Examination with a desk-model prism spectroscope revealed a very weak absorption line at 460 nm. Magnification showed that these outermost sections contain fluid inclusions and internal fractures running parallel to their length.

The next layer, which was semitranslucent, appeared to be an assemblage of very small mineral fragments (including, perhaps, colorless quartz and mica?) held together by a

Figure 14. This 667.74-ct imitation watermelon tourmaline "crystal" specimen is actually a complex assembly of several materials. Photo by Maha Smith-DeMaggio.

transparent, colorless cementing agent that contains numerous gas bubbles. The large transparent core of the specimen at first appeared to be pink. However, illumination with a fiber-optic light pipe revealed that it was actually colorless with a dark pink surface coating. The colored coating was clearly visible in areas near either end of the specimen, where the ground-matter-and-cement layer failed to completely cover the core. Polariscope testing showed this innermost section to be doubly refractive, and microscopic examination revealed what appeared to be fluid inclusions. X-ray powder diffraction analysis conclusively identified the core as quartz.

On the basis of these tests, we determined that the specimen was actually a complex assemblage that consisted of, from core to periphery: a large section of rock crystal quartz, a coating of dark pink coloring agent, and a layer of mineral fragments in cement—all housed within slices of tourmaline.

GEMOLOGICAL ABSTRACTS

Dona M. Dirlam, Editor

COLORED STONES AND ORGANIC MATERIALS

Taaffeite crystals. A. R. Kampf, *Mineralogical Record*, Vol. 22, No. 5, 1991, pp. 343–347.

This in-depth study clarifies long-standing errors in the original description of taaffeite crystal morphology. Several taaffeite (pronounced "tarfite") crystals were analyzed and crystallometrically measured by contact and reflected-light goniometry. Idealized orthographic projections (two-dimensional graphic representations) of a crystal from Sri Lanka and another from China show crystal form and indices for the crystal faces. Taaffeite crystals are generally pyramidal or bipyramidal and are often truncated by basal pedia (crystal forms with only a single face). Although cleavage has not been previously reported for taaffeite, planar features on three of the Sri Lankan crystals studied indicate a {0001} cleavage that tends to degenerate to conchoidal fractures. The bipyramidal crystals from China may be twinned by reflection on {0001}. Two diagrams, two tables, and six color photographs accompany the text. *LBL*

DIAMONDS

Cheap cut diamonds from Yakutia (in Russian). S. Agafonov, *Izvestiya*, July 29, 1992, p. 5.

Yakutia, formerly the province of Yakutsk and now an autonomous republic known in the Yakut dialect as Sakha, is the major diamond-producing region in the Russian Federation. This report, from the Moscow edition of the *Izvestiya* newspaper, disclosed that a Japanese company called Arda has signed a joint-venture agreement with the republic of Sakha to purchase cut diamonds. In the first phase, already under way, Sakha will provide Arda with 50,000 to 100,000 ct annually.

The article also notes that only the Diamond Fund of the Russian Federation (formerly the Soviet Diamond Fund) can block the joint venture and, according to Agafonov, Sakha effectively controls the Diamond Fund. Moreover, Sakha reportedly exercised "diamond autonomy" from the

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fund at an amount of 20% of total extraction by March of this year, which indicates that the Sakha-Arda joint venture will likely proceed as planned.

James Marker and Shane DeBeer

Court sides with miners at Crater of Diamonds. R. Shor, *Jewelers' Circular-Keystone*, Vol. 163, No. 10, October 1992, pp. 68–69.

In spite of opposition from environmentalists, Continental Diamonds of Canada, a consortium representing four mining companies, has won the right to take samples of the diamond-bearing pipe in Arkansas's Crater of Diamonds State Park. The tests were extended to determine the full size of the diamond-bearing pipe. Test drilling in 1940 indicated that the diamond-bearing material went as deep as 250 ft. (about 80 m), but new tests have shown the diamond deposits to be as deep as 600 ft. and to cover a wider area than previously believed. Once these recent results have been evaluated, the parties involved will decide whether to proceed to phase 2, testing to determine if there is an economic supply of gem-quality diamonds, which could take an additional year. Richard Davies, executive director of the Arkansas Parks and Recreation Commission, says the Crater of Diamonds is unique among diamond localities because it is composed of a "hybrid" of kimberlite and lamproite minerals. (African and Russian diamond pipes occur in kimberlite, whereas Australia's Argyle deposit occurs in lamproite.) The author concludes with a short discussion on the potential for a viable diamond mine in the Lac de Gras region of the Northern Territories of Canada.   *KBS*

Famous diamonds of the world XLVI: Some notable diamonds in 1990. I. Balfour, *Indiaqua Annual 1991*, Vol. 55, pp. 251–254.

Ian Balfour highlights notable diamonds of 1990, especially those offered at auction in 1990, including several fancy-colored stones and a number of large ones.

Balfour begins with a 20.62-ct lozenge-shaped fancy pink diamond that was auctioned by Sotheby's in February 1990 at St. Moritz. Unfortunately, he does not give a sale price.

Another diamond, the Moon of Baroda, sold at Christie's in New York two months later for US$297,000, more than double its pre-sale estimate of $120,000. Mr. Balfour questions the credibility of a "peculiar" story in Christie's sale catalog about the 24-ct, light yellow pear shape and gives his version of the recent history of this exotic diamond.

The Agra, a 32.24-ct fancy light pink diamond, sold at Christie's June 1990 auction in London. Mr. Balfour briefly outlines the history of this infamous stone, offering new information that did not appear in his book, *Famous Diamonds*. It was purchased by the CIBA Corporation in Hong Kong for £4,070,000.

Not offered at auction, but an "important newcomer," is the Guinea Star. In 1990, the William Goldberg Corp.

in New York unveiled the 89.01-ct shield-shaped gem [illustrated on the cover of the Spring 1991 issue of *Gems & Gemology*] and its two satellite stones. All three were fashioned from a rough stone that weighed 255.61 ct.

Juli L. Cook

The lure of diamonds. J. Contreras, *Newsweek*, November 9, 1992, pp. 34–35.

Contreras reports on the widespread illegal mining, trading, and selling of diamonds in northern Angola's Lunda Norte Province. The diamonds are recovered from gravels in open pits by local *garimpeiros* (independent miners) along the Cuango River near Cafunfo. These diamonds are then taken to Luanda, Angola's capital, and smuggled to Belgium—where De Beers could spend an estimated $300 million in 1992 to buy them so they do not flood the market.

In May 1991, the Angolan government signed a peace treaty with the UNITA guerrillas, ending 16 years of civil war. Until the signing, diamond mining in Lunda Norte had been strictly regulated. It was illegal to dig for diamonds on land belonging to Endiama, the state-owned corporation holding title to the Cuango River basin. Once the cease-fire was in place, illegal prospectors took over the basin. The value of stones smuggled out of the region this year is expected to surpass that of Angola's official diamond exports of $200 million.

De Beers is concerned that these black-market diamonds could affect the already soft diamond market, in which they control 80% of the rough. In addition to demanding that the Angolan government "crack down" on illegal trafficking, they gave the government $200,000 to help finance a "dragnet" operation that was carried out in June. However, because there was no follow-up, the trafficking resumed, reportedly dominated by French-speaking Zaireans.

RT

Prospects for new applications of diamond. B. L. Jones, *Industrial Diamond Review*, Vol. 52, No. 551, April 1992, pp. 175–179.

It is well known that diamond has numerous highly desirable physical properties, such as high thermal conductivity, low thermal expansion coefficient, low coefficient of friction, high hardness, high transparency in the visible and infrared portion of the spectrum, high refractive index, and chemical and radiation inertness. Because of the uniqueness of natural diamonds and the high cost of large high-temperature, high-pressure synthetic diamonds, the industrial applications of diamond so far have been largely limited to abrasive grits and cutting tools.

Recent developments in low-pressure diamond synthesis have led to products that duplicate several remarkable properties of natural diamond. For example, type Ib synthetic diamond absorbs more light as its temperature increas-

es. This, along with its chemical and radiation inertness, makes it useful as a thermal probe in adverse environments. Synthetic diamond crystals can also be used as radiation detectors. Because diamond is made of carbon atoms, its response to radiation is roughly equivalent to that of human tissue. Because of its unique electronic properties, it offers considerable sensitivity, range, and linearity. Other applications can be found in cutting tools, pressure sensors, optical windows, luminescent display devices, micromachine elements, and high-density, high-power electronic devices. Although only a few of these applications are of direct interest to the jeweler-gemologist, the fact that they stimulate greater interest in the methods of diamond manufacture could have a significant impact on the gem industry at large. *EF*

An X-ray study of some Argyle diamonds. S. Clackson and M. Moore, *Industrial Diamond Review*, Vol. 52, No. 551, April 1992, pp. 192–194.

The Argyle mine in Western Australia produces one-third of the world's output of natural diamond (although only a small portion is gem quality). A "run of mine," or unsorted batch, of 158 millimeter–size diamond crystals from this locality were studied. Most of the crystals were irregularly shaped or octahedral, with a small percentage of macles, dodecahedra, and tetrahedra. Gray and brown were the dominant colors, with a small number of pinks. Black inclusions were present in over 70% of the stones, and hexagonal pits were common on the crystal surfaces. Synchrotron Laue photography was used to characterize the crystalline quality of all the samples. Nearly all had a mosaic structure; that is, the crystal was composed of many misoriented constituent crystallites. The degree of mosaicity and the proportion of stones exhibiting these features is higher for Argyle diamonds than for specimens from three of the major South African mines. This physical imperfection may explain the high wear resistance of Argyle diamonds in industrial applications and the difficulty encountered in polishing them. *EF*

GEM LOCALITIES

L'aigue-marine au Brésil: 2. Les gîtes primaires (Aquamarine in Brazil: 2. Primary deposits). J.-P. Cassedanne and J.-N. Alves, *Revue de Gemmologie a.f.g.*, No. 111, June 1992, pp. 11–14.

According to the authors, aquamarine is probably the colored gem material that has contributed most to the fame of Brazil as a gem-producing country. In Brazil, all primary deposits of beryl (excluding emerald) are pegmatites. Although beryl is common in Brazilian pegmatites, gem-quality aquamarine is not.

Most aquamarine pegmatites are found in the Oriental

pegmatite province, which incorporates parts of the states of Bahia, Minas Gerais, and Espirito Santo, although a few are from the Nordeste and Borborema fields in other parts of the country. They are all granitoid pegmatites, and are usually found in granitic batholiths or inselbergs.

In the authors' experience, Brazilian aquamarine pegmatites can be roughly divided into three classes: simple, intermediate, and complex. The "simple" type is common in the Nordeste fields and contains beryl "eyes" (an "eye" is a gemmy nodule in an otherwise nongem crystal). The "intermediate" and "complex" types have an increasingly complex mineralogy and history and are most common in the Oriental fields. The authors give many examples to illustrate the various categories and the properties of the pegmatites described. They identify the Brazilian aquamarine deposits as primarily of the zoned to (slightly) complex type, and from moderate to shallow in depth (emplacement ranging from 1.5 to 5 km).

Although crystallization of a pegmatite is a complex process, the most important part is the separation of the aqueous fluids, rich in rare and volatile elements, from the magma when temperatures cool to 650°–750°C. At about 550°C, the magma crystallizes completely and geodes start to form. Aquamarine crystals generally grow at this stage. *EF*

L'aigue-marine au Brésil: 2. Les gîtes primaires [suite] (Aquamarine in Brazil: 2. Primary deposits [continuation]). J.-P. Cassedanne and J.-N. Alves, *Revue de Gemmologie a.f.g.*, No. 112, September 1992, pp. 7–11.

In this second article, Cassedanne and Alves describe the prospecting, mining, and geochemistry of Brazilian aquamarine pegmatites, based on extensive personal experience and bibliographic research.

There is little true prospecting for aquamarine deposits in Brazil; they are usually found by chance. Nevertheless, the authors propose a number of prospecting guides based on, for example, the type of pegmatite and the accessory minerals in it. However, these guides can only assess the probability that aquamarine is present, not the quality of the material or its economic potential.

Mining in Brazil is still rudimentary and erratic. Although some operations are mechanized, most are very inefficient. Sorting is always done by hand. The authors estimate that only 30%–40% of the aquamarines mined in Brazil are from primary—pegmatitic—environments.

Of the various types of pegmatites defined by different authors, aquamarine pegmatites correspond best to A. E. Fersman's type 4, with "fluorite, beryl and amazonite, smoky quartz and some albite, traces of lepidolite and no gem tourmalines." The formation temperature is about 550°C. There is sometimes a local or regional zonation of aquamarine pegmatites. The associated granites range in

age from 510 My in the Araçuaí region to 650 My in the Conselheiro Peña region. *EF*

The cornflower-blue sapphires of Kashmir. Extract from a talk given by Dean S. M. Field before the Canadian Gemmological Association, Toronto, April 1991, *Canadian Gemmologist*, Vol. 13, No. 2, 1992, p. 55–58.

This informative paper describes the history of the Kashmir sapphire mines and their effect on the gem and jewelry industries.

The first Kashmir sapphires were discovered accidentally in 1881 by local villagers sifting through rubble deposited by an earthquake-generated landslide. Completely unaware of the potential worth of their find, at first the villagers played with the bright blue crystals or traded them for an equal amount of "much-treasured" borax or salt!

Later, after depleting the original supply, villagers and nomads traced the sapphire to an altered pegmatite 50–100 m above the valley floor. Although the host rock proved friable, so much so that crystals could be removed by hand or with only crude tools, mining was an exhausting chore in the thin air at almost 14,000 ft. (4,267 m).

Eventually, the Maharaja of Kashmir learned that the blue stones were sapphires more beautiful than any in his collection, and he seized the mines. "No doubt he consoled the workers with a few bags of salt," comments Field. The "old mines," as they were called, were soon worked out, as were a few nearby deposits. By 1981, there was virtually no commercial sapphire production in Kashmir.

Field intersperses history of the mines with descriptions of sapphires in general and of the cornflower-blue stones in particular, including the O'Dunne sapphire. Currently owned and exhibited by the Canadian Museum of Nature in Ottawa, it is cited as an example of a Kashmir stone thought to be from the original mine. This approximately 17-ct rounded cushion-shaped cabochon, which once belonged to a granddaughter of Queen Victoria, was donated to the Smithsonian Institution in 1973 by Mrs. Eugene O'Dunne. It was subsequently traded to the W. Pinch collection, which the Canadian museum acquired between 1987 and 1990. *JEC*

A report of a recent visit to the diamond deposits in Liaoning Province, People's Republic of China (in Japanese). I. Sunagawa, *Journal of the Gemmological Society of Japan*, Vol. 15, No. 1–4, 1990, pp. 37–45.

Author I. Sunagawa describes his visits to several areas in the northeast China province of Liaoning, where diamond-bearing kimberlite pipes have been found. The eight-day excursion was organized by the International Mineralogical Association as part of its 15th general meeting, held in June–July 1990. The author discusses the geology and mineralo-gy of these diamondiferous pipes, only a few of the more than 100 kimberlite pipes found in northeast China since 1974. Many contain enough diamonds to make mining economically feasible. A pipe in Jingangshi was being actively mined at the time of the visit; mining and processing are described. *Masao Miki*

INSTRUMENTS AND TECHNIQUES

Investigation for the discrimination between elephant tusks and mammoth tusks by ICP emission spectrometry and X-ray fluorescence spectrometry (in Japanese). S. Sato, N. Horiuchi, M. Yamazaki, and Y. Nishida, *Journal of the Gemmological Society of Japan*, Vol. 16, No. 1–2, 1991, pp. 35–43.

Ecological concerns have resulted in a ban on the use of elephant tusks and created a need for a substitute. One response has been the appearance on the market of mammoth, or "fossilized," ivory. Elephant ivory and mammoth ivory are very similar in structure. Because both exhibit engine-turning, the feature used to separate ivory from its simulants, it was necessary to find a more sophisticated technique to separate these two ivories.

By examining 12 elephant and 16 mammoth tusks, the authors found that they could distinguish between the two types by using inductively coupled plasma atomic emission spectroscopy (ICP-AES) to determine weight ratios of strontium (Sr) to calcium (Ca). Although the two materials are similar in composition, the Sr to Ca weight ratio in mammoth tusks is 0.4–1.1 $(\times 10^{-3})$ as compared to 0.8–4.0 $(\times 10^{-3})$ in elephant tusks.

The authors also discuss a simpler method to differentiate the two ivories: by measuring the peak-intensity ratio of Sr to Ca by X-ray fluorescence spectrometry (XRFS). They then describe the relationships between the weight ratios obtained by ICP-AES and the peak-intensity ratios obtained by XRFS. *Masao Miki*

Essais de datation et détermination de l'origine des émeraudes par la méthode rubidium-strontium (Emerald age and origin determination using the rubidium-strontium method). Ph. Vidal, R. Lasnier, and J.-P. Poirot, *Revue de Gemmologie a.f.g.*, No. 110, March 1992, pp. 70–71.

This article reports on the application of a classic age-dating technique to key problems in emerald identification—the separation of natural from synthetic stones, and the confirmation of geographic origin. The method, called isotopic geochronology, determines the age of a mineral based on analysis of traces of rubidium (Rb) and strontium (Sr). Although this technique is destructive, because it requires a few hundredths of a carat of the material in question, it could still be useful on rough emerald or to test large lots of faceted stones, where a small part could be sacrificed with-

out jeopardizing the value of the whole. The authors describe details of the technique and provide results for 20 gems (17 natural and three synthetic).

Some of the accompanying minerals show that emeralds can be divided into three different groups. Precambrian emeralds (Brazil, Zambia, Madagascar) are extraordinarily enriched with radiogenic strontium; estimated ages range from roughly 500 to 2,500 My. Mesozoic and Cenozoic emeralds (Colombia, Pakistan, Afghanistan) show little enrichment in radiogenic strontium. Because of uncertainties introduced in the measurement by these small concentration values, the ages of these stones cannot be reliably determined. Synthetic emeralds show very low concentrations of both strontium and rubidium, and geochemical characteristics that are very different from natural emeralds. In one Zambian emerald, Rb and Sr were actually in the emerald lattice, and not in its inclusions.   *EF*

Guided light. K. Nassau, *Lapidary Journal*, Vol. 46, No. 6, September 1992, pp. 61–66.

Guided light is light directed and controlled by means such as lenses, mirrors, or reflections. Light guiding also occurs in a faceted gemstone. In this article, Dr. Nassau clearly and thoroughly explains the concept of "total internal reflection" and its practical applications. In addition, he offers a technical note to help interested readers understand the mathematical relationship between Snell's law of refraction and the critical angle.

Dr. Nassau also describes how the above principles have been used in the development of fiber-optic technology. One jeweler-specific application discussed is a patented fiber-optic illumination system for jewelry display cases. The primary advantage of this system is the ability to direct high-intensity illumination on multiple objects without significantly increasing temperature in the jewelry case.
Gustave P. Calderon

Laser tomographic observations of heat-treated sapphire from Sri Lanka (in Japanese). J. Shida, *Journal of the Gemmological Society of Japan*, Vol. 15, No. 1–4, 1990, pp. 22–27.

Heat treatment of sapphire to enhance body color is a widely known process. However, there have been a number of reports concerning cracks observed in heat-treated stones during the final plating of finished jewelry. Laser tomography reveals distinctive patterns in heat-treated corundum from Sri Lanka. Common characteristics include an unnatural scattering pattern of inclusions, high-relief fluorescence patterns, and a spiky or triangular pattern caused by structural stress. Scattering and fluorescence patterns were also observed in naturally colored stones, but the heat-treated stones exhibited greater transformation in crystal structure, with high-relief patterns typical. Shifting and movement

of the inclusions as a result of heat treatment also contributes to the structural transitions. Differences in pressure and temperature of treatment will result in a variety of structural arrangements in the crystal systems, but in virtually every case the uneven stresses in the crystal systems will create some structural weakness in the stones.
Takashi Hiraga

JEWELRY HISTORY

Beads that speak. E. Blauer, *Lapidary Journal*, Vol. 46, No. 7, October 1992, pp. 20–27.

Blauer outlines and details the cultural significance of the bead jewelry worn by the Maasai and Samburu tribes of East Africa. The colors of the beads, the pattern arrangement, and the particular style of a piece may indicate the wearer's tribe and clan, as well as his or her age, marital status, wealth, and position within the clan. Some beads, however, are worn purely for the purpose of ornamentation.

The glass beads, made in Czechoslovakia, are brought to East Africa by Indian traders, and then are purchased by the tribespeople with money earned through the sale of their livestock. The choice of colors in a piece depends not only on what beads are available and what is considered fashionable, but also on which colors should sit next to one another, which reflects the cultural belief that certain colors are strong or weak. The Maasai and Samburu tribes also make jewelry for tourists, but it is not representative of that worn by the tribespeople. In tourist jewelry, little regard is given to how colors are combined or patterned.

The author also details the types of bead jewelry worn by the different age groups and their significance. The article is illustrated with nine color photographs.

This issue of *Lapidary Journal* is referred to as the "Bead Annual" and contains eight other bead-oriented articles plus a list of bead suppliers.   *RT*

Heritage happenings: Jewelry takes its place in American museums. J. Zapata, *Jewelers' Circular-Keystone*, Vol. 163, No. 11, November 1992, pp. 60–63.

The lack of good jewelry collections on display in American museums has long been a source of disappointment to those interested in antique and period jewelry in the United States. Recently, however, more museum curators in this country are viewing jewelry with the same regard that they have for other decorative arts. More and more jewels are being acquired to expand existing museum collections or build new ones.

American museums that are following this trend include the Metropolitan Museum of Art, Walters Art Gallery, Cooper-Hewitt, Toledo Museum of Art, Newark Museum, and American Museum of Natural History. The author outlines the types of jewelry in these collections and provides the names of some of the curators. It is hoped

that these museums reflect a growing trend, and that we will be seeing more public jewelry collections in the future. Five color photos accompany the text.   *EBM*

The heritage jewelry market: Uncharted territory. S. Harkness and J. G. McCleery, with R. Shor, W. G. Shuster, S. Spencer, M. Thompson, and R. Weldon, *Jewelers' Circular-Keystone,* Vol. 163, No. 8, August 1992, pp. 92–109.

Responding to the growing market for antique, period, and estate jewelry, *Jewelers' Circular-Keystone (JCK)* made an in-depth survey of this segment of the trade. Included among the 2,500-plus participants were antique dealers, collectors, pawnshop owners, and jewelry retailers. All were questioned about the volume and nature of their sales. Results of the study show that, despite the recession, most of those polled thought that business was good to excellent and should continue strong through 1995. Many other fascinating facts are also covered, including dollar volume (by type of dealer) and how auction houses and appraisers are faring.

The boom in this market apparently can be attributed to a more educated and interested clientèle, the fact that heritage jewelry is exempt from the federal luxury tax, and the use of pawnshops as a "banking alternative" in these tough economic times. One "specific demographic group" that seems to be seeking heritage jewelry is the professional woman between the ages of 25 and 45, who wants a piece of history or of wearable art.

Despite the overall glowing report, a few caveats are mentioned, including the shortage of quality merchandise, the detection of stolen goods, and the greater number of fine reproductions on the market. Accuracy of evaluation and appraisal of heritage jewelry are two other points to consider before jumping into this business, *JCK* advises. Superficial product knowledge could prove disastrous, and an education in art history, jewelry design, gemology, metal identification, as well as appraising, is recommended.

A helpful bibliography and a list of organizations servicing the heritage jewelry industry are included. Statistical charts and bar graphs are interspersed with photos of period jewelry to illustrate this very thorough presentation.
                                                              EBM

Late antique jewellery: Pierced work and hollow beaded wire. J. M. Ogden and S. Schmidt, *Jewellery Studies,* Vol. 4, 1990, pp. 5–12.

This article reports on a scholarly study of two techniques of jewelry manufacturing that were prevalent during the late Roman and early Byzantine periods (about 300–600 A.D.): (1) a fine type of pierced work that creates a lacy lattice effect, and (2) hollow beaded wire work used as decorative edging. The authors speculate that the techniques were developed to give clients the maximum "show" for a

relatively small amount of gold, which was more expensive than labor at that time. They cite the "Maximum Price Edict of Diocletian" of 301 A.D., which set what a goldsmith could charge per ounce of gold worked: 50 denarii for "normal work" and 80 denarii for "subtle work." The pierced work and beading would probably fall under the "subtle" category.

Using a microscope, the authors examined several examples of pierced work and/or hollow beading from the period, and then performed various experiments to replicate the authentic examples. Their findings are given in detail, and the article is well illustrated with both drawings and photographs.

The authors conclude that there were two types of pierced work. In the simpler variety, common during the third and fourth centuries, a small chisel was used to produce open designs. The finer examples of pierced work, generally from a later date, were made by punching holes in a thin sheet of gold that was fixed over pitch, resin, or wax, and then "opening" the holes using a triangular graving tool.

Although pierced work has been studied for some time, this is the first formal examination of hollow beaded wire. Various methods for achieving the effects seen in jewelry from this period are discussed. Experiments showed that the gold had to be of high purity, at least 22k. A tube would be formed from a thin sheet of gold and then crimped and rolled between two grooved plates, producing one bead at a time on the tube. Evidence of charcoal in several examples suggests that the tube was formed around a thin wooden twig before it was beaded. The wood not only supported the tube while it was being beaded, but also kept the tube from being deformed if it was bent into a circle. The process of soldering the beaded tube to a jewel would turn the wood to charcoal.

The article concludes with a discussion of terminology, followed by 34 footnotes for the text.   *EBM*

Nostalgias y recuerdos de los tesoros de los galeones Santa Margarita, Nuestra Señora de Atocha, Nuestra Señora de la Concepción y Virgen de las Maravillas (Remembrances of the treasures from the galleons Santa Margarita, Nuestra Señora de Atocha, Nuestra Señora de la Concepción and Virgen de las Maravillas). R. Munoa, *Boletín del Instituto Gemológico Español,* Vol. 34, June 1991, pp. 19–25

Years ago, Mr. Munoa began a meticulous study of silver and gold, especially the role these metals have played in Spanish history. His research has concentrated on how these metals and other goods, such as gems, were transported from the "New World" to Spain in the 1500s and early 1600s. His initial research contributed to the 1984 publication (with Alejandro Fernández and Jorge Rabasco) of *La Enciclopedia de la Plata Española y Virreinal Americana (The Encyclopedia of Spanish and American Viceregal Silver).*

To underscore the importance of these metals, Munoa points out that treasures from the "New World" financed entire armies, the Spanish Crown, and an architectural boom, as well as further travels and discoveries. Transporting these treasures to Spain, Munoa notes, was complex and dangerous. Boats leaving the West Indies and other Caribbean areas were often attacked by pirates or sunk during storms. Treasures recovered from the galleons Nuestra Señora de la Concepción, Virgen de las Maravillas, and Nuestra Señora de Atocha are the primary focus of this broad article. He describes his often-nostalgic efforts to reconstruct their provenance and ultimate destinations. Mr. Munoa has conducted research through Christie's auction house, treasure hunter Mel Fisher, the Maritime Heritage Society, and various other sources.

The article includes 18 color photographs and figures showing some of the treasures found and the metal markings used to help determine their provenance. *RW*

The origins of engraved pictorial scrimshaw. S. M. Frank, *Antiques*, Vol. 142, No. 4, October 1992, pp. 510–521.

Scrimshaw, which reached the height of its popularity in the mid-19th century, is the artistic engraving of ivory and bone from sperm whales and other ocean mammals. The advent of sperm whale hunting in the Pacific Ocean provided sailors with an abundance of both free time and marine ivory. As a result, engraved pictorial scrimshaw came into its own as an artistic medium. Scrimshaw could be freehand original scenes or portraits, but was usually traced or copied from published illustrations. Because scrimshaw was primarily intended to be souvenirs or gifts, sailors concentrated on the mainstream rather than the risqué. Naval battles, domestic vignettes, and whaling scenes were among the most popular subjects.

"Scrimshawing" was best done when the marine ivory or bone was still fresh and saturated with natural oils. If a whale tooth, for example, had dried and become brittle, the whalers would soak it in brine to soften it. Natural ridges and imperfections in shape would be scraped off, and the root end of the tooth sawed flat to provide a suitable base. The surface would be further smoothed by sharkskin or pumice and then burnished with a cloth. To copy a drawing, the sailor would lay the original over the ivory and prick through it with a sailmaker's needle. The pattern of dots left by this process would be connected by engraving and filled with a coloring agent.

While scattered examples of professional scrimshaw exist, for most of the artists it was simply a way to alleviate the boredom of long voyages to and from distant whaling grounds. When the whaling industry began its decline in the late 19th century, pictorial scrimshaw declined with it. This fascinating article is richly illustrated and contains numerous detailed notes. *AGP*

A treasury of American crafts. D. M. Bolz, *Smithsonian*, Vol. 23, No. 7, October 1992, pp. 30, 32.

An exhibit at the National Museum of American Art's Renwick Gallery, "American Crafts: The Nation's Collection," celebrated the gallery's 20th anniversary and showcased its permanent collection, which includes jewelry by Mary Lee Hu and Earl Pardon as well as 128 other works. Not just jewelry was exhibited; Tiffany Favrile glass, ceramics, fabric hangings, wood sculpture, and stoneware were also displayed. Open from September 25 to January 10, 1993, the show traced the evolution of American crafts in the 20th century. Pieces selected for the permanent collection are chosen on the basis of aesthetic qualities, historic importance, style, and technical skill involved. It is comforting to know that, in today's mass marketplace of assembly-line artwork, respect is still being fostered for the unique.

JEC

Victorian Scottish jewelry: Highlander style with a British twist. V. Swift, *Jewelers' Circular-Keystone*, Vol. 163, No. 11, November 1992, pp. 55–59.

One of the most popular types of jewelry during the Victorian era was Scottish pebble jewelry. Inspired by a renewed passion for all things Scottish (known as the Scottish or Celtic Revival), these jewels were made in traditional Scottish motifs and incorporated varieties of quartz from the Scottish Cairngorm Mountains. Agates were arranged in colorful patterns to imitate the tartan plaids of the Scottish clans. Citrine, known as cairngorm, was used as central or accent stones.

This article covers the history surrounding the resurgence of interest in Scottish heritage jewelry, and provides names for and reasons behind different elements of a traditional Scottish Highland costume. Discussed are the badge or clan pin, which showed the crest of the wearer surrounded by a belt and buckle; the "dirk," a small sword sometimes accompanied by its scabbard; the "claymore," a great sword with a basket hilt; the "targe" or shield brooch, which sometimes incorporated the cross of St. Andrew, Scotland's patron saint; and the ubiquitous Scottish thistle.

The article is an interesting look at the evolution of this type of jewelry during the 19th century. For those interested in pursuing the subject further, a bibliography is provided. Three color photos illustrate the text, two of which show examples of the jewels being discussed. *EBM*

The winter queen in exile. D. Scarisbrick, *Country Life*, March 19, 1992, pp. 70–71.

Using historical references and portraits as sources, the author describes the impressive collection of jewels that belonged to Elizabeth, the Princess Royal of Great Britain (1596–1662) and later Queen of Bohemia.

Elizabeth's father, James I of England, believed that a grand display of wealth demonstrated the power of royalty. A portrait of Elizabeth at age seven shows her already bedizened with ruby and diamond jewels on her clothing, a pearl and ruby necklace, a diamond earring, and ruby-and-diamond hair ornaments. Scarisbrick also describes suites of jewelry from other portraits, and she itemizes jewels and gifts that Elizabeth received at her wedding to Prince Frederick in 1613. Elizabeth's jewels were to stand her in good stead, as the fortunes of this once-privileged couple changed for the worse. Much of her collection had to be sold or pawned to maintain their household after a Catholic rebellion usurped them as the Protestant monarchs of Bohemia. Elizabeth and Frederick were dubbed the Winter King and Queen because their reign lasted no longer than one winter's snow.

Scarisbrick is sympathetic toward this gracious queen, who never lost her dignity or generosity despite her straitened circumstances. Brief but tantalizing, this two-page article leaves you wanting to know more about one of history's great ladies and her collection of jewelry. Two of the several portraits mentioned accompany the article, along with two sketches of jewels and one photo of an enameled watch that Elizabeth had given to a loyal friend.   *EBM*

JEWELRY RETAILING

Here today, here tomorrow: How to survive. L. B. Kahn, *Jewelers' Circular-Keystone*, Vol. 163, No. 11, November 1992, p. 94.

This article is a reminder not to discount prices when times are tough. Discounting not only sends mixed messages to the customer, it also damages a store's profit margin and pricing credibility. Especially in larger metropolitan areas, where so many jewelry stores are similar, the art of survival in the business world is knowing the ins and outs of marketing. Retailers must focus on selling a product and creating an image that differentiates their stores from others. An important consideration is merchandise selection. If the competition is constantly undercutting a store's prices, that store and its competitors probably have the same merchandise. Therefore, the customer's decision to buy is made on the basis of price alone. The retailer should set his or her business apart from the competition by offering a unique selection of merchandise based on its salability for the specific marketplace. Other suggestions include controlling inventory turnover, and maintaining a good, up-to-date customer list.   *KBS*

SYNTHETICS AND SIMULANTS

Synthesis and characteristics of diamond using nonmetallic catalysis (in Japanese). H. Kanda and M. Akaishi, *Journal of the Gemological Society of Japan*, Vol. 16, No. 1–2, 1991, pp. 3–13.

Diamond synthesis by metallic catalysis has been widely known since General Electric's first success with the process.

However, natural diamonds presumably do not form by metallic catalysis. The authors report on their identification of several nonmetallic substances that are ideal for diamond synthesis, such as carbonate, hydroxide, sulfate, phosphate, and borate. Compared to metallic catalysis synthesis (5 GPa at 1300°–1500°C), nonmetallic synthesis requires higher temperature and pressure settings (5.5–8 GPa at 1800°–2100°C). In addition, the growth rate with nonmetallic synthesis (a few micrometers [110—cubic—direction] to 50 micrometers [111—octahedral—direction] in 30 hours) was much slower than that of metallic synthesis (3 mm/day). The different growth rates in the [110] and [111] directions produced by nonmetallic synthesis contribute to the formation of octahedral crystals. Typical features of these crystal faces are: triangular, hexagonal, and roundish growth patterns on the {100} faces; and trigonal and quadrangular pyramid marks on the {111} faces. To obtain accurate spectral readings, the researchers cooled the synthesized diamonds with liquid nitrogen before cathodoluminescence spectroscopy. Careful examination revealed four spectral patterns common in diamonds: N3 center, H3 center, 575-nm peak, and 430-nm band. Although diamonds grown naturally, by metallic synthesis, and by nonmetallic synthesis all share some spectral features, their spectral distribution patterns differ. With the cathodoluminescence spectroscope, diamonds formed by different methods can be separated easily from one another.   *Takashi Hiraga*

TREATMENTS

An interesting 'oiled' emerald. J. I. Koivula and R. C. Kammerling, *South African Gemmologist*, Vol. 6, No. 2, 1992, pp. 6–10.

Examination of an emerald crystal that the owner thought might have been assembled is the topic of this short article with three illustrations. The owner had submitted the crystal, which was simply mounted in a pendant, to the GIA Gem Trade Laboratory in Santa Monica, California, for identification.

The rough crystal was apparently glued into its 18k gold cap with a transparent epoxy-like substance. Refractive indices, read from several rough but flat faces, were 1.57–1.58. Suspicion originally was raised by the numerous spherical to semi-spherical bubbles throughout the entire crystal that were visible to the unaided eye. These bubbles were found to be enclosed in fluid-filled cavities that ran parallel to the c-axis of the stone. Microscopic examination also revealed several small three-phase fluid inclusions, which are typically associated with Colombian emeralds. An oily-smelling fluid sweated out of the cavities after the crystal was exposed for a short time to the low heat of the microscope's darkfield illumination system. This sweating fluid caused some bubbles to move and others to expand.

On the basis of the viscosity of the fluid, it was concluded that this fluid was probably oil rather than a more solid filler such as Opticon.   *JEC*

Oxidation treatment of the sapphires from Shandong Province, China. C. Wang, Y. Yang, and G. Li, *Journal of Gemmology*, Vol. 23, No. 4, 1992, pp. 195–197.

Blue sapphires from China are frequently too dark to be salable. This article describes a method for lightening such stones by electrolysis in a bath of molten chemical salts at 940°C. The equipment and procedures for this treatment are described, and visible absorption spectra are given for a natural stone, an electrolysis-treated stone, and a traditionally heat-treated stone. It is noted that the stones treated by electrolysis lost approximately 8% of their weight to the molten salts bath.

Results are described as improved clarity and "a pure blue color." The gray hue that often occurs in high-Fe-content sapphires after traditional heat treatment was not observed. Unfortunately, the article does not include photographs of treated stones, or information on their possible identifying characteristics.

Meredith Mercer

LETTERS

simply accept these names for what they are, and not try to create some pedigree in an effort to justify them?

Now let's look at feldspar nomenclature. The plagioclase feldspars consist of a complete solid-solution series with end members that are pure NaAlSiO or CaAlSiO. The sodic end member is *albite*, the calcite end member is *anorthite*, the intermediate species with increasing calcium content are *oligoclase, andesine, labradorite,* and *bytownite.* These are all defined as *plagioclase,* not as distinct mineral species.

In spite of IMA acceptance of these names (which were old before the IMA was born), they are a convenience, a contrivance, and arbitrary. It would be far more accurate to refer to the plagioclase feldspars by their *albite/anorthite* ratios. But the contrivance is an old one, so it stands—and makes conversational if not scientific sense.

Sunstone describes a plagioclase feldspar that often exhibits an optical phenomenon caused by platy inclusions of various compositions. *Sunstone* is not synonymous with *oligoclase* (remember, *oligoclase* is a contrivance). In the spirit of letting market forces drive industry-specific terminology, I recommend that *sunstone* be applied to aventurescent *plagioclase* feldspars of variable albite/anorthite ratios in which the aventurescence is caused by, but not limited to, platelets of hematite or native copper.

The *heliolite* issue referred to by both Dr. Gübelin and Mr. Liddicoat was raised first in Dr. Frederick H. Pough's January 1989 *Lapidary Journal* "Mineral Notes" column, in which Dr. Pough renewed his quixotic pursuit of the name *heliolite* to describe the transparent facetable phase of Oregon labradorite. In his 1983 *Journal of Gemmology* article, "Heliolite, a Transparent Facetable Phase of Calcic Labradorite," Dr. Pough credits the creation of the name to a Mrs. Rogers, widow of one of the original claimants at the Plush (southern Oregon) deposit. There is no mention in that article of the obscure French references that Dr. Pough uses as defense and justification for *heliolite* in his 1989 "Mineral Notes" discussion, in which—by contrast—there is no mention of Mrs. Rogers. And, contrary to Dr. Pough's *Lapidary Journal* claim that the term was "presented" and "approved" at an IMA meeting in Orleans, France, an official of the IMA's Commission on New Minerals and Mineral Names advised me that "*heliolite* has no standing as a mineral name. According to the records, a proposal to validate the name has never been submitted to this commission." He added that Dr. Pough's name does not appear among the list of authors in the abstracts volume of the 1980 IMA meeting in Orleans. Given Dr. Pough's contradictory information, I am curious that such reputable scientists as Dr. Gübelin and Mr. Liddicoat would support such a term.

I suggest that such a varietal name has no true mineralogical value, no value to the gem trade, and will only add confusion to an already-confusing nomenclature. I would dearly love to be able to define Oregon sunstone as a new, distinct, variety of feldspar. Alas, this is not the case. As unusual as this mineral and location are, the chemical and physical observations require the conclusion that this material is a high-calcium plagioclase feldspar, *period.*

The question remains, What do we call this material? First, I must point out that any formal changes will be met with a great deal of resistance by those pesky market forces. Moreover, any nomenclature that attempts to differentiate Oregon *sunstone* strictly by a single physical characteristic will not be accepted or formally adopted by the scientific community.

If we can all agree that, by definition, *sunstone* is aventurescent feldspar, there is no reason to search for another name to apply to the transparent Oregon material: Careful examination reveals that there are always copper lamellae present.

My "entry fee" into this quagmire is that there is no living person who has mined as many *sunstones* as I have: 2.5 million carats and counting. With my partner and co-mine-owner Larry Gray, we have taken *sunstone* from an undervalued, obscure gem material to a place of industry prominence and respect. Regardless of its scientific propriety, Oregon *sunstone* is the name that is, and will continue to be, applied by my partner and myself to the entire range of production from the Ponderosa mine.

CHRISTOPHER L. JOHNSTON, B.S.
Boise, Idaho

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Indexes prepared by Dona Dirlam

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