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GEMS & GEMOLOGY

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Featuring:

Paraíba Tourmaline

California Spessartine

*Malaya Garnet
from Madagascar*

*"Voices of the Earth"
Collection*

THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA

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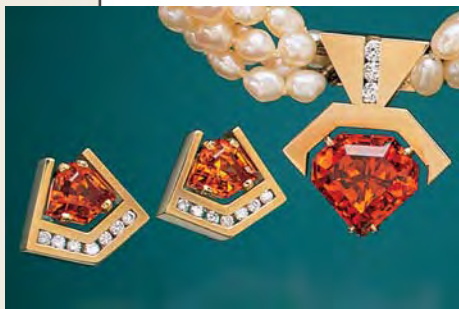
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May We Take a Bow?

We don't normally engage in self-approbation at *Gems & Gemology*, but we like to think that our successes reflect the growing success of gemology, as a science and a profession. It is with great pleasure, then, that I announce that in 2001, for the fifth time in the last decade, *Gems & Gemology* won First Place for peer-reviewed journals in the prestigious Gold Circle Awards competition sponsored by the American Society of Association Executives. In the words of ASAE, "entries are judged on achievement of objectives, comprehensiveness and clarity of content in relation to the journal's specialty, standards for peer-review," and "effectiveness of writing, format and graphic design."

First, I want to thank the many authors, editors, contributors, and reviewers from around the world, both within and outside GIA, who supply the information for each issue of *G&G*. The well-respected names on our masthead are only a partial list of the many experts who contribute to the knowledge provided in our pages. Next, I'd like to thank the photographers who supply the images and help make our illustrations as accurate as that information. What would *G&G* be without them? Last, I would like to take this opportunity to introduce you to the core people in the *G&G* office who work long and hard to bring you a final product that is at the same time educational, readable, and attractive. They are an eclectic bunch, who have added much to the breadth and depth of the journal over the years.

Karen Myers has been art director of *G&G* since December 1999, and is responsible for the redesign of the journal. Karen, who won several awards as a freelance artist, has worked in magazine publishing since 1993. A native "Cajun" from southern Louisiana, Karen holds a bachelor's degree in Fine Arts from McNeese State University in Lake Charles, Louisiana. Her dry sense of humor and ability to stay calm in the face of tight deadlines are invaluable to the department. Every issue, Karen works round the clock at our printer in Pennsylvania to ensure the accuracy of color on each page, in each photograph.

Stuart Overlin has been assistant editor since December 1997. Not only does he coordinate the peer-review process and participate in writing and editing each issue of the journal, but he also maintains the *G&G* Web page (www.gia.edu/gandg). A graduate of the U.S. Naval Academy in Annapolis, Maryland, Stuart served as an officer in the U.S. Navy for five years prior to joining the *G&G* staff. He sailed to the Far East, Middle East, and Africa aboard the USS *Tripoli* in 1994 and on the USS *Peleliu* in 1996.

Brendan Laurs joined *Gems & Gemology* as senior editor in September 1997. Since the Spring 2001 issue, he also has served as editor of the expanded Gem News International (GNI) section. A native of southern California, Brendan developed an early interest in geology while exploring the gem-bearing pegmatites of San Diego County. After receiving his B.S. degree in geology at U.C. Santa Barbara, he obtained an M.S. in geology at Oregon State University in 1995, studying emerald and tourmaline deposits in the Karakoram Mountains of Pakistan. More recently, Brendan has visited Madagascar and Brazil to obtain first-hand knowledge of important gem deposits for the journal.



K. Myers S. Overlin B. Laurs A. Keller

As for me, it's been my pleasure to serve as editor of *G&G* since 1981, when the journal underwent its first major redesign since it was founded by Robert M. Shipley in 1934. I arrived with several years of experience managing professional journals in business and medicine, as well as undergraduate

and graduate degrees from Cornell and Georgetown Universities, respectively. With the help of GIA's best gemologists and a first-rate Editorial Review Board, and the steady backing of senior management, we established a review and production system to ensure the highest quality of information and most accurate reproduction. My kudos go to you, the reader, for continuing to support the journal and our efforts to advance the science of gemology.

With this final issue of the 2001 volume year, *G&G* offers a medley of gemological topics: "Paraíba" tourmaline from Brazil, spessartine garnet from California, Malaya garnet from Madagascar, and the works of leading North American lapidary artists. Particularly timely are the GNI reports on the impact on various gems of postal irradiation (to eliminate anthrax spores), as well as the tremendous potential of gem deposits in Afghanistan. By one estimate, gem mining could bring as much as \$200 to \$300 million annually to this impoverished nation.

I am also pleased to announce that the Spring 2002 issue will celebrate Richard T. Liddicoat's 50th anniversary as editor-in-chief of *Gems & Gemology* with articles from leading gemologists worldwide. It's a very special beginning to what we hope will be another award-winning year for *G&G* . . . and gemology.

Alice S. Keller, Editor
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AN UPDATE ON “PARAÍBA” TOURMALINE FROM BRAZIL

By James E. Shigley, Brian C. Cook, Brendan M. Laurs, and Marcelo de Oliveira Bernardes

Vivid blue, green, and purple-to-violet cuprian elbaïtes, renowned in the gem trade as “Paraíba” tourmalines, continue to be recovered in small amounts from northeastern Brazil. Since the initial discovery of this copper-bearing tourmaline in 1982, production has been sporadic and has not kept up with the strong market demand. Mining currently takes place at the original discovery—the Mina da Batalha—and at adjacent workings near São José da Batalha in Paraíba State. At least two pegmatite localities (the Mulungu and Alto dos Quintos mines) in neighboring Rio Grande do Norte State have produced limited quantities of cuprian elbaïtes. All of these pegmatites occur within Late Proterozoic metamorphic rocks of the Equador Formation; the source of the copper is unknown. Six blue to blue-green elbaïtes from Mulungu had lower copper contents (up to 0.69 wt.% CuO) than the brightly colored Mina da Batalha material reported in the literature.

Unusually vivid “neon” blue, green-blue, green, and violet elbaïte tourmalines first appeared in the jewelry trade in 1989 (Koivula and Kammerling, 1989a). Some of these colors were so striking (figure 1) that initially there was uncertainty over the identity of the material. Eventually it was learned that they were recovered from several small granitic pegmatite dikes at a single deposit near the Brazilian village of São José da Batalha in north-central Paraíba State.

Fritsch et al. (1990) described the gemological properties and visible absorption spectra of these new gem elbaïtes, and demonstrated the relationship between their colors and their unusual chemical compositions. They reported that the blue-to-green colors are primarily due to copper (Cu^{2+}), whereas increasing absorption due to manganese (Mn^{3+}) gives rise to reddish violet-to-violet colors (see also Henn and Bank, 1990, 1991; Rossman et al., 1991). The Paraíba tourmalines represented the first recorded instance of copper occurring as a coloring agent in this mineral. More recently, gem tourmalines colored by copper have been found elsewhere in northeastern Brazil, and in a locality near Ilorin in western Nigeria (Henricus, 2001;

Milisenda 2001; Smith et al., 2001; Zang et al., 2001). The colors of some cuprian elbaïtes can be changed by heat treatment, and some are fracture-filled to improve their apparent clarity.

During the 1990 Tucson gem show, prices for this material skyrocketed from a few hundred dollars to over \$2,000 per carat in just four days (Federman, 1990; Reilly, 1990). Restricted availability due to limited production over much of the past decade has only added to the value and mystique of these cuprian elbaïtes. In recent years, 3+ ct fine-quality blue to green-blue faceted tourmalines from the São José da Batalha area have sold for \$20,000 per carat in Japan (R. Van Wagoner, pers. comm., 2001).

Until recently, difficulties involving legal ownership caused restricted access to the Mina da Batalha. In August 2000, however, the authors were able to visit the locality and gather first-hand information on the geology, current mining activities, and tourmaline production. During this same trip, we also

See end of article for About the Authors and Acknowledgments.
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Figure 1. These tourmalines (2.45–9.60 ct), recovered from the Mina da Batalha in Brazil's Paraíba State in the early 1990s, are representative of some of the "turquoise" blue and blue-green tourmaline colors produced at this locality. Courtesy of K. Elawar; photo © Harold & Erica Van Pelt.

briefly visited the Mulungu mine near Parelhas (figure 2) in neighboring Rio Grande do Norte State (see Laurs and Shigley, 2000a,b), which has produced small amounts of cuprian tourmalines. A recent article by Austin (2001) describes the recovery of gem tourmalines from secondary alluvial and eluvial deposits adjacent to the Mina da Batalha.

The Mina da Batalha deposit is one of many gem pegmatite areas in the Borborema geologic province of northeastern Brazil. Some of these pegmatites have been mined for strategic minerals since the 1940s, and more recently for tourmaline, aquamarine, and other gems (Almeida et al., 1944; Silva et al., 1995; Pinto and Pedrosa-Soares, 2001). To date, only a few pegmatites have produced copper-bearing elbaite tourmalines, within a narrow region that extends approximately 90 km northeast from São José da Batalha into Rio Grande do Norte. In this article, we describe the geology of the Mina da Batalha and associated alluvial/eluvial deposits, and also update the gemology of "Paraíba" tourmaline. Brief descriptions of cuprian elbaite from two other pegmatite mines (Mulungu and Alto dos Quintos) in Rio Grande do Norte State also are included.

Members of the gem trade typically use the name *Paraíba* for vivid blue to blue-green tourmalines from northeastern Brazil. However, in this

article, we consider *Paraíba tourmaline* to be a trade name for blue, green, and purple-to-violet elbaite tourmalines from the Mina da Batalha and associated deposits near São José da Batalha that contain at least 0.1 wt.% CuO (an amount of copper that is easily detected by energy-dispersive X-ray fluorescence [EDXRF] chemical analysis; see Fritsch et al., 1990, p. 204).

LOCATION AND ACCESS

Pegmatites containing gem tourmalines are found throughout the Serra das Queimadas mountain range (known locally as the Serra dos Quintos) in both Paraíba and Rio Grande do Norte. This general area lies about 230 km northwest of Recife and 210 km west-northwest of João Pessoa (again, see figure 2). It is about 7° south of the equator.

The Mina da Batalha can be reached by flying to Recife, João Pessoa, or Campina Grande (the closest commercial airport). From the last, a paved road leads 60 km west to the towns of Joazeirinho and Assunção, and a dirt road then proceeds 14 km to the village of São José da Batalha (located 4.5 km north of Salgadinho). The mine is situated on a small steep-sided hill known as Morro Alto, about 2 km west-southwest of the village (figure 3).

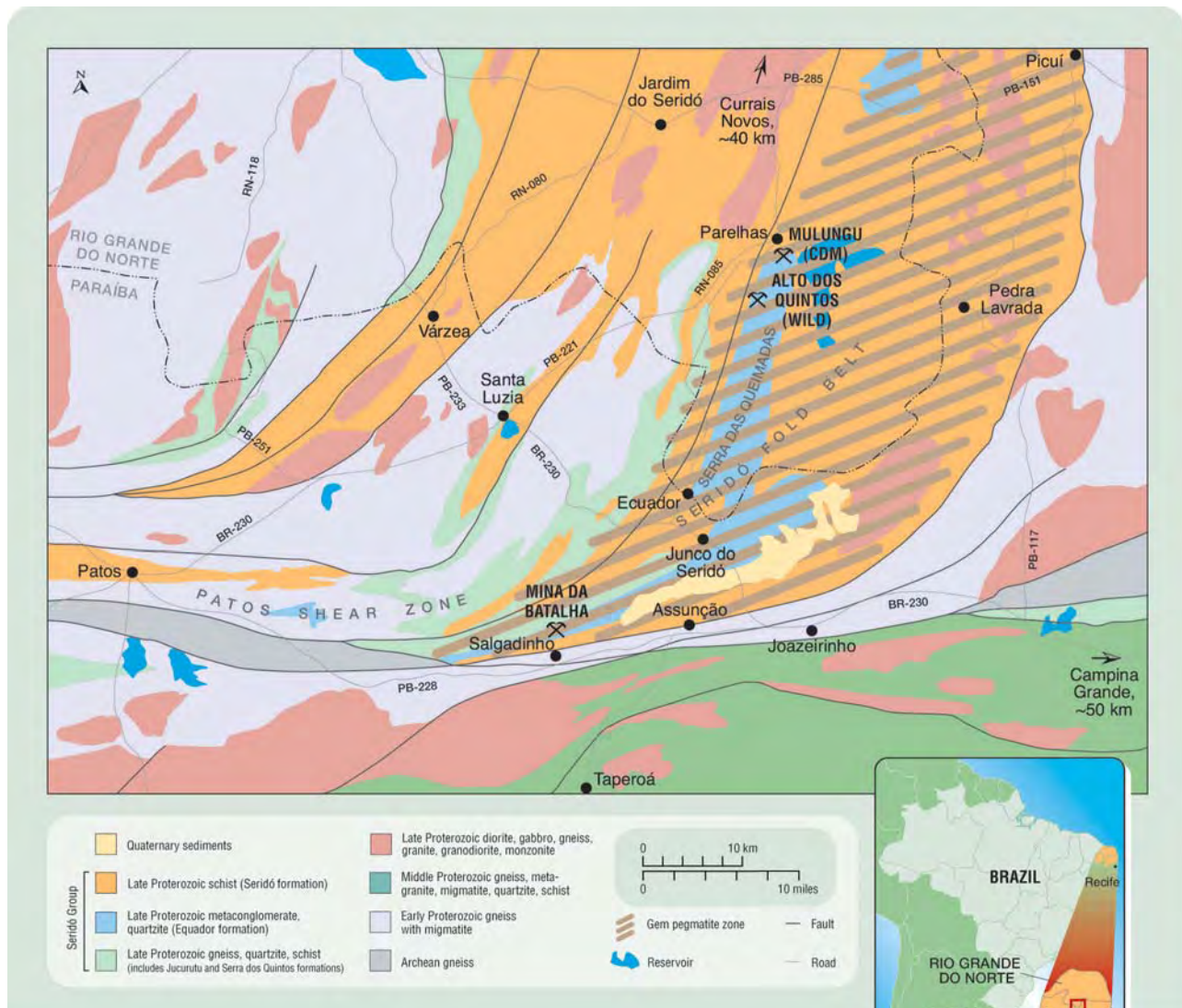


Figure 2. This generalized regional geologic map shows the major rock types and tectonic structures (the Seridó fold belt and Patos shear zone) in Paraíba and Rio Grande do Norte States in northeastern Brazil. Locations are indicated for the Mina da Batalha and the Mulungu (also known as the Capoeira, Boqueirãozinho, or CDM mine) and Alto dos Quintos mines (also known as the Wild mine), the area of gem pegmatite mineralization, as well as local towns and roads. The majority of the gem pegmatites are found in the quartzites of the Equador formation. Modified from Jaguaribe SE (2000).

The topography in this part of northeast Brazil has been eroded over geologic time to form a peneplain—a relatively flat or gently undulating land surface known locally as the *Planalto da Borborema*. Occasional prominent steep-sided granitic hills, called *inselbergs*, project upward above the surrounding terrain. Elevations typically range from about 200 to 1,000 m above sea level. Rainfall averages between 25 and 100 cm per year. A semiarid climate is created by high temperatures (24°–28°C or ~80°F average, occasionally exceeding 40°C/104°F), and by periods of drought that reoccur every eight to 10 years (each lasting one to five years). The local vegetation, called a *caatinga* forest, consists of low-

to mid-sized trees, thorny bushes, and cacti.

This is one of the poorest and more sparsely populated regions of Brazil. Farming, ranching, manufacturing of tile and ceramics, and small-scale mining provide a difficult subsistence for the local people. Historically, production of industrial beryl, mica, quartz, feldspar, kaolin clay, and ores of uranium, tantalum, niobium, tungsten, tin, and some gold has been important for the local economy, although market demand for some of these commodities has varied considerably over the past decades (see Beurlen, 1995). Gemstones are a byproduct of these mining activities, but high extraction costs and a weak national economy have curtailed mining

Figure 3. This view, looking south in August 2000, shows Morro Alto on the right and the Serra do Frade ridge on the skyline. Extensive mine dumps from the Mina da Batalha are visible at the base of Morro Alto, and stockpiled dump material and eluvium/alluvium is present along the base of the ridge. Photo by Brendan M. Laurs.



for gems throughout this region and much of Brazil in recent years. Nonetheless, the very high values of these cuprian elbaïtes have stimulated local exploration for other potential sources of this gem material.

GEOLOGIC SETTING

Regional Geology. The geology of northeastern Brazil is quite complex (again, see figure 2). This region, known as the Borborema Province, consists mainly of Archean and Early Proterozoic gneisses and migmatites, as well as Late Proterozoic igneous and metamorphic rocks. Included in the latter are those of the Seridó Group (which consists of the Jucurutu, Equador, Seridó, and Serra dos Quintos formations). Radiometric age dating indicates that several major episodes of regional deformation (or orogenies) took place in this geologic province, producing widespread metamorphism, folding, and faulting, and accompanied by several periods of granitic magmatism (see Jardim de Sá, 1984; Jardim de Sá et al., 1987; Ferreira et al., 1998; Sial et al., 1999; Brito Neves et al., 2000; Nascimento et al., 2000).

The most recent of these tectonic cycles—between 650 and 480 million years (m.y.) ago—is referred to as the Brasiliano–Pan-African orogeny. This continental-scale tectonic system extended into western-central Africa (around Nigeria), as these geologic events occurred prior to the separation of South America from Africa (see Trompette, 1994). Within the Borborema Province, rocks of the Seridó Group were folded into a series of northeast-trending anticlines and synclines that comprise the Seridó fold belt (Ebert, 1970; Corsini et al., 1991; Vauchez et al., 1995). Numerous granitic bodies and associated pegmatites formed during the latter stages of this orogeny, between about 510 and 480 m.y. ago (van Schmus et al., 1995; Beurlen et al., 2000; Araújo et al., 2001). The pegmatites are confined mostly to the Seridó fold belt (Ebert, 1970; Corsini et al., 1991; again, see figure 2); more than 200 are known within an area measuring approximately 75 × 50 km that

stretches southward from the town of Currais Novos (Silva et al., 1995). The majority of the mineralized pegmatites occur within the Seridó and Equador formations, which form much of the 30-km-long Serra das Queimadas range (Silva, 1993).

The Borborema pegmatites typically form tabular-, lens-, or dike-like bodies that vary from tens to hundreds of meters in length, and up to tens of meters in width. The larger pegmatites have a simple mineralogy—mainly feldspars, quartz, and mica (muscovite and some biotite). The smaller, but more numerous, “complex” pegmatites are internally zoned, and typically contain central quartz core zones (sometimes rose quartz). They have a varied mineralogy, often with gem and rare-element minerals (e.g., beryl, tantalite-columbite or manganotantalite, spodumene, cassiterite, garnet, and tourmaline), which have made them targets of mining activities.

In some areas, much of the feldspar (in both types of pegmatite) has been altered to white kaolin clay. Kaolinization appears particularly strong in the pegmatites lying south of the town of Ecuador (including those at the Mina da Batalha), whereas the feldspars are relatively unaltered in those to the north (e.g., at the Mulungu and Alto dos Quintos mines). The kaolinite formed after crystallization of the pegmatites and their gem minerals, and is not related to the presence of copper. The source of the copper in the tourmalines is unknown, but it is generally thought to have been derived from underlying copper-bearing rocks and incorporated into the pegmatitic magmas (Karfunkel and Wegner, 1996).

Local Geology. Gem-bearing pegmatites are present over a distance of several hundred meters on and adjacent to Morro Alto (figure 4). This hill forms part of a ridge called Serra do Frade, within the Serra das Queimadas mountain range. These pegmatite dikes are locally referred to as “lines” by the miners (numbered 1 through 6, with the last also called the “Jucuri” line [figure 5] after a prominent tree that grew near its outcrop). Individual pegmatites are

tabular or vein-like in shape, and vary in thickness—from a few centimeters up to 2 m, although portions of line 4 are up to 4 m thick. The most productive dikes for gem tourmaline are typically less than 1 m thick.

As seen on Morro Alto, the pegmatites are oriented roughly parallel to one another; they strike southeast (60°–70°). They are typically separated from one another by 5–20 m of host rock (a foliated muscovite quartzite of the Equador formation). The steeply dipping (65°–75° northeast) dikes discordantly cross-cut the foliated quartzite (which dips 35°–40° south). Contacts between the pegmatite dikes and the quartzite are sharp and distinct, with very little or no hydrothermal alteration of the latter. The pegmatites are primarily composed of kaolinized feldspar, along with quartz and micas (muscovite and lepidolite). Besides schorl and elbaite tourmalines, other accessory minerals include tantalite, manganotantalite, amethyst, and citrine.

Typical of gem pegmatite deposits elsewhere,

tourmaline mineralization at the Mina da Batalha is distributed irregularly within the pegmatites. Mr. Barbosa's experience has shown that the most promising areas for exploration are near the quartz core zones, where tourmaline occurs in association with lepidolite mica. Mineralized zones within a dike, which typically consist of a series of small ("fist"-sized) clay-filled "pockets" or thin "stringers," can extend for a distance of several meters. Less commonly, the gem tourmaline is found intergrown with massive quartz or embedded in kaolinized feldspar. Some of the larger tourmaline crystals embedded in quartz have been partially or totally replaced by lepidolite mica to form pseudomorphs.

Observations during mining revealed that different colors of tourmaline were encountered at various levels within the pegmatites. In addition, each dike tends to produce somewhat different colors, quantities, and qualities of tourmaline. According to Heitor Barbosa (pers. comm., 2001), line 1 produced the greatest quantity of crystals and the

Figure 4. This simplified sketch map shows the locations of the pegmatite dikes referred to as "lines" 1 through 4 (5 and 6 are not shown) on Morro Alto. Also shown are property boundaries for groups that are currently engaged in the recovery of gem tourmaline. Both primary (pegmatite) and secondary (alluvial/eluvial) deposits are being worked. Modified from mine map commissioned by Heitor Barbosa, January 2000.

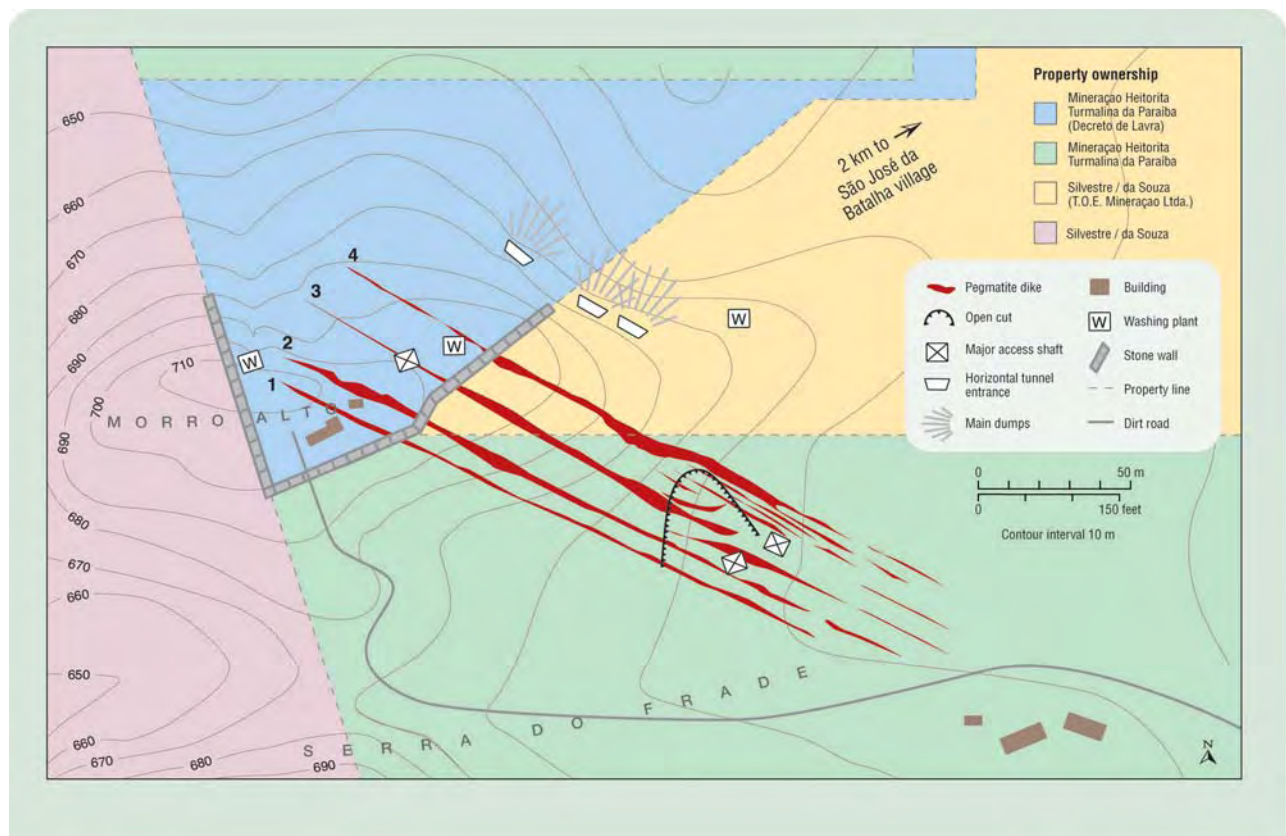




Figure 5. This view, looking northwest in August 2000, shows the excavation of line 6 (called the *Jucuri line* in this area) that was mined beneath shallow alluvium by T.O.E. *Minação Ltda.* The narrow width, steep dip, and elongate shape of the dike are typical of pegmatites in the São José da Batalha area. Photo by David Sherman.

Figure 6. Although most of the tourmaline crystals found in the Mina da Batalha area are broken and/or chemically etched fragments (right crystal, 10.5 grams), in rare instances they are euhedral with well-formed terminations, as shown by the crystal on the left (14.8 grams). Courtesy of Heitor Barbosa.



largest (mainly green, as well as grayish purple that would heat treat to bright greenish blue). Line 2 yielded smaller amounts with better color—particularly in green and the prized blue that did not need heat treatment. Lines 3 and 4 produced a variety of colors, but in lesser qualities and quantities. Line 6 produced small crystals with good blue-to-green colors, and line 5 was not productive.

Most of the tourmaline crystals from both the pegmatites and the adjacent alluvial/eluvial deposits are found as naturally broken and/or corroded fragments weighing less than one gram. In rare instances, the crystals are euhedral with well-formed terminations (see Wilson, 2002; figure 6). The crystals may be evenly colored, as in figure 6, or multi-colored (blue, violet, green, purple, etc.) with various color-zoning patterns centered on the c-axis (figure 7; Cook, 1994). Occasionally, they are color zoned parallel to the c-axis.

HISTORY AND MINING OF THE MINA DA BATALHA AREA

Mining the Primary Pegmatites on Morro Alto. In 1982, a year following the discovery of tourmaline in a manganotantalite prospect on Morro Alto by the Brazilian Geologic Survey (CPRM), Heitor Barbosa organized initial mining by a group of about 13 *garimpeiros* (Koivula and Kammerling, 1990b; Barbosa and Cook, 1991). Three of the six dikes (lines 1, 2, and 3) were excavated downward from their outcrops at the top of the hill. In August 1987,

Figure 7. This 5.53 ct polished crystal fragment from the Mina da Batalha is color zoned perpendicular to the c-axis. As seen in the inset (magnified 5×), the zones are separated by either sharp or diffuse boundaries. Photos by John I. Koivula.





Figure 8. In the early 1990s, numerous near-vertical shafts were dug to explore the pegmatites on Morro Alto at the Mina da Batalha (left). Each shaft is marked by a white dump. A similar view, looking north, is shown in August 2000 (right). Most of the pegmatite dump material and underlying soil have been scraped from the hillside for stockpiling and processing to recover tourmaline fragments. The wall was constructed in the late 1990s to prevent entry into Heitor Barbosa's property. Also visible on the top of Morro Alto in the right photo are a small washing plant (to the left), a new building for the workers, and a water tank. Photos by Brian C. Cook.

small amounts of tourmaline fragments with bright blue sections were first encountered at depths of about 30 m within lines 1 and 2. Later that year, Mr. Barbosa filed a mining claim (*alvara de pesquisa**) on the Morro Alto pegmatites.

Subsequently, several kilograms of gemmy green crystals were recovered that yielded hundreds of carats of fine-quality cut stones. Mina da Batalha tourmaline was first sold in Brazil in late 1988. February and March 1989 witnessed the production of the first facet-quality bright blue tourmalines, with rough as large as 10.5 grams. Some of this material was provided to GIA for examination (Hargett and Kane, 1989; Koivula and Kammerling, 1989a,b); Fritsch et al. (1990) described the broad range of material from the mine, and attributed the

unusual coloration to both copper and manganese.

Maximum production of gem tourmaline occurred in 1990–1991. By this time there were numerous shafts (figures 8 and 9), some of which reached depths of more than 60 m. Hundreds of meters of horizontal tunnels also were driven along the dikes at various levels from the shafts. Remarkably, most of the mining was accomplished by candlelight using only simple hand tools and occasional blasting. The pegmatite material was hoisted to the surface in buckets by hand-driven winches, and the contents were sieved or washed prior to removing the tourmaline by hand.

For most of the 1990s, the mine was embroiled in ownership disputes, and several opposing groups were active at the deposit. These competing mining activities (some illegal) were frequently disorganized, haphazard, and ineffective at sustaining gem tourmaline production. Between 1992 and 1996, mining came to a near standstill due to lengthy court cases involving mine owners, foreign investors, politicians, and local groups or individuals. As a result of the legal proceedings, the mine site was divided into several sections with different owners (Weldon, 1999). Mr. Barbosa retained the majority of the workings on Morro Alto under a mining deed (a *decreto de lavra***). Other groups or individuals divided the remaining portion (about 1,000 ha) among themselves under an *alvara de pesquisa*. From 1994 until recently, the only significant production came from processing of the former mine dumps, which yielded several kilograms of tourmaline fragments (most less than 0.5 ct).

In 1997, Mr. Barbosa began restoring the under-

**Alvara de pesquisa* ("exploration right"): Rights granted to an applicant by the Departamento Nacional de Produção Mineral (DNPM) to stake a claim on an area to explore for minerals or gemstones. This authorization is valid for three years, but it does not constitute legal ownership of a mine.

***Decreto de lavra* ("mining decree"): Mining rights granted by the DNPM after the applicant has successfully passed through the exploration stage on a patented mining claim. The applicant must have submitted a full development plan for the mine as well as an environmental impact report. The decree is valid for the rest of the mining life of the deposit, as long as the grantee fulfills his legal obligations and provides an annual report on mining activities.

ground workings at the Mina da Batalha (Barbosa and Cook, 1999). He also began construction of a large stone wall on part of the mine site to prevent illegal entry. In 1998–1999, two horizontal tunnels were driven southwest from near the base of Morro Alto to intersect the pegmatites, providing better access to deeper, unmined areas. The ore and waste rock could then be removed by wheelbarrow through these tunnels rather than by haulage up the near-vertical shafts. In 1999, Mr. Barbosa initiated a core-drilling program and hired a geologist to help guide future mining.

The following year, Mr. Barbosa purchased an additional section of the property, so he now owns about 80% of the Morro Alto hill (the remaining 20% is owned by João and Edna Silvestre Henrique de Souza). He installed fluorescent lighting in the tunnels and an electric winch, and in August 2000 he resumed underground mining (figure 10) with two teams of miners using pneumatic hammers. A small washing plant has been in operation since March 2000. Its processing capacity is about 28 m³ of material per day. A more sophisticated processing plant, with a capacity of 45 m³ per day, should be fully operational by February 2002. Mr. Barbosa estimates that as much as 10,000 m³ of pegmatite material has been processed since mining commenced at the Mina da Batalha (pers. comm., 2001).

Mining the Areas Surrounding Morro Alto. Beginning in 1998, efforts were initiated to recover gem tourmaline from alluvium below Morro Alto, and from eluvium on the top and sides of the hill. In 1999, T.O.E. Mineração Ltda. entered into a leasing agreement with João and Edna Silvestre Henrique de Souza to explore (via an *alvara de pesquisa*) a portion of the pegmatites on the western side of the Morro Alto, as well as secondary deposits lying downslope (figure 11), on property owned by the de Souzas. This group is working an alluvial area of approximately 100 × 1,000 m, and an eluvial area of approximately 80 × 200 m (D. Sherman, pers. comm., 2001).

Equipment used to recover tourmaline from the area surrounding Morro Alto includes a hydraulic excavator, backhoe, and dump truck. A small washing facility—which can process up to 20 m³ of material per day—began operation in early 2000. With a large volume of material awaiting processing, a larger processing plant—which can handle 200–320 m³ of material a day—was built and became operational in October 2000 (figure 12). After large rock fragments (>5 cm) are removed, the finer material passes



Figure 9. This shaft at the Mina da Batalha follows one of the pegmatites to a depth of approximately 20 m, and provides access to an extensive part of the underground workings. When looking down the shaft, the narrow width (typically about 1 m) and steep dip are clearly evident (see inset). The shafts were dug using hand tools, and the pegmatite material was removed by winch. Photos by Brendan M. Laurs.

Figure 10. Heitor Barbosa is shown with a pegmatite in a tunnel at the Mina da Batalha. The white areas in the pegmatite are kaolinized feldspar, and the dark gray areas are quartz. The sides of the tunnel consist of the quartzite of the Equador formation that hosts the pegmatite. Photo by Brendan M. Laurs.

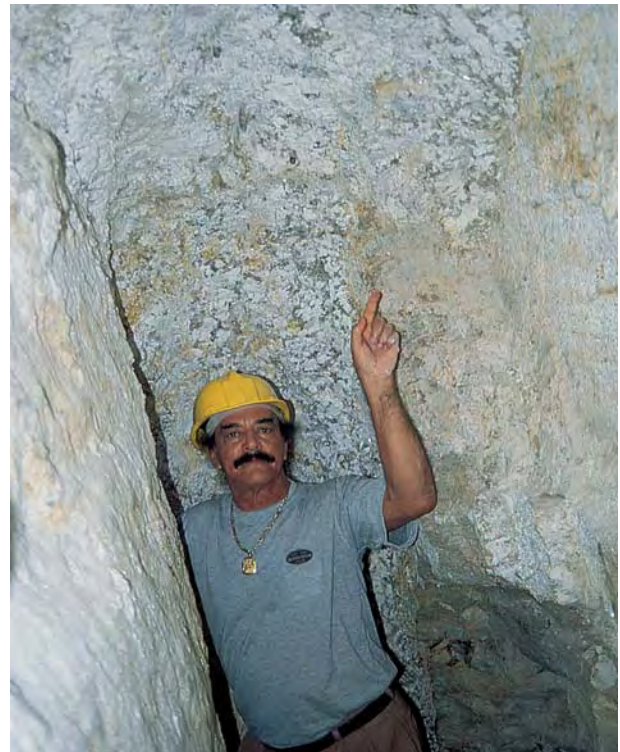




Figure 11. This view, looking southeast from Morro Alto in August 2000, shows the large area that is being worked to recover gem tourmaline from alluvium and eluvium. The stockpiled mine dumps will also be processed for gem tourmaline. Photo by Brendan M. Laurs.

through dry and wet vibrating sieves to form a concentrate (sized 6 mm to 5 cm). The tourmaline is then hand-picked from the concentrate.

Although some tourmaline has been recovered from alluvial sediments near the surface, the best production came from older alluvium (covered by 1–2 m of overburden) that may represent a former stream channel (Austin, 2001). In addition, T.O.E. is working an extension of one of the pegmatite dikes

Figure 12. T.O.E. Mineração Ltda. has constructed a large processing plant to recover gem tourmaline from stockpiled mine dumps and alluvial/eluvial material surrounding Morro Alto. Photo by David Sherman.



(line 6, or Jucurí; again, see figure 5). T.O.E. also excavated an unmined portion of line 4 while mining eluvium on the flank of Morro Alto.

Exploratory work by T.O.E. has revealed additional pegmatite dikes beneath the alluvium at depths of about 2 m (Austin, 2001; Sherman, 2001). These dikes strike in a significantly different direction from those on the hill, and are likely to be separate pegmatites not recognized previously (D. Sherman, pers. comm., 2001). In September 2001, Mr. Barbosa located a new pegmatite near the western edge of his property; this dike also strikes nearly perpendicular to the others on Morro Alto. The de Souzas are exploring another pegmatite that lies west of line 1 just beyond the property boundary of Mr. Barbosa. This dike has yielded small quantities of yellow-green tourmalines (S. Barbosa, pers. comm., 2001). Ongoing work at the Mina da Batalha and in the surrounding area is revealing the structural complexity of the dike system.

PRODUCTION FROM THE MINA DA BATALHA AND SURROUNDING AREA

Production of the best blue-to-green cuprian tourmaline (see, e.g., figure 13) during the past decade has not kept up with market demand. Most production from the Mina da Batalha came during 1989–1991, when an estimated 10,000–15,000 grams of gem-quality (i.e., facetable plus some cabochon quality) crystals and fragments were recovered (H. Barbosa, pers. comm., 2001). Since 1992, tourmaline production from the Mina da Batalha has been sporadic and limited (Koivula et al., 1992a; Koivula et al., 1993c, 1994). However, in recent years the supply of “Paraíba” tourmaline has increased (see, e.g., “Strong demand in Japan...,” 1999; “New find of Paraíba...,” 2001).

Production by T.O.E. since mid-2000 has exceeded 100 grams of gem-quality blue to green-blue tourmaline per month; their total production of various colors to date is about 3 kg (D. Sherman, pers. comm., 2001). The largest gem-quality fragment recovered from the alluvium thus far weighed about 8 grams, although the typical size is less than 1 gram.

Most cut cuprian elbaïtes from the São José da Batalha region range from 0.15 to 0.75 ct. However, the area is the source of several large faceted stones, such as a 33.13 ct green rectangular cushion cut (see figure 6 in Koivula and Kammerling, 1991b, p. 184) and a >45 ct bluish green trilliant (W. Larson,



Figure 13. This crystal (5.0 cm high) and cut stone (4.0 ct) illustrate the intense color of fine-quality copper-bearing tourmaline from the Mina da Batalha. From the Mike Scott collection; photo © Harold & Erica Van Pelt.

pers. comm., 2001). Blue crystals exceeding 30 grams have been found, but gem-quality blue crystals over 3 grams are rare. The 15.0 ct blue cuprian tourmaline in figure 14 was faceted from the 14.8 gram crystal shown in figure 6. The largest good-quality blue tourmaline crystal found to date reportedly weighed 41 grams (H. Barbosa, pers. comm., 2001).

In the experience of co-authors BC and MB, the preference in the trade is for the bright, saturated greenish blue or violetish blue to blue, and to a lesser extent, “pure” green tourmalines from Paraíba. Members of the trade often describe the more vibrant colors with names such as “neon” or “electric.” “Heitorita” is a trade name used by Heitor Barbosa and his associates for the small production of intense blue to blue-green tourmalines that do not need heat treatment (see, e.g., figure 6).

OTHER BRAZILIAN SOURCES OF CUPRIAN ELBAITE

The high demand for “Paraíba” tourmaline has stimulated a search for similar material from other pegmatite deposits throughout the region. Table 1 includes sources that are known by us, or have been reported by others, to have produced blue-to-green cuprian tourmalines. The Mulungu and Alto dos Quintos mines are described below. In the experience of BC and MB, none of these occurrences has yet produced material of saturated (vibrant) blue to blue-green colors similar to that from the Mina da Batalha and the surrounding area.

Reports of additional localities for copper-bearing gem tourmalines in this region of Brazil include: (1) Paraíba State—Alto Quixaba pegmatite north of Frei Martinho (Ferreira et al., 2000); and (2) Rio Grande do Norte State—Bolandeiro pegmatite, 36 km south-southeast of Parelhas (Bhaskara Rao et al., 1995), and Gregorio pegmatite, 20 km south-southwest of Parelhas (Adusumilli et al., 1994); see also Karfunkel and Wegner (1996).

Figure 14. The center stone in this pendant is a 15.0 ct tourmaline from the Mina da Batalha, which was cut from the 14.8 gram crystal in figure 6. The stone is surrounded by 16 carats of diamonds. Photo by Luna Wong; courtesy of Fine Gems Ltd., Hong Kong.



Mulungu Mine. In 1991, cuprian elbaïtes were discovered in colluvium at what is known as the Mulungu mine, located 5 km north-northeast of Parelhas and 60 km northeast of the Mina da Batalha. This mine has also been called the Capoeira, Boqueirãozinho, or CDM (see, e.g., Adusumilli et al., 1993; Karfunkel and Wegner, 1996; Johnson et al., 2000).

Only recently (1999) have elbaïte crystals been found in the primary pegmatite, which forms an elongate, lenticular body that intrudes at a steep angle into a metasedimentary host rock. It strikes in an east-west direction, and is exposed over a distance of about 200 m. The maximum width is at least 10 m. The pegmatite is mineralogically zoned, and consists of feldspar, muscovite, and quartz, with accessory tourmaline, fluorapatite, and phosphate minerals. It also contains chalcocite and digenite, two copper sulfides that are rare in pegmatites, but occur here in pods up to 20 cm in diameter in the footwall portion (Robinson and Wegner, 1998; Falster et al., 2000). Mining takes place from an open pit dug into the colluvium, as well as from some underground tunnels that follow

the zone of tourmaline mineralization within the pegmatite dike (figure 15).

In the early years of production, some cuprian tourmaline from this mine was mixed with Mina da Batalha material, and sold as tourmaline from the "new Paraíba mine" (figure 16). It reportedly also has been marketed as tourmaline from the Mina da Batalha ("The nomenclature controversy," 2001).

Alto dos Quintos Mine. This pegmatite body occurs on a hillside about 9 km south of Parelhas (and 45 km northeast of the Mina da Batalha). Also known as the Wild mine (Soares, 1998; Soares et al., 2000a; figure 17), it is exposed over an area of 150 by 20 m. The principal minerals include feldspar, quartz, and muscovite; accessory minerals include apatite, beryl, columbite, spodumene, lepidolite, and gahnite. In 1995–1996, this pegmatite deposit produced some large (up to 25 cm long), multicolored-tourmaline mineral specimens. Most of the copper-bearing tourmalines are not gem quality, although facetable crystals have been recovered from pegmatite pockets on at least two occasions in 2000 and 2001. Small

TABLE 1. Summary of gemological data on copper-bearing tourmalines.^a

Locality	Mina da Batalha, Paraíba ^b	Mina da Batalha, Paraíba ^b	Alto dos Quintos mine, Rio Grande do Norte	Mulungu mine, Rio Grande do Norte	Edeko mine, western Nigeria ^c
Source	Fritsch et al. (1990)	Henn and Bank	Soares (1998, (1990)	This study (2000a,b)	Smith et al. (2001)
Number of samples	13	6	12	6	1
Colors	B, bG, bPr, BG, G, gGr, prPk, Pr, vB, yG	B, G	B	B, BG, bG, gB	prPk to B, bG, V
Refractive indices					
n_g	1.619–1.621	nr	1.624	1.618–1.619	1.620
n_o	1.638–1.646		1.646	1.638–1.639	1.638
Birefringence	0.018–0.025	nr	0.022	0.019–0.021	0.018
Specific gravity	3.03–3.12	nr	3.03	3.08–3.10	nr
Copper content (wt.% CuO)	0.37–2.38	0.75–2.47	0.60–0.78	0.41–0.69	nr
Other chemical elements reported	Bi, Pb, Zn	nr	Bi, Zn	Bi, Pb, Zn	nr
UV fluorescence	Inert (LW, SW)	nr	nr	Inert (LW, SW)	Inert (LW, SW)
Inclusions	Three-phase, fingerprints, growth tubes, metallic flakes	nr	Two-phase, fingerprints	Fingerprints, feathers, growth tubes, two-phase, filled fractures ^d	Fluid inclusions

^a Abbreviations: B = blue, BG = blue-green, bG = bluish green, bPr = bluish purple, G = green, gB = greenish blue, gGr = greenish gray, Pr = purple, prPk = purplish pink, V = violet, vB = violetish blue, yG = yellowish green; nr = not reported.

^b Additional data for tourmaline from the Mina da Batalha are provided by Bank et al. (1990), Bank and Henn (1990), Ferreira et al. (1990), Brandstätter and Niedermayr (1993, 1994), and Cassedanne (1996).

^c See also Milisenda (2001) and Zang et al. (2001); the latter reported 0.51–2.18 wt.% CuO, as well as traces of Bi, Pb, and Zn.

^d Falster et al. (2000) reported plate-like copper inclusions and up to 1.4 wt.% CuO in tourmaline from Bocheiron Zinho, another name for the Mulungu mine.



Figure 15. Cuprian elbaite tourmaline is occasionally recovered from the Mulungu mine near Parelhas, Rio Grande do Norte. This August 2000 photo shows one of three main shafts, along with a building being constructed for mine staff and support materials. Photo by Brendan M. Laurs.

gemmy areas in some of these crystals were fashioned into “sky-blue” melee-sized gems, and have also been sold as “Paraíba” tourmaline.

GEMOLOGICAL CHARACTERISTICS AND CHEMICAL COMPOSITION

Over the past decade, a small number of faceted blue-to-green tourmalines have been submitted to the GIA Gem Trade Laboratory to determine if they contained copper and met the gemological description of Paraíba tourmaline (see, e.g., Reinitz, 2000). In all those cases where sufficient copper was detected by EDXRF chemical analysis, the gemological properties were found to be consistent with the data reported by Fritsch et al. (1990) in the original material. However, to expand the data on copper-bearing tourmalines from this region, we characterized six blue to bluish green faceted tourmalines from the



Figure 16. The faceted blue tourmaline on the left (4.65 ct) is representative of fine copper-bearing tourmaline from the Mulungu mine near Parelhas, while the other two stones (5.73 and 2.87 ct) are from the Mina da Batalha. Photo by Maha Tannous.

Mulungu mine; samples known to be from the Alto dos Quintos mine were unavailable for examination.

Materials and Methods. The six Mulungu tourmalines (0.47–1.35 ct, reportedly heated) were supplied by one of the authors (MB). Refractive indices were measured with a Duplex II refractometer. Specific gravity was calculated by the hydrostatic method from three sets of weight measurements recorded with a Mettler AM100 electronic balance. Fluorescence to UV radiation was documented in darkroom conditions using a standard long-wave (365 nm) and short-wave (254 nm) GIA GEM Instruments UV lamp. Observations of internal features were made with a binocular gemological

Figure 17. Located 9 km south of Parelhas, the Alto dos Quintos mine has been explored for cuprian elbaite for several years. Photo by Brendan M. Laurs.



microscope. Quantitative chemical analyses for 17 elements were obtained on all six Mulungu tourmalines (see table 2).

Results and Discussion. The gemological properties of Mulungu tourmalines examined for this study, and information taken from the published literature on material from this and other localities, are summarized in table 1. The R.I. and S.G. values of all the copper-bearing tourmalines fall within the ranges reported for elbaïtes in general (compare to Dietrich, 1985; Deer et al., 1997). As reported by Fritsch et al. (1990), Koivula et al. (1992b), Brandstätter and Niedermayr (1993, 1994), and Cassedanne (1996), the most interesting inclusions in "Paraíba" tourmaline are copper, but we did not observe copper inclusions in our Mulungu samples. However, Falster et al. (2000) reported plate-like copper inclusions in tourmaline from Bocheiron Zinho, another name for the Mulungu mine. Internal features in our

Mulungu samples consisted of "fingerprints" comprised of liquid and liquid-and-gas inclusions, low-relief feathers, occasional growth tubes, and flash-effect colors from what appear to be oil-filled fractures (this oil could be forced out of the fractures with a thermal reaction tester).

The chemical analyses of our Mulungu samples revealed a generally lower copper content than has been reported for elbaïtes of similar color from the Mina da Batalha (up to 0.69 wt.% CuO versus up to 2.38 wt.% CuO, respectively; see tables 1 and 2). Tourmalines of similar color from Alto dos Quintos are reported to have a similar copper content (up to 0.78 wt.% CuO) as our Mulungu samples (Soares, 1998). However, the Cu content of the Nigerian cuprian tourmalines analyzed thus far is similar to that of the Mina da Batalha material, with up to 2.18 wt.% CuO (Zang et al., 2001). Similar amounts of other chromophoric elements (i.e., Mn, Fe, Ti, Cr, and V) were present in gem tourmalines from both

TABLE 2. Microprobe analyses of blue to blue-green cuprian elbaïte from the Mina da Batalha (Paraíba) and Mulungu (Rio Grande do Norte) mines.^a

Property/ chemical component	Mina da Batalha (Fritsch et al., 1990) ^b				Mulungu mine (this study) ^c					
	Blue	Bluish green	Bluish green	Blue- green	Blue	Blue- green	Green- blue	Green- blue	Green- blue	Bluish green
Color	Blue	Bluish green	Bluish green	Blue- green	Blue	Blue- green	Green- blue	Green- blue	Green- blue	Bluish green
Refractive index										
n_e	1.619	1.620	1.620	1.621	1.619	1.618	1.618	1.619	1.618	1.618
n_o	1.639	1.640	1.640	1.646	1.639	1.638	1.638	1.638	1.638	1.639
Birefringence	0.020	0.020	0.020	0.025	0.020	0.020	0.020	0.019	0.020	0.021
Specific gravity	3.11	3.09	3.12	3.12	3.09	3.09	3.09	3.08	3.08	3.10
Oxides (wt.%)										
SiO ₂	36.97	36.75	36.83	36.53	37.00	37.07	35.99	37.21	37.79	36.97
TiO ₂	bdl	0.07	0.11	0.06	bdl	bdl	bdl	0.03	0.02	0.06
Al ₂ O ₃	38.95	38.99	39.35	38.58	40.81	37.62	37.64	41.35	40.43	37.63
Bi ₂ O ₃	0.11	0.83	0.03	bdl	0.47	0.27	0.46	0.48	0.81	0.47
V ₂ O ₃	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
FeO ^d	bdl	0.15	0.34	0.07	bdl	0.26	0.03	0.23	0.08	0.30
MnO	2.30	1.32	0.85	1.48	0.42	3.15	2.05	0.81	0.79	2.49
CuO	0.72	1.08	2.37	1.76	0.44	0.54	0.69	0.51	0.40	0.41
MgO	bdl	0.18	0.95	bdl	bdl	bdl	bdl	bdl	bdl	bdl
CaO	0.55	0.19	0.24	0.05	0.47	0.46	0.59	0.08	0.13	0.56
Na ₂ O	2.26	2.32	2.47	2.49	1.91	2.23	2.05	1.99	1.99	2.14
K ₂ O	0.02	0.02	0.02	0.02	0.04	0.04	0.03	0.03	0.03	0.04
PbO	bdl	bdl	0.02	bdl	0.08	0.08	0.23	0.04	0.02	0.06
ZnO	bdl	0.11	0.08	0.25	0.03	bdl	bdl	0.08	0.24	0.50
F	na	na	na	na	0.77	1.21	1.11	0.42	0.56	1.18
Partial total ^e	81.88	82.01	83.66	81.29	82.44	82.93	80.87	83.26	83.29	82.81

^a Abbreviations: bdl = below detection limit, na = not analyzed.

^b See also Bank et al. (1990), Ferreira et al. (1990), Henn and Bank (1990), Henn et al. (1990), Rossman et al. (1991), Brandstätter and Niedermayr (1993, 1994), and Simmons et al. (2001).

^c Data obtained with a JEOL JXA-733 electron microprobe at the California Institute of Technology, Pasadena, California. Operating conditions: 15 kV beam voltage, 25 nA beam current, 10 micron spot size, with mineral or synthetic compounds as standards and the CITZAF data correction procedure. Analyses represent the average of three data points on the table facet.

^d All iron reported as FeO.

^e Partial totals do not include Li₂O, B₂O₃, and H₂O, which could not be analyzed by the electron microprobe. Chromium and chlorine were below the detection limit in all of the samples we analyzed.

deposits. Trace elements that are unusual in elbaite tourmalines (such as Bi, Pb, and Zn) but present in the Mina da Batalha material are also present in Mulungu tourmaline and in cuprian tourmalines from other localities (Brazil and Nigeria). Thus, it is not possible to conclude that a blue-to-green cuprian tourmaline is from the original Batalha deposit solely on the basis of chemical composition.

CUTTING AND DISTRIBUTION

Most rough from the São José da Batalha area is sold to select cutting firms in Brazil and Germany. In turn, they sell the faceted material directly to a small number of dealers and jewelry manufacturers in the U.S., Japan, and Europe. Very special crystals or cut stones are marketed to private collectors.

Cutting of “Paraíba” tourmaline is similar to that for other gem tourmalines. Although some of this material is distinctly pleochroic, the bright blue tourmaline exhibits minimal pleochroism so faceting can be done in any orientation. Because of the high value of the rough, polished stones may display a variety of shapes and sizes to maximize yield. Some cutters feel that these tourmalines appear to be more resistant to chipping during manufacturing than other tourmalines.

The larger and higher-quality blue cuprian tourmalines from the São José da Batalha area have been sold mainly in Japan and the U.S. Additional markets include Europe, Hong Kong, Singapore, and Taiwan (“Paraíba tourmaline output...,” 1999). The brightly colored stones are commonly set in high-karat gold jewelry (see, e.g., figure 18).

TREATMENTS

As mentioned above, the six Mulungu cuprian tourmalines were “oiled” to minimize the visibility of surface-reaching fractures, as is commonly done with emeralds. Reportedly, some “Paraíba” tourmaline is also fracture-filled (see “Paraíba’s Tucson connection,” 2001). However, in the experience of BC and MB, this treatment is done only to lower-quality material. This practice is used in Brazil for a variety of colored gemstones to improve their apparent clarity.

Heating is also widespread with the cuprian elbaites. It is the understanding of BC that almost all of the material from the Mulungu mine is heat treated as a standard practice. According to R. Van Wagoner (pers. comm., 2002), at least 80% of the transparent blue to greenish blue material from the São José da Batalha area is heated. However,



Figure 18. Tourmaline from the Batalha mine is set in these rings of high-karat gold. Manufactured by Brian C. Cook and Paula Bailey; photo by Maha Tannous.

depending on the pegmatite being worked, there is a variable percentage of rough produced that is “common” green and cannot be improved with heat treatment. Heating is usually carried out after faceting so that few fluid inclusions are present. It requires careful control of temperatures as well as heating and cooling times, in addition to the proper selection of the starting material (which only comes through experience).

The treatment is carried out in simple electric furnaces without any atmosphere controls, typically at temperatures ranging from 480° to 620°C. These temperatures are significantly higher than some of those reported initially (e.g., 225°–250°C in Koivula and Kammerling, 1991a) and are slightly higher than those reported by Koivula and Kammerling (1990c): 350° to 550°C. According to R. Van Wagoner (pers. comm., 2002), in general purplish red stones turn “emerald” green at 480°–500°C but will lighten if heated too far. The “neon” blue and “turquoise” colors can be produced at 550°–620°C, depending on the starting color. Darker stones typically are more saturated after heating, but in some cases the color will fade if the stone is heated at too high a temperature.

Currently, we know of no reliable means to distinguish most of the heated and non-heated cuprian tourmalines except, perhaps, by the presence of visual indications such as undamaged or heat-damaged fluid inclusions. Heating is complicated by the complex chemical composition of tourmaline, and any of a variety of color-causing elements (some in different valence states) that may be present in an individual stone. Note, too, that not all colors of “Paraíba” tourmaline can be improved by heating. In very general terms, the following color changes can be achieved with heat treatment (Bernardes,

1999; R. Van Wagoner, pers. comm., 2002; see also figure 17 in Fritsch et al., 1990, p. 202).

- Purplish red → “emerald” green
- Purple → light purple
- Greenish blue → “neon turquoise”
- Violet to violetish blue → light blue to “neon” blue
- Dark blue → “neon” blue

IMITATIONS

Various substitute gem materials have occasionally been offered as “Paraíba” tourmaline, including tourmalines that lack copper. Some other imitations are:

- Bluish green apatite from Brazil and Madagascar (Koivula and Kammerling, 1990a; Koivula et al., 1993a), and blue cat’s-eye apatite (Koivula and Kammerling, 1991c)
- Doublets of tourmaline and colorless glass (Koivula and Kammerling, 1991c)
- Triplets of colorless beryl and blue or blue-green cement (Koivula et al., 1993b; Johnson and Koivula, 1996)
- Triplets of topaz and greenish blue cement (DelRe, 1995)
- Irradiated blue topaz (Koivula and Kammerling, 1991c)
- Greenish blue Tairus hydrothermal synthetic beryl (W. Barshai, pers. comm., 2001)

Standard gemological properties can be used to separate each of these imitations from cuprian elbaite.

CONCLUSION

Over the past decade, blue-to-green cuprian elbaites from the São José da Batalha area in Paraíba State have enjoyed strong demand due to their bright, saturated colors. Following the first important finds in the late 1980s, gem tourmaline production from the Mina da Batalha slowed until recently because of legal disputes over mine ownership, as well as disorganized and often ineffective mining. Recovery during the past two years from the surrounding area has provided additional gem tourmaline. The settlement of legal disputes at the Mina da Batalha and its environs has initiated a new stage of mining activity, resulting in further production of cuprian tourmaline.

Copper-bearing tourmalines have been found in at least two other pegmatites in the neighboring state of Rio Grande do Norte, which has led to expanded exploration for gem pegmatites in this region. A recent discovery of cuprian tourmaline, possibly geologically related to the Brazilian occurrences, has also been made in Nigeria. These finds have complicated the nomenclature of “Paraíba” tourmaline. Although some gem dealers believe they can identify the bright blue Mina da Batalha cuprian tourmalines on the basis of color, saturation, and brilliance, studies to date indicate that the gemological properties and chemical compositions of the cuprian tourmalines from these various sources overlap to such an extent that they cannot be distinguished by standard gem-testing methods.

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SPESSARTINE GARNET FROM RAMONA, SAN DIEGO COUNTY, CALIFORNIA

By Brendan M. Laurs and Kimberly Knox

For most of the 20th century, the principal source of fine spessartine was the area around the Little Three mine near the town of Ramona in southern California. Two pegmatites—the Hercules-Spessartite and the Spaulding dikes—yielded most of the estimated 40,000–50,000 carats of facet-grade rough mined from 1956 to 1994. Prized for its bright orangy yellow to yellowish orange color, Ramona spessartine has similar R.I. and S.G. values to those of most other pegmatitic gem spessartines. Typical internal features are wavy two-phase partially healed fractures, negative crystals, needles/tubes, growth patterns, and anomalous birefringence; mineral inclusions are rare. The composition of four samples (ranging from light orangy yellow to yellow-orange) was $\text{Sps}_{94.8-88.8}\text{Alm}_{4.7-11.0}\text{Gro}_{0.5-0.2}$, and the absorption spectra of all samples showed strong peaks for Mn^{2+} and subordinate Fe^{2+} bands.

The Little Three mining area near Ramona, California, has produced a variety of pegmatite gems, most notably an intense orange spessartine garnet (figure 1). The Ramona district lies within the extensive southern California pegmatite belt (figure 2). In the early part of the 20th century, San Diego County was one of the world's major gem-producing areas in terms of variety and quantity of material (Tucker and Reed, 1939). The most sought-after gem was tourmaline, recovered principally from the Mesa Grande and Pala districts. Beryl (aquamarine and morganite), spodumene (kunzite, first discovered at Pala), topaz, and smoky quartz were also important, but spessartine was relatively rare—except in the Ramona pegmatites. The bright orangy yellow to yellowish orange color and brilliance of the Ramona spessartines (figure 3), as well as the fact that this was the premier source of top-quality material for decades, have contributed to a premium on their price that was eclipsed only in the late 1990s by fine spessartine from Namibia and Nigeria (S. Robertson, pers. comm., 2001).

Despite the historical importance of Ramona spessartine, very little has been published on its gemological characteristics (see, e.g., Tisdall, 1961). This article describes the history and production,

mining methods, geology, and gemology of spessartine from this historic locality. An explanation of the unique conditions necessary for the formation of gem-quality spessartine in granitic pegmatites also is proposed.

HISTORY AND PRODUCTION

Spessartine was not well known as a gemstone until relatively recently. There is no history of the mineral before the 19th century (Rouse, 1986). The first pegmatite mine in the Ramona district, the Little Three, was discovered in May 1903 by H. W. Robb of Escondido, California (Kunz, 1905). It was named for Mr. Robb and his partners, Dan MacIntosh and Charles F. Schnack, who purchased the 40 acre (16.2 hectare) parcel of land from a rancher (Foord et al., 1989; LeMenager, 1989). Although this particular mine has never been an important source of spessartine, its yield of fine specimens of topaz, tourmaline, and other minerals has made it the most

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Figure 1. Spessartine from Ramona is prized for its intense orange color. The 10.25 ct spessartine in the pendant was cut from material recovered at the Spessartite mine in 1975. The spessartine in the ring on the right weighs 4.1 ct, and the spessartines in the earrings weigh about 2.5 ct each. Courtesy of Kerith Graeber; photo © Jeff Scovil.

important mine in the district. For this reason, Ramona spessartine is often referred to as coming from the “Little Three” mine.

By the end of 1903, several mines and prospects were staked in the Ramona district within an area smaller than 520 hectares (2 square miles). Kunz (1905) provided the best description of the early mines—including the Little Three, A.B.C. (or Daggett), and Hercules (see figure 4). Considerable amounts of topaz, tourmaline, spessartine, and beryl were recovered at the Ramona mines via open cuts and tunnels in the early years (figure 5; see Sterrett, 1908; Tucker, 1925; Tucker and Reed, 1939; Simpson, 1960; Weber, 1963). From 1903 to 1905, Kunz (1905) reported that over 10 kg of spessartine were produced from the district, yielding faceted gems up to 8 ct. By 1909, however, the near-surface deposits at the Little Three mine were considered exhausted (Spaulding, 1977). The collapse of the Chinese tourmaline market in 1912 halted pegmatite mining in southern California (Foord et al., 1989), and there was very little activity for the next four decades.

In 1947, Louis Spaulding and his son, Louis Spaulding, Jr., established several claims in the area (Simpson, 1960). Intensive mining began in 1955 at the Little Three mine, and since then the Spaulding family has been the most important producer of gems and minerals from the Ramona pegmatites. After his father’s death in 1973, Spaulding Jr. single-handedly took over work on several of the pegmatites, particularly the Little Three and Hercules-Spessartite dikes.

Although several mines in the Ramona district have produced spessartine, the best sources were the Hercules-Spessartite and Spaulding mines (again, see figure 4). The Spaulding dike was found

in December 1955, and the faceted spessartines produced initially were rather small (0.5–1.5 ct; Sinkankas, 1957). About 3,000 carats of faceting rough were mined over the period 1956–1959 (Sinkankas, 1959; Weber, 1963). From 1964 until shortly before his death, Spaulding Sr. produced 9,000 carats of faceted spessartine from this mine, but only three stones exceeded 6 ct (L. Spaulding Jr., pers. comm., 2001).

The Hercules-Spessartite pegmatite has a longer and more productive history. The Hercules mine was located in August 1903 on the northwest portion of this dike by A. V. Pray, S. G. Ingle, and H. Titus, who worked it for several years (Simpson, 1960). About 15 pounds (6.8 kg) of spessartine were produced during the period 1903–1905 (Kunz, 1905). After mining in the district resumed following the 1912 collapse of the Chinese tourmaline market, owners R. B. Winstead and G. Converse worked the property and even resurveyed it in 1954 (Simpson, 1960), but their production was not recorded. The Hercules was claimed by Elbert McMacken and Herb Walters in the 1960s and early 1970s; for two years during this period (1965–66), a portion was worked by John Sinkankas and his son (Sinkankas, 1967, 1976; figure 6). Bryant Harris purchased the mine in the late 1970s and worked it with E. “Buzz” Gray until 1984, but with little success (E. Gray, pers. comm., 2001).

The southern portion of the Hercules-Spessartite dike was mined by Spaulding Sr. in 1959; these workings were called the Spessartite mine (Simpson, 1963). This area later became the most important source of spessartine in the district—and produced several stones over 10 ct (see, e.g., figure 1)—when Spaulding Jr. expanded the open cut, beginning in 1975. In August 1987, Spaulding Jr. recovered a 72.5

ct piece of rough that was faceted by Buzz Gray into a 39.63 ct gemstone (figure 7), the largest cut spessartine known to date from Ramona and among the more than 2,300 grams of gem rough produced from 1987 to 1990 (L. Spaulding Jr., pers. comm., 2001). More large stones and mineral specimens (figure 8) were recovered from the Spessartite mine in 1993–1994. Among these was the 27.30 ct gem featured in the *objet d'art* called “The Light of Ramona” (figure 9). Additional small finds of spessartine were made by Spaulding Jr. at various Ramona mines up to 1995, and by another group in 1996–1997 (San Diego Mining Co., 2001), but there has been no significant garnet production since then.

Although total production figures are not available, Foord et al. (1989) estimated that about 40,000 carats of facet-grade spessartine have been

recovered from the Ramona district. (Note that Foord et al. [1991] indicated 70,000 carats of spessartine, but this appears to be a misprint.) Spaulding Jr. (pers. comm., 2001) also estimates the total production from the district at 40,000–50,000 carats of facet-grade spessartine. Much of the spessartine obtained by Spaulding Sr. was sold to George Ashley in Pala for cutting and distribution. Spaulding Jr. sold most of his facetable spessartine to Jonté Berlon Gems.

LOCATION AND ACCESS

The Little Three mine area is located in the Hatfield Creek valley, approximately 50 km (31 miles) northeast of metropolitan San Diego, and about 6 km (4 miles) east-northeast of the rural town of

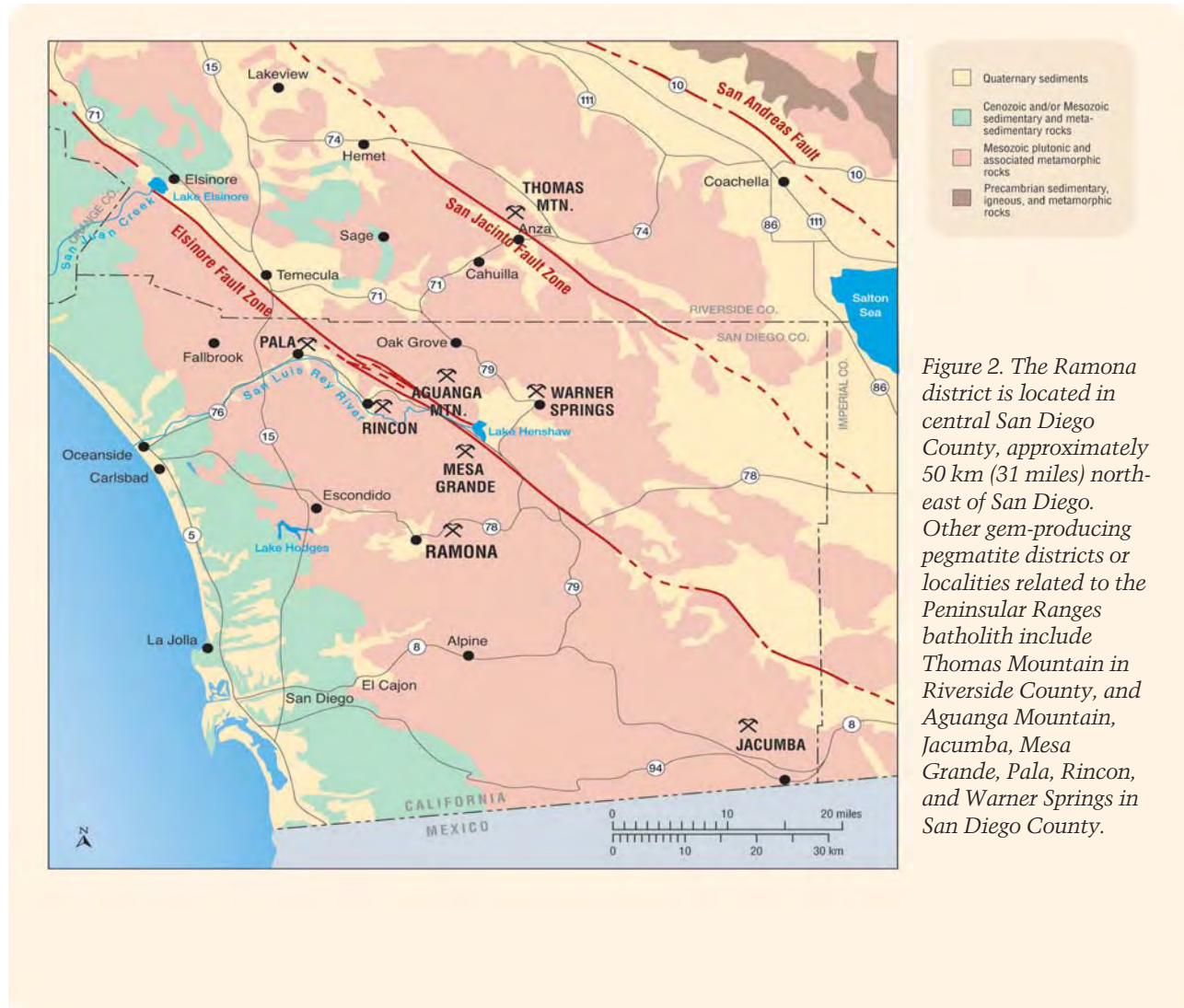


Figure 2. The Ramona district is located in central San Diego County, approximately 50 km (31 miles) north-east of San Diego. Other gem-producing pegmatite districts or localities related to the Peninsular Ranges batholith include Thomas Mountain in Riverside County, and Aguanga Mountain, Jacumba, Mesa Grande, Pala, Rincon, and Warner Springs in San Diego County.



Figure 3. Ramona spessartine (here 1.02–5.15 ct) typically ranges in color from orangy yellow to yellowish orange. Courtesy of Buzz Gray and Bernadine Johnston; photo © Harold and Erica Van Pelt.

Ramona. A paved highway leads from Ramona to a private dirt road that is shared by several landowners, and public access is prohibited. The authors visited the area at various times during 1997–2001.

Lying at an altitude of 580–700 m (1,900–2,300 feet), the mining area is a scenic parched terrain with rolling hills, covered with the dense scrub vegetation typical of San Diego County’s chaparral regions. The climate includes a little frost in winter, but temperatures can exceed 105°F (40.6°C) in summer. Most mining activity has taken place above ground, and the small diggings eventually become concealed by regrowth of the chaparral.

GEOLOGY

The geology of the Ramona pegmatites has been documented by numerous researchers, and it remains one of the best-studied pegmatite districts in the world (see, e.g., Merriam, 1948; Sinkankas,

1957; Simpson, 1960, 1963; Stern et al., 1986; Foord et al., 1989; Patterson, 1997; Morgan and London, 1999). The area is characterized by a complex series of intrusions that consist mostly of tonalite, with gabbro-diorite, diorite, granodiorite, and granite. These rocks have been mapped, classified, and named differently by various geologists, as compiled by Patterson (1997); they are all part of the Peninsular Ranges batholith of mid-Cretaceous age (120–100 million years [m.y.] old; Krumenacher et al., 1975). Radiometric dating of the muscovite from the Hercules mine yielded ages between 98.7 and 100 m.y. (Foord et al., 1991).

The Ramona district contains a series of pegmatite dikes in a northwest-trending belt about 4.5 km (2.8 miles) long and up to 1.6 km (1 mile) wide. Overall, the dikes strike northwest, and dip gently to moderately west to southwest. The pegmatites mined thus far typically range in thickness from 0.4 to 1.8 m (1.3 to 6 feet), and can be traced for distances up to 1,060 m (3,500 feet). In the vicinity of the Little Three mine, the dikes form locally undulating dip-slopes (i.e., erosion exposed the top surface of the pegmatites), so they

Figure 4. The Ramona district consists of a series of northwest-trending granitic pegmatites that have intruded tonalite and diorite. The locations of the main productive mines are shown: Little Three, Hercules, Spessartite, Spaulding, and A.B.C. Several other claims and prospects are not shown, owing to minor production and/or complexities in their naming and location. Modified from Simpson (1960), Weber (1963), and Foord et al. (1989).

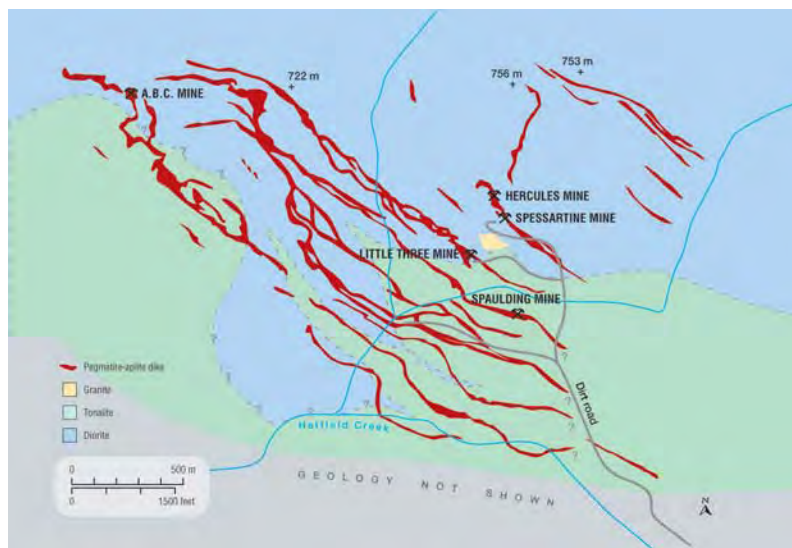




Figure 5. Before the collapse of the Chinese tourmaline market in 1912 halted pegmatite mining in San Diego County, significant gem production was obtained from the Ramona area. The main disturbance is the Little Three mine (left arrow), and the small dumps higher on the hillside are the Hercules mine (right arrow). Photo by D. B. Sterrett, U.S. Geological Survey, circa 1910.

Figure 7. This magnificent necklace was constructed in 1987 with more than 165 carats of Ramona spessartine (Koivula and Kammerling, 1988). The center stone, at 39.63 ct, is the largest cut spessartine known from Ramona. Courtesy of Michael M. Scott; photo © Harold and Erica Van Pelt.



Figure 6. The Hercules dike was mined for spessartine by John Sinkankas and his son John William Sinkankas in the mid-1960s. This photo shows Sinkankas Jr. drilling the pegmatite in preparation for blasting. Photo by John Sinkankas, February 1966.

were well positioned for surface mining.

Both Simpson (1960, 1963) and Stern et al. (1986) presented detailed maps of the mineralogical zoning. The dikes are typically layered, with pegmatite in the upper portion and aplite in the lower. For simplicity, these composite dikes are referred to simply as “pegmatites” throughout this article. The aplite is a fine-grained assemblage of quartz, sodic plagioclase, K-feldspar, schorl, and almandine-spessartine. The upper portion of the aplite is conspicuously banded, which miners refer to as “line rock.” The coarse-grained pegmatite is formed mostly of “graphic” quartz-perthite intergrowths (Simpson, 1962) and schorl, almandine-spessartine, and muscovite. Near the contact of these two units is a “pocket” zone that is characterized by relatively large euhedral crystals of quartz, feldspar, and other minerals. These minerals are often intergrown except in cavities where well-formed, free-standing crystals are attached to the pocket walls or suspended in clay. The largest, most economically important pockets in the Ramona district have yielded blue topaz, dark green tourmaline, and pale blue or pink beryl, but no spessartine (see, e.g., Foord et al., 1989).

The Ramona pegmatites show distinct differences in mineralogy and style of mineralization, even within a specific pegmatite (see, e.g., Sinkankas, 1957; Stern et al., 1986; Foord et al., 1989). Some of the pegmatites are mineralized only with spessartine (e.g., the Spaulding mine), whereas

others have only topaz, beryl, and/or colored tourmaline assemblages (e.g., the A.B.C. mine); also, various assemblages may be present in the same pegmatite, but in different areas separated by several meters (e.g., the Little Three and Surprise mines). Kunz (1905) was the first to describe this mineralogical zoning. Sinkankas (1957) reported that gem spessartine has been found only in areas that do not have colored tourmaline, which was confirmed by Spaulding Jr. with continued mining.

Most of the spessartine has been mined from small pockets and a unique vuggy feldspar-rich rock with little or no quartz (see box A). This distinctive rock contains numerous small, irregularly shaped corroded cavities, and has been called "cottonball spar" or "popcorn rock" by miners, who recognized it as a good indication of spessartine mineralization (Simpson, 1960; J. Sinkankas, pers. comm., 1998). The corroded rock locally crosscuts the pocket zone and overlying pegmatite, but is not found in the underlying aplite. It is commonly located in areas of pegmatite that are jointed and fragmented with subsequent recrystallization of quartz on the fracture

Figure 8. Many large stones and attractive gem crystals of spessartine were recovered from the Spessartite mine during the late 1980s to mid-1990s. The rough and cut (15.93 ct) stones shown here are courtesy of Buzz Gray and Bernadine Johnston; photo © Harold and Erica Van Pelt.



Figure 9. "The Light of Ramona" features a 27.30 ct cushion-cut spessartine accented by 62.23 carats of spessartine, all from Ramona, and 3.81 carats of feldspar. The design replicates the natural isometric crystal habit of garnet (see figure 8), as conceptualized by Bernadine Johnston and Buzz Gray. The piece is mounted on a covellite pedestal, with more spessartines at the base. It was designed by Kim Knox, and constructed by her together with Zane A. Gillum and Alan F. Hovey of Golden Pacific Arts, San Diego, California. Photos © Harold and Erica Van Pelt.

BOX A: RARITY AND FORMATION CONDITIONS OF SPESSARTINE

What are the conditions necessary to form gem-quality spessartine in granitic pegmatites? Traces of spessartine-almandine garnet are not uncommon in these pegmatites, where they form as small (2 mm or less) fractured crystals that are intergrown with the enclosing feldspars, quartz, and schorl tourmaline. However, very few pegmatites contain facetable spessartine. At the Ramona mines, the common occurrence of gem-spessartine within vuggy, corroded feldspar-rich rock suggests its formation is related to this rock type. This appears to be the case at other gem spessartine pegmatite as well, such as Alto Mirador in northeastern Brazil (figure A-1).

The corrosion and secondary crystallization of minerals (including spessartine) within the vuggy pegmatite at Ramona has been attributed to late-stage hydrothermal fluids that persisted after crystallization of the dikes (Sinkankas, 1957, 1997; Simpson, 1963). Such fluids evolve during the crystallization of all miarolitic (pocket-bearing) pegmatites (Černý, 2000), but only rarely does gem spessartine form. Sinkankas (1997) suggested that the hydrothermal solutions were introduced from “below” via channels created by earth movements. While such “open-system” conditions may have locally contributed to the etching and regrowth of some minerals in the pockets and vuggy rock, stable isotopic studies by Taylor et al. (1979) suggest that pocket minerals sampled from the Little Three and Hercules-Spessartite dikes crystallized under dominantly “closed-system” conditions.

The most important geochemical considerations for spessartine ($Mn_3Al_2Si_3O_{12}$) crystallization in granitic pegmatites appear to be: (1) pre-enrichment of the melt in Mn, and (2) concentration of Mn via pegmatite crystallization until the late-stage formation of gem-bearing pockets. The generation of Mn-enriched melts was mentioned briefly by London et al. (2001). Mn is not abundant in most granitic melts, and is concentrated (with other rare elements such as lithium, beryllium, and boron) in pegmatites through a process known as fractional crystallization. Mn is incompatible with the feldspars and quartz that constitute the bulk of pegmatite crystallization, so it becomes progressively concentrated during crystallization, particularly in the presence of fluorine (see, e.g., Černý et al., 1985). Together with rare elements and volatiles, Mn accumulates in the late-stage aqueous fluids that form the pegmatite pockets (see, e.g., Shigley and Kampf, 1984; Černý et al., 1985). It has been proposed that some of the Mn needed to form the gem spessartine was derived from the corrosion of previously crystallized almandine-spessartine (Sinkankas, 1997).

Why is spessartine so rarely found in the pockets? During pegmatite crystallization, the concentration of other elements (especially lithium) may stabilize minerals that consume Mn. The late-stage accumulation of Li may stop spessartine from forming in the pockets because the Mn will be preferentially incorporated into lepidolite and elbaite. At the Little Three mine in particular, Morgan and London (1999) and London et al. (2001) suggested that this mechanism halted spessartine crystallization. Likewise,

the accumulation of phosphorus (P) can consume manganese through the crystallization of Mn-Fe phosphates. As expected, the important spessartine-bearing dikes in Ramona (Hercules-Spessartite and Spaulding) do not contain lepidolite, elbaite, or phosphates, but it is conceivable that traces of these minerals could be present in other pegmatites that contain enough Mn to crystallize spessartine at late stages.

The bright orange color of gem spessartine from Ramona and other localities is achievable only with low Fe contents. Iron is typically more abundant than Mn in granitic pegmatites, but it also is depleted from the melt far faster than Mn by the crystallization of mafic minerals such as schorl and biotite (Foord and Kleck, 1993; London et al., 2001). Biotite is rare or nonexistent in the gem spessartine dikes in Ramona, so schorl (which is common) is the mineral responsible for depleting Fe. Indeed, London et al. (2001) reported that Mn is incompatible in schorl, so crystallization of this tourmaline can contribute to an increasing Mn:Fe ratio in the residual pegmatitic melt-fluid system.

The rarity of commercially important pegmatitic deposits of gem spessartine is apparently due to the strong geochemical correlation between Mn and Li in granitic pegmatites (Černý et al., 1985). Spessartine is common within the inner zones of “complex” granitic pegmatites that contain lithium (Baldwin and von Knorring, 1983), although it typically is not gem quality. The crystallization of facetable spessartine requires unusual conditions favoring enrichment of Mn, but not Li (and P), as well as the depletion of Fe in the late stages of pegmatite evolution.

Figure A-1. Gem spessartine is commonly associated with vuggy, corroded pegmatite. At the Alto Mirador pegmatite in northeastern Brazil (see Johnson and Koivula, 1999), facetable spessartine was recovered from a gem pocket and associated corroded pegmatite in the area shown here—particularly to the left of the large feldspar crystal (marked by a partial rim of schorl) above the hammer. The quartz core zone of the pegmatite is visible to the upper right. Photo by Brendan M. Laurs.



surfaces (J. Sinkankas, pers. comm., 1998).

Simpson (1960, 1963) noted that spessartine is found in a blue-gray clay (containing tourmaline needles) in the vugs or in larger cavities and fractures, sometimes with quartz, albite, potassium feldspar, and schorl (see also Sinkankas, 1997); rarely, it occurs with pale blue-to-pink beryl or pink apatite (L. Spaulding Jr., pers. comm., 2001). Although the spessartine in the "popcorn rock" is always corroded, the garnet crystals in the larger cavities may be either euhedral or corroded. In some places, such as in the productive open cut of the Spessartite mine, the feldspar-rich rock in the center of the pegmatite was altered to a 40-cm-thick layer of pink clay, in which the gems were "floating" (L. Spaulding Jr., pers. comm., 2001). Further north in this pegmatite (which was productive over about 45 m) spessartine from the Hercules mine typically formed in pockets with little or no associated corrosion of the surrounding pegmatite; here, the spessartine was not etched and well-formed mineral specimens were recovered, with the orange garnet commonly perched on cleavelandite (bladed albite) associated with schorl and smoky quartz (J. Sinkankas, pers. comm., 1998).

MINING

As is the case with most pegmatites, experience and intuition are key to determining where to dig for spessartine and other gems in the Ramona district. Most of the mining has been surficial, accomplished by "peeling" away the upper portion of the pegmatites that lie exposed on the hillside. This was initially done with a pry bar and occasional explosives. In addition to small open cuts, a few tunnels explore portions of the pegmatites that lie further underground. Most of the work done by Spaulding Jr. has been accomplished in open cuts using a bulldozer, backhoe (figure 10), and a minimal amount of drilling and blasting.

The gem-bearing pockets are carefully excavated using chisels, ice picks, and wooden sticks (figure 11). The pocket contents are carefully cleaned in oxalic acid to remove iron staining. Mineral specimens—rather than gem rough—are most sought after. The spessartine crystals attain sizes up to 3–4 cm and form showpieces when attached to a matrix of white cleavelandite and black schorl tourmaline (see, e.g., figure 12 here and figure 3 of Foord and Kleck, 1993). Only broken, damaged, or otherwise non-specimen-quality crystals are faceted. According to Spaulding Jr., only about 1% of the spessartine found in the pockets has been facetable.



Figure 10. Most of the spessartine production from Ramona came from the Spessartite mine, which was expanded with a backhoe. The pegmatite is dipping into the open cut from the right side. Courtesy of Louis Spaulding Jr.

Figure 11. Spessartine-bearing pockets are carefully excavated by hand, as shown here at the Spessartite mine. Courtesy of Louis Spaulding Jr.





Figure 12. Fine mineral specimens from the Ramona pegmatites are prized by collectors. The aesthetic combination of orange spessartine, black schorl, and white cleavelandite are unrivalled by spessartine specimens from other localities. Gemstones such as the fine 5.15 ct example shown here are faceted only from broken, damaged, or otherwise non-specimen-quality crystals. Photo © Harold and Erica Van Pelt.

MATERIALS AND METHODS

The Ramona study samples consisted of 14 faceted spessartines (0.47–15.93 ct) loaned by Jonté Berlon Gems, and 16 faceted (0.27–1.26 ct) and two mineral specimens (with a total of four garnets on matrix) from the GIA collection. The two matrix samples were typical of dozens of Ramona spessartine mineral specimens examined by the senior author over the past several years. Standard gemological properties were obtained on all the faceted stones. A Duplex II refractometer with a near-sodium equivalent light source was used for refractive index readings. Specific gravity was determined by the hydrostatic method, and a desk-model spectroscope was used to examine the absorption spectra. Reaction to ultraviolet radiation was viewed with four-watt long- and short-wave UV lamps. Internal features and anomalous birefringence were observed with a standard gemological microscope; the latter was

also viewed with a polariscope. Laser Raman microspectrometry was performed using a Renishaw 2000 Ramascope on selected faceted samples to identify mineral inclusions.

Four of the samples—ranging from light orangy yellow to medium yellow-orange, which is representative of most faceted material from Ramona (figure 13)—were analyzed further. Their chemical composition was measured by electron microprobe (Cameca SX-50), and UV-Vis-NIR absorption spectra were obtained in the region 250–2500 nm with a Hitachi U4001 spectrophotometer. Grain mounts (one per sample) of spessartine from selected worldwide localities (i.e., Minas Gerais and Rio Grande do Norte, Brazil, and Maevatanana and the Sahatany Valley in Madagascar) were also analyzed by electron microprobe for comparison with the Ramona samples. Data for spessartine from other localities were taken from the literature.

RESULTS

Description of the Rough. The two mineral specimens consisted of gem-quality spessartine crystals on a matrix of cleavelandite feldspar; one specimen also had schorl. The spessartine was light yellowish orange to medium brownish orange with no eye-visible color zoning. The crystals were transparent in areas between fractures, some of which were partially healed. All of the spessartines on one of the specimens showed corrosion features consisting of lustrous micro-stepped surfaces (see, e.g., figure 14). These etch features appear similar to those observed on spessartine from other pegmatites (see, e.g., figure 1 of Sinkankas and Reid, 1966). Both dodecahedral and trapezohedral faces were observed on the crystals. The dodecahedral faces showed subtle diamond-shaped growth hillocks, while the trapezohedral faces were smooth on the specimen that was not corroded.

Visual Appearance and Gemological Properties. The results of the gemological characterization are presented in table 1, together with data for spessartines from other localities for comparison.

The samples ranged from light orangy yellow to dark brownish orange; most were light orangy yellow to medium yellow-orange (again, see figure 13). These samples represent the range of color of gem spessartine from the Ramona district. None of the stones showed eye-visible color zoning. The samples were transparent with relatively few inclusions visible with the unaided eye.

Refractive indices ranged from 1.799 to 1.808, although samples in the commercially most desirable orangy yellow to yellow-orange color range had R.I. values of 1.799–1.803. Overall, the lightest orange samples had lower R.I. values. S.G. values fell within 4.19–4.26, and showed no correlation to color or R.I. value. All stones were inert to both short- and long-wave UV radiation.

Microscopic observation revealed wavy planes of one- or two-phase (liquid-gas) inclusions in nearly all stones (see, e.g., figure 15), as documented in spessartine by Gübelin and Koivula (1986), Rouse (1986), and Webster (1994). Individual inclusions within these partially healed fractures and “fingerprints” appeared as points, subparallel elongate and needle-like forms, and irregular bodies. In five samples, we saw linear arrays of tiny particles forming wisps and clouds; these were typically associated with the fingerprint-like features. Flat, isolated two-phase (liquid-gas) inclusions were present in two samples (see, e.g., figure 16). Three-phase (solid-liquid-gas) inclusions also were seen in a few samples. Fractures (i.e., “feathers”) were rare, and showed jagged outlines.

Several samples had relatively large negative crystals and/or elongate etch channels. These channels typically showed striated surfaces and irregular angular shapes (see, e.g., figure 17), although one had a rectangular cross-section that tapered lengthwise into a tube. A swarm of minute, parallel needles (probably hollow tubes) was seen in two samples. Mineral inclusions were rare. Raman analysis identified irregular-shaped, colorless inclusions with a rough texture in three samples as albite (see, e.g., figure 18), and a black tapered crystal in one sample as columbite (figure 19). Another sample contained three minute colorless crystals surrounded by tension fractures and subtle dark halos (figure 20); these appeared to be zircon, but they could not be identified by Raman analysis due to their small size and position in the stone.

Most samples showed faint growth zoning, with planar, angular, and irregular patterns. Strong planar growth zoning was seen in a few samples (see, e.g., figure 21), where it corresponded to sharply defined planar zones of anomalous birefringence that were visible in certain orientations. All samples displayed anomalous birefringence (see, e.g., figure 22), typically as light gray areas that appeared cloud-like with diffuse boundaries, or as irregularly shaped zones that were centered around points or nodes when the samples were rotated. In some samples, patches of birefringence had a cross-hatched appear-



Figure 13. These four orangy yellow to yellow-orange spessartines (0.48–1.15 ct), part of the study sample, show the range of color that is most representative of faceted material from Ramona. Photo by Maha Tannous.

ance. With the exception of the strong planar pattern mentioned above, the birefringence frequently did not show any relation to the growth features seen with plane polarized light. When viewed with the polariscope, anomalous double refraction was visible in most of the samples; the birefringence formed gray patches or linear zones with subtle to obvious intensity.

Chemical Composition and Absorption Spectroscopy.

The four samples analyzed by microprobe showed a consistent decrease in manganese and increase in iron as the color varied from light orangy yellow to medium yellow-orange (table 2). The greatest manganese concentration (40.67 wt.% MnO) was recorded in the lightest orangy yellow sample, and falls near the highest values found in the literature for gem-quality spessartine. Traces of titanium and calcium were detected in all four samples, but magnesium was below the

Figure 14. Corroded spessartine crystals typically show a series of lustrous micro-stepped surfaces. Photomicrograph by John I. Koivula; magnified 2×.

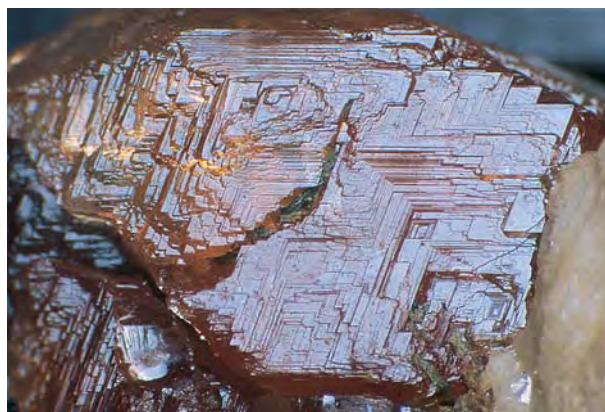


TABLE 1. Properties of spessartine from various localities.^a

Property	Ramona, California	Ramona, California ^b	Minas Gerais, Brazil ^c	Madagascar	Mozambique
Reference/no. of samples	This study/30	Tisdall (1961)/4	Unpublished GIA research/1	Tisdall (1962)/nr	Bank et al. (1998)/nr
Color	Orangy yellow to brownish orange	Yellowish orange	Orange	Orange-red, dark to pale	Brownish orange
Optic character	ADR	nr	Slight ADR	nr	Strong ADR
Refractive index (range)	1.799–1.808	>1.81	1.800	>1.81	>1.81
Specific gravity	4.19–4.26	4.17	4.20	4.17	4.15–4.18
Internal features	Wavy partially healed fractures, growth patterns, negative crystals, etch channels, needles/tubes, linear clouds, isolated fluid inclusions, feathers, mineral grains (albite, columbite)	Angular three-phase inclusions, "fingerprints"	Subparallel reflective stringers, irregular needles, small transparent crystals, parallel planar growth zoning	No three-phase inclusions; fine, close striae (like synthetic ruby)	Growth zoning; feathers of film-like fluids; minerals observed as needles or platelets with high birefringence
Absorption spectra (nm) ^d	Cutoff at 435–440; bands at 460, 480–485, and 520–525; 504 line and 570 band in some samples	Cutoff at 439; wide band at 461, wide, very strong band at 482; faint shadow at 502, faint broad band at 527	Spessartine spectrum, with very strong band at 430	Absorption in blue-violet, with strongest band centered at 432; intense bands centered at 461 and 484; weak bands at 505 and 527	Absorption features at 408, 422, 428, 460, 483, and 524

^a Abbreviations: ADR=anomalous double refraction, nr=not reported, SR=singly refractive. In addition, 50 spessartine-almandine garnets from Amelia, Virginia, ranging from dark red-brown to pale orange, had R.I.'s of 1.795–1.809 and S.G.'s of 4.16–4.19 (Sinkankas and Reid, 1966).

^b See also Anderson (1961).

^c 4.81 ct sample; see also Bank et al. (1970) and Johnson and Koivula (1999).

^d Also known as Mandarin garnet; from the "original" mining area in northwest Namibia that was discovered in 1992; see also Koivula et al. (1993).

^e Also known as Mandarin garnet; from a different mining site about 30 km south of the original site, discovered in 1995; see also Kammerling et al. (1995), Bank et al. (1996).

^f Also known as Kashmirine.

^g Determined by either spectroscopic or spectrophotometric means; values reported for this study are as observed with the spectroscope.

detection limit (<0.01 wt.% MgO). The composition of these Ramona spessartines can be summarized as $\text{Sps}_{94.8-88.8}\text{Alm}_{4.7-11.0}\text{Gro}_{0.5-0.2}$.

The spectroscope revealed a cutoff at 435–440 nm in all samples. Weak to moderate bands were centered at approximately 460 nm and 520–525 nm, and a strong band was present at approximately 480–485 nm. The latter band formed a region of general absorption with the 504 nm band in the darkest samples. In lighter samples, the 504 nm band was

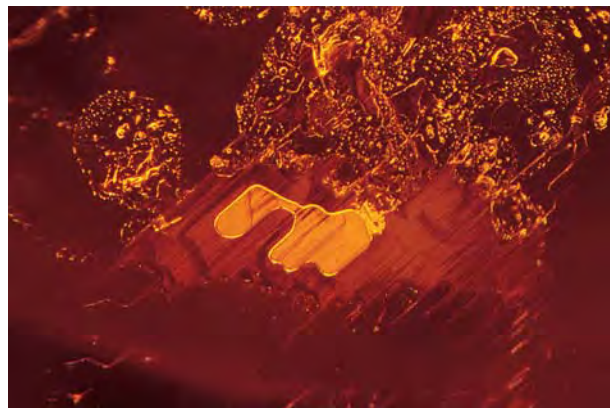
very weak or nonexistent. Another band at 570 nm could be seen in all but the lightest stones.

All four Ramona samples showed similar absorption spectra with the spectrophotometer in the UV-Vis-NIR range. The strongest peak was located at approximately 409 nm; on the shoulder were two additional strong peaks at approximately 421 and 430 nm (figure 23). Also present in the visible range were bands at approximately 460, 483, 504, 525, and

Figure 15. "Fingerprints" consisting of wavy planes of variously shaped two-phase (liquid-gas) inclusions were commonly observed in the Ramona spessartine. Photomicrograph by John I. Koivula; magnified 35 \times .



Figure 16. Flat, isolated two-phase (liquid-gas) inclusions were seen in only two spessartine samples. Note also the partially healed fractures consisting of minute two-phase inclusions in the upper part of the photo. Photomicrograph by John I. Koivula; magnified 20 \times .



Namibia ^d	Namibia ^e	Iseyin, Nigeria	Pakistan ^f	Lundazi, Zambia
Koivula et al. (1993)/3; Lind et al. (1994)/13 Orange	Johnson and Koivula (1996a)/7 Orange	Milisenda and Zang (1999)/6, Zang et al. (1999)/9 Orange-yellow	Henn (1996)/n.r.; Johnson and Koivula (1996b)/4 Orange-red to "cherry" red; slight yellowish orange to brownish orange or red-orange	Johnson et al. (1999)/5 Orange
nr 1.790–1.797	SR 1.789–1.790	nr 1.801–1.803	Weak ADR 1.798–1.802	nr 1.799–1.800
4.09–4.15 Angular and roiled growth structures, curved fibers, rounded crystals, dark angular crystals	4.12–4.14 Quartz, fibrous amphibole, oxides (ilmenite, hematite, senaite), barite	4.18–4.23 Two-phase inclusions along healed fractures, zircon with tension cracks	4.05–4.18, 4.19–4.20 "Fingerprints," growth zoning, K-feldspar, acicular inclusions	4.20–4.25 Typical garnet growth bands and "fingerprints"
Cutoff at 445, distinct diffused band above 460; stronger, wider diffused band at 480–490; weak diffused band at 525–545. Also lines at 408, 421, and 430	Lines at 412, 424, 432 (edge), 462, 485, and 495	"Typical spessartine absorption features" plus local maxima at 469, 482, and 527	Mn ²⁺ bands at 408, 421, 430, 460, and 482; Fe ²⁺ bands at 503, 524, and 564	Cutoff at 435, bands at 460, 480, and 530; weak 504 line

570 nm. Within the near-infrared region were broad regions of absorption centered at about 1300 and 1700 nm (the latter being very subtle), and two bands of low intensity around 2300 nm.

DISCUSSION

For several decades, the Ramona area was the principal source of the world's high-quality spessartine gemstones. Other historic localities for gem-quality spessartine include Madagascar (Tisdall, 1962); Amelia, Virginia (Sinkankas and Reid, 1966; Sinkankas, 1968); Ceará, Brazil (Pough, 1965; Cassedanne and Cassedanne, 1977b); Minas Gerais and Rio Grande do Norte, Brazil (Bank et al., 1970; Cassedanne and Cassedanne, 1977a; Johnson and Koivula, 1999; Ferreira et al., 2000); Kenya

(Medenbach et al., 1978); and Sri Lanka (Noor Deen, 1984). Myanmar and India have also been reported as spessartine sources (Webster, 1994). More recently, gem spessartine has been recovered from Pakistan (Henn, 1996; Johnson and Koivula, 1996b) and Mozambique (Bank et al., 1998). Particularly fine material has been produced from Namibia (Koivula et al., 1993; Lind et al., 1994; Johnson and Koivula, 1996a), Nigeria (Milisenda and Zang, 1999; Zang et al., 1999), and Zambia (Johnson et al., 1999). All of these deposits probably have a common geologic origin (granitic pegmatites), except for those in Namibia. The gemological and chemical characteristics for spessartine from Ramona are discussed below and compared to data from other localities.

Ramona spessartine that is most likely to be seen in the gem trade is characterized by an intense

Figure 17. This irregular-shaped etch channel in a 0.61 ct spessartine is bounded on both sides by strong growth lines. Photomicrograph by John I. Koivula; magnified 15 \times .

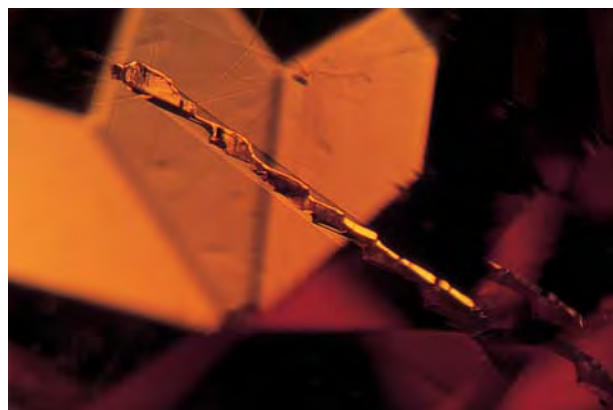
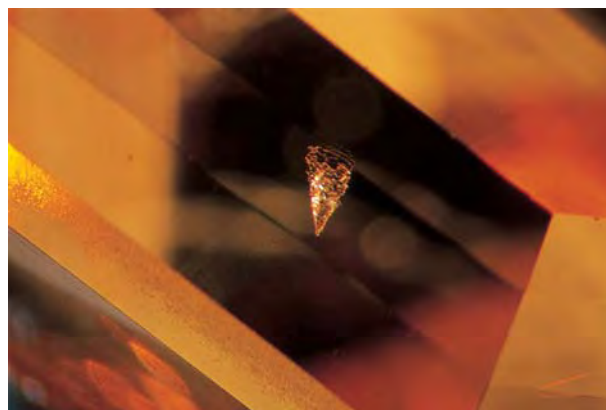


Figure 18. Raman analysis confirmed that this rough-surfaced, irregular platy inclusion is albite. Photomicrograph by John I. Koivula; magnified 15 \times .



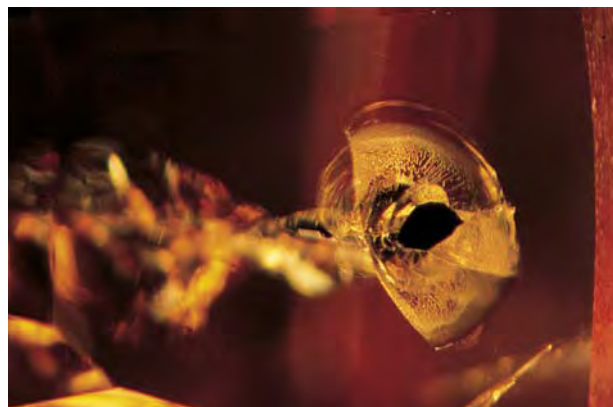


Figure 19. Surrounded by a stress fracture, this black inclusion in spessartine was identified as columbite by Raman analysis. Photomicrograph by John I. Koivula; magnified 10 \times .



Figure 20. These three minute colorless crystals surrounded by tension fractures appear to be zircon, but they could not be identified by Raman analysis due to their size and position within the stone. Photomicrograph by John I. Koivula; magnified 20 \times .

TABLE 2. Chemical composition of gem-quality spessartine from various deposits.^a

Reference Description	Ramona, California ^b				Minas Gerais, Brazil ^c	Rio Grande do Norte, Brazil ^d	Sahatany Valley, Madagascar ^e	Maevatanana, Madagascar
	This study Lt. orangy yellow, 0.48 ct, R.I.=1.799	This study Med.-lt. orangy yellow, 0.70 ct, R.I.=1.800	This study Med.-lt. orange- yellow, 1.15 ct, R.I.=1.801	This study Med. yellow- orange, 0.92 ct, R.I.=1.802	This study Orange-yellow, fragment	This study Lt. orangy yellow to yellowish orange, fragments	This study Orange-yellow, fragment	This study Orange-yellow, fragment
Oxides (wt.%)								
SiO ₂	36.30	36.58	36.71	36.32	36.36	36.57–36.72	36.52	36.35
Al ₂ O ₃	20.56	20.38	20.28	20.49	20.78	20.15–20.85	20.78	20.86
TiO ₂	0.07	0.06	0.07	0.04	na	0–0.16	na	na
MnO	40.67	40.02	38.33	37.16	39.09	34.97–41.25	35.81	35.89
MgO	<0.01	<0.01	<0.01	<0.01	<0.01	0.44–1.48	<0.01	<0.01
FeO ^f	2.06	2.89	3.62	4.64	3.04	1.03–4.83	4.23	3.39
CaO	0.18	0.07	0.06	0.06	0.57	0.39–0.40	1.81	2.85
Total	100.01 ^g	100.05 ^h	99.07	98.71	99.84	99.76–99.69	99.15	99.34
End members (mol.%)								
Spessartine	94.8	93.2	91.3	88.8	91.3	82.0–94.6	84.7	83.8
Almandine	4.7	6.6	8.5	11.0	7.0	2.4–10.9	9.9	7.8
Grossular	0.5	0.2	0.2	0.2	1.7	1.2	5.4	8.4
Pyrope	—	—	—	—	—	1.8–6.0	—	—

^aAbbreviations: lt.=light, med.=medium, na=not analyzed, nr=not reported. Analyses performed for this study used a Cameca SX-50 electron microprobe, with minerals or synthetic compounds as standards, an accelerating voltage of 20 kV, sample current of 15 mA, and the data correction procedure of Pouchou and Pichoir (1985). The following elements also were sought but not detected (detection limits shown are wt.%): F=0.21, Na₂O=0.02, P₂O₅=0.02, Sc₂O₃=0.05, TiO₂=0.03, V₂O₅=0.05, Cr₂O₃=0.04, ZnO=0.09, SrO=0.02, Y₂O₃=0.07, SnO₂=0.05. All other analyses were by electron microprobe, except for the Nigerian spessartine (by SEM-EDS). In addition, 50 electron microprobe analyses of spessartine from the Amelia, Virginia, yielded Sps₅₀Alm₄₀Gro₇ to Sps₃₅Alm₃Gro₂ (Sinkankas and Reid, 1966). Major- and trace-element data for spessartine-almandine garnets from several localities is presented in Taylor (1998).

^bChemical data on Ramona spessartine is found in several publications. Taylor et al. (1979) determined an oxygen isotope value ($\delta^{18}O$) of +5.4‰ for a pocket crystal from the Hercules-Spessartite dike. In a sample containing 3.0% Fe, Foord et al. (1989) recorded the following trace elements by emission spectrometry: 0.07% Ca, 0.05% Ti, 0.0015% Mg, 70 ppm Sc, 70 ppm Ge, 150 ppm Y, 50 ppm Zr, 30 ppm Nb, 70 ppm Gd, 50 ppm Dy, and 3 ppm Yb. Taylor (1998, p. 37) recorded average values of 0.39 wt.% P₂O₅ and 0.17 wt.% TiO₂, and no Zr or F, in two electron microprobe analyses of a sample with an average composition of Sps_{83.9}Alm_{14.7}Gro_{1.41}; additional trace elements were measured by direct-coupled plasma emission spectrometry (ppm)—Li=21, Nb=83.5, Cs=1.5, Ta=27.5, Pr=0.3, Nd=1.8, Eu=0.5, Gd=1.5, Tb=0.3, and Dy=6.1. See also Foord and Kleck (1993).

^cSee also Bank et al. (1970).

^dRange from 21 analyses of three samples from the Alto Mirador mine.

^eSee also von Knorring and Baldwin (1969) and Schmetzer et al. (2001).

^fAll iron is reported as FeO.

^gAlso contained 0.17 wt.% P₂O₅.

^hAlso contained 0.05 wt.% P₂O₅.



Figure 21. Parallel planar growth zoning was conspicuous in a few of the spessartines, with angular and irregular growth patterns also noted. Photomicrograph by John I. Koivula; magnified 10 \times .

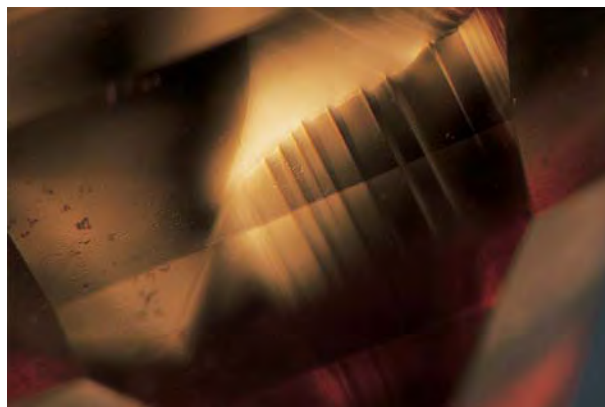


Figure 22. Anomalous birefringence was evident as irregular patterns with diffuse boundaries in all the spessartine samples. Here, planar growth zoning transects an area showing anomalous birefringence. Photomicrograph by John I. Koivula; magnified 10 \times .

Namibia	Nigeria	Pakistan	Zambia
Lind et al. (1994)	Zang et al. (1999)	Henn (1996)	This study
Orange	Orange-yellow	Orange-red to "cherry" red	Orangy yellow, fragment
33.93–36.70	36.1	36.39	36.51
18.87–20.35	21.4	20.60	20.79
up to 0.11	nr	nr	nr
37.63–42.60	40.6	36.98	40.86
2.71–3.20	0.94	nr	<0.01
0.89–1.08	0.64	4.45	1.53
0.41–0.58	0.27	1.58	0.22
99.18–100.47	99.95	100.00	99.91
84.0–87.0	up to 94	85.3	95.8
1.9–2.0	1.5–11	10.1	3.5
1.1–1.4	nr	4.6	0.7
9.8–12.6	3.5	—	—

orangy yellow to yellowish orange color; R.I. values of 1.799–1.803; S.G. values of 4.19–4.26; internal features consisting most commonly of wavy planes of partially healed fractures, negative crystals, and growth patterns (planar, angular, and irregular); and absorption bands at approximately 460, 480–485, 504, 520–525, and 570 nm, with a cutoff at 435–440 nm.

To the best of our knowledge, Tisdall (1961) published the only other article on the gemology of Ramona spessartines. He reported a higher R.I. value (>1.81) than we measured in our samples. However, our values are similar to those reported for spessartine by Stockton and Manson (1985: 1.798–1.808), as well as by Liddicoat (1989) and

Webster (1994): 1.790–1.797 or 1.789–1.790. Our R.I. values also are consistent with those reported for other localities (see table 1), with the exception of Namibian spessartine with its lower range (1.789–1.797). Also, reported values for samples from Madagascar and Mozambique were over the limits of a standard refractometer (>1.81). Sinkankas and Reid (1966) documented somewhat lower R.I. values of 1.795–1.798 for near-end-member spessartine from Amelia, Virginia, and a general increase in R.I. with increasing iron content and darker color (e.g., approximately 1.808 for compositions around $\text{Sps}_{62}\text{Alm}_{38}$). We also recorded a general increase in R.I. with darker color. In the four chemically analyzed samples, there was a systematic correlation of R.I. with spessartine-almandine content: 1.799 to 1.802 for $\text{Sps}_{94.8}\text{Alm}_{4.7}\text{Gro}_{0.5}$ to $\text{Sps}_{88.8}\text{Alm}_{11.0}\text{Gro}_{0.2}$.

The S.G. values we obtained, 4.19–4.26, were higher than the 4.17 value determined by Tisdall (1961) using ethylene dibromide, and also higher than the general range given by Liddicoat (1989) and Webster (1994) for spessartine: 4.12–4.18 and 4.12–4.20, respectively. However, our values fall within the range Stockton and Manson (1985) determined for spessartine (4.18–4.27), and they are comparable to those reported for spessartine from some other localities (i.e., Brazil, Nigeria, and Zambia; see table 1).

The features we observed with magnification are consistent with the "fingerprints" (partially healed fractures) and angular three-phase inclusions that Tisdall (1961) found in his four samples of Ramona spessartine. The negative crystals and growth zoning seen in our samples also have been previously noted (Rouse, 1986 and Liddicoat, 1970, respectively; see also table 1). However, the linear clouds and

inclusions of albite and columbite identified in this study have not been reported in spessartine from other localities. It was not surprising to find albite inclusions, since Ramona spessartine is commonly intergrown with albite (cleavelandite). Also, Nb-Ta oxides such as columbite are relatively common in late-stage albitic mineral assemblages in granitic pegmatites (see, e.g., Černý, 1992). Inclusions of schorl also have been reported in spessartine from Ramona (E. Gray, pers. comm., 2001), but not from other localities.

The four Ramona samples we analyzed by electron microprobe were similar in chemical composition to those from the other pegmatite localities in table 2 (i.e., all but Namibia), although higher calcium contents were recorded in spessartines from most of the other deposits. The highest Mn contents (i.e., spessartine component) were measured in samples from Ramona, Zambia, Brazil (Rio Grande do Norte), and Nigeria. The lowest Fe contents (i.e., almandine component) were found in material from Nigeria and Namibia. The compositions of samples analyzed from Madagascar and Pakistan are similar to one another, and show higher Ca and lower Mn than the others. The Namibian spessartine is enriched in magnesium compared to the others, reflecting its unique geologic environment within metamorphic rocks. Magnesium is not typical of granitic pegmatites (Černý et al., 1985), although traces may be derived from host rocks surrounding a pegmatite.

The visible absorption features we observed are comparable to data reported by Tisdall (1961) for

Ramona spessartine. The Mn^{2+} bands (at approximately 409, 421, 430, 460, and 483 nm) recorded in our samples also are consistent with those measured by Lind et al. for spessartine from Ramona and Namibia (see also Manning, 1967; Stockton and Manson, 1985). Also, Fe^{2+} -related bands at approximately 504, 525, and 570 nm in our samples are consistent with those reported by Lind et al. and Stockton and Manson. However, additional Fe^{2+} -related bands at 610 and 690 nm recorded in Ramona spessartine by Lind et al. were not evident in the samples we analyzed (again, see figure 23).

Overall, the absorption spectra of the four Ramona samples were similar, as expected from their relatively narrow range in color and composition (again, see figure 13 and table 2). The spectra were dominated by an intense Mn^{2+} absorption at approximately 409 nm (again, see figure 23); this peak is actually the result of combined strong absorptions at 407 and 411 nm (Stockton and Manson, 1985). The darker samples showed a subtle increase in the strength of the 504 and 570 nm peaks, as expected from the spectroscopy and chemistry results. The Mn^{2+} peaks at approximately 430, 460, and 483 nm in the darkest sample were less defined than in the other samples.

The broad regions of absorption in the near-infrared region (at about 1300, 1700, and 2300 nm) may be due to traces of hydroxyl groups (compare to Lind et al., 1994). Hydrous components in garnet are most easily detected in the infrared spectra (as absorption bands in the 3600 cm^{-1} region), which were not collected in this study; traces of hydrogen

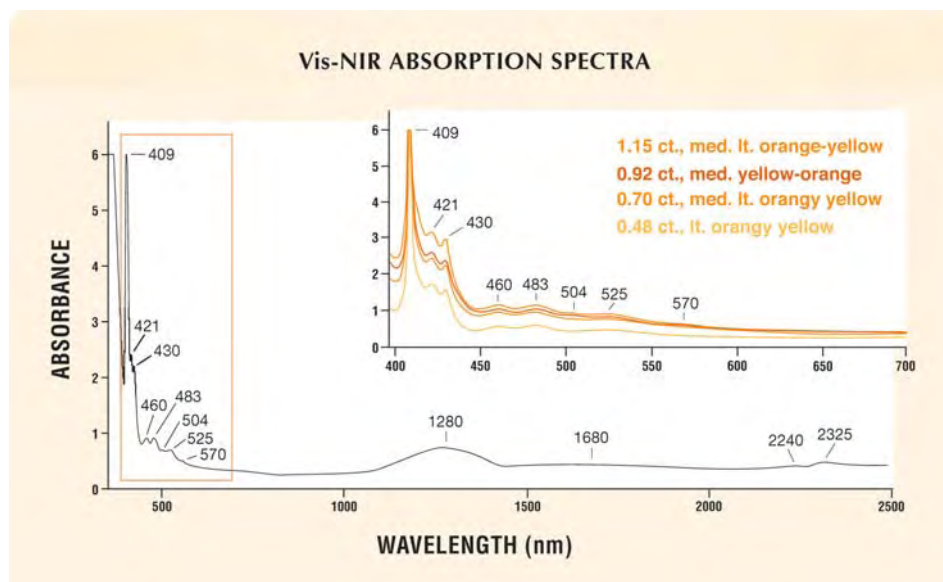


Figure 23. This UV-Vis-NIR absorption spectrum of a 0.70 ct medium-light orangy yellow spessartine is representative of the Ramona material. It shows a dominant peak at 409 nm, with additional strong peaks at 421 and 430 nm and several smaller peaks; broad regions of absorption in the near-infrared are located at around 1300, 1700, and 2300 nm. The inset shows the absorption spectra of all four samples pictured in figure 13 in the visible region (400–700 nm). Note the subtle increase in the strength of the 504 nm peak in the darker samples. The four samples measured 2.9–4.3 mm from table to culet; path distances of the beam could be significantly longer.

(expressed as 0.038 wt.% H₂O) were found in Ramona spessartine by Rossman et al. (1988) by nuclear reaction analysis.

According to Fritsch and Rossman (1987), the orange color of spessartine is caused by Mn²⁺ in a site with distorted cubic coordination. Iron causes the intrinsic yellow-orange color of spessartine to darken into red and brown hues (Sinkankas and Reid, 1966). The orangy yellow to brownish orange color seen in Ramona spessartine is due to a combination of absorptions from Mn²⁺ and Fe²⁺.

Identification. Our review of the literature revealed no report of the growth of gem-quality spessartine in the laboratory, and we know of no treatments done to the natural material. Spessartine may resemble orange grossular, and at one time the Ramona material was thought to be hessonite (Sinkankas, 1959); it was called “hyacinth” (a varietal name for orange grossular) by the locals in the early years of mining (L. Spaulding Jr., pers. comm., 2001). Stockton and Manson (1985) studied three types of reddish orange garnet that could be confused with one another—“malaya,” grossular, and spessartine-almundine—and found they could be separated by their R.I. values and spectroscopic spectra.

Spessartine also may resemble zircon, sphene, topaz, and citrine (Liddicoat, 1989), but these can be separated easily with standard gemological testing. Federman (1994) noted the similarity between spessartine and Mexican fire opal, but also pointed out their obvious gemological differences. Spessartine also resembles the rare gem clinohumite, but the two minerals can be readily separated on the basis of optical properties and UV fluorescence (Hyrsl, 2001).

CONCLUSION

The historic Little Three mining area in Ramona, California, was the principal source of gem-quality spessartine for most of the 20th century. Most of the spessartine production occurred sporadically from 1956 to 1994. An estimated total of 40,000–50,000 carats of facetable rough was mined chiefly from the Hercules-Spessartite and the Spaulding dikes, within vuggy corroded pegmatite and small “pockets.”

Ramona spessartines characteristically are a bright orangy yellow to yellowish orange, with few (if any) eye-visible inclusions. Internal features such as wavy planes of partially healed fractures, anomalous birefringence, and growth patterns are comparable to spessartine from other localities, but linear clouds, inclusions of albite and columbite, and the common occurrence of negative crystals in the study samples appear unique to Ramona. Four analyzed samples of the characteristic color range were spessartine rich: Sps_{94.8}Alm_{4.7}Gro_{0.5} to Sps_{88.8}Alm_{11.0}Gro_{0.2}. Absorption spectra showed corresponding strong peaks for Mn²⁺ and subordinate Fe²⁺ features.

Because the most accessible portions of the Ramona spessartine-bearing pegmatites have been mined, a significant investment in time and work will be necessary before commercial production can resume. Also, in recent years, the Ramona locality has been overshadowed by abundant production of spessartines from Namibia and Nigeria. Nevertheless, the price of fine spessartine (as reported by *The Guide*) appears to be stable, and the highest-quality material is gradually increasing in value. With the greater popularity of spessartine in both high-end jewelry and mass-produced goods (Henricus, 2000), the stone is in strong demand by the gem trade. Certainly any future production of Ramona spessartine will find a ready market.

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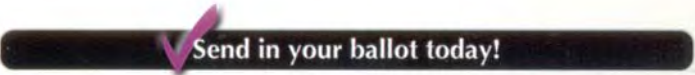


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PINK TO PINKISH ORANGE MALAYA GARNETS FROM BEKILY, MADAGASCAR

By Karl Schmetzer, Thomas Hainschwang, Lore Kiefert, and Heinz-Jürgen Bernhardt

Malaya garnets from Bekily, Madagascar, are predominantly pink to pinkish orange, with some stones orange to red. Discovered only in the late 1990s, the majority are intermediate members of the pyrope-spessartine series with variable contents of almandine and subordinate grossular. The refractive index, specific gravity, and color of these garnets are related to their iron and manganese contents. Inclusions identified by Raman analysis are rutile needles and platelets, graphite, quartz, apatite, zircon, and sillimanite. Negative crystals were also seen. Important differences in predominant color and chemistry were noted when the Bekily garnets, only the second commercial source of malaya garnet, were compared to malaya garnets from East Africa, which have been available since the late 1970s.

The Bekily area of southern Madagascar, which produces attractive color-change (blue-green to purple) garnets (Schmetzer and Bernhardt, 1999), also has produced garnets that are mainly pink to pinkish orange (figure 1), and less commonly orange to red. These garnets first appeared in the local market about 1997.

Pyrope-spessartines that contain only minor amounts or traces of vanadium and chromium have been reported to occur in colors ranging from pink to red to orange and even yellow-orange (see, e.g., Rouse, 1986; Arem, 1987; and Dirlam et al., 1992). Until recently, the only commercial source for this type of garnet was the large mining area in East Africa that covers various localities in northern Tanzania and southern Kenya, which is commonly referred to as the Umba mining region. Gemological and chemical data for the Umba garnets were published by Saul et al. (1978), Jobbins et al. (1978), Schmetzer and Bank (1981a,b), and Stockton and Manson (1982); a detailed examination of inclusions appeared in Gübelin (1981). Various trade names such as "malaya" (malaia), "umbalite," and "pyral-

spite" have been applied to intermediate pyrope-spessartine garnets in this color range, but only "malaya" has found international acceptance in the trade and the literature (see, e.g., references above and Curtis, 1980; Stockton and Manson, 1985; Keller, 1992; and Hänni, 1999). Limited amounts of rough are still mined in northern Tanzania and marketed as malaya garnet (Karl Egon Wild, pers. comm., 2001). In this article, the term *malaya* is used for garnets that are pink to pinkish orange, as well as orange to red, that are composed primarily of pyrope-spessartine. Note, however, that there is no established definition of this term based on a precise compositional range.

[Editor's note: Although a trade name, because of its long acceptance in the trade, for the balance of the article malaya will not be enclosed in quotation marks or capitalized.]

See end of article for About the Authors and Acknowledgments.
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Figure 1. Malaya garnets from Bekily, Madagascar, are predominantly pyrope-spessartine. The color of these six pink to pinkish orange samples (2.94–4.06 ct) is representative of more than 97% of the commercially available malaya garnets from this locality. Photo by Maha Tannous; incandescent light.



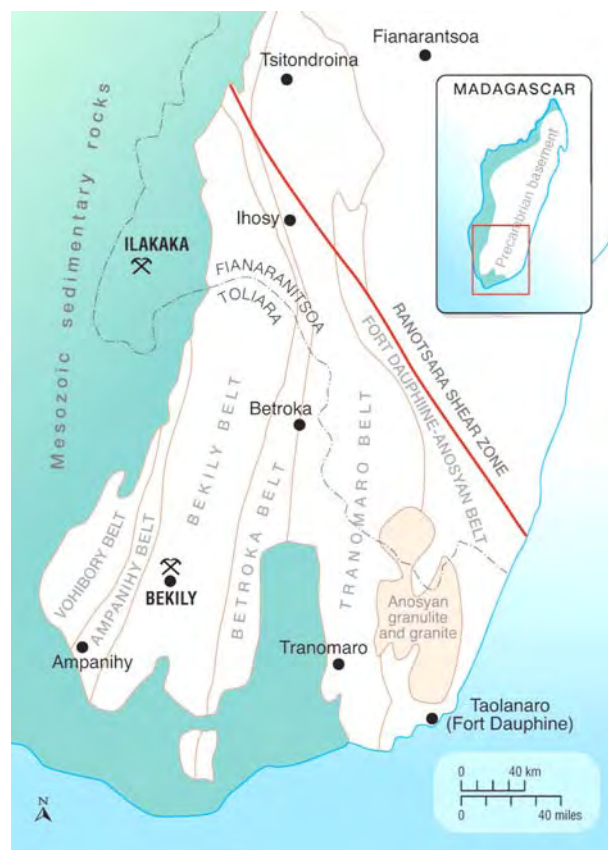
A brownish pinkish orange pyrope-spessartine from an unknown locality reportedly in central Madagascar was documented by Johnson and Koivula (1998). Zylberman (1999) described a parcel of predominantly pink to pinkish orange pyrope-spessartine garnets from an unknown primary source in Madagascar. He included gemological properties and chemical data, and noted a distinct shift of color between daylight and incandescent light. A new occurrence of malaya garnets in Madagascar also was reported by Hänni (1999), but the exact locality was not provided.

The present study was undertaken to characterize the predominantly pink to pinkish orange garnets from the mining region near Bekily in Madagascar. The large number of intermediate pyrope-spessartines in this group make this locality, to the best of our knowledge, the second commercial source of malaya garnets in the world today. Samples of pink-to-red Bekily garnets in their host rock also were examined, as were faceted samples representing other colors of pyrope-almandine-spessartine. Last, the Madagascar samples are compared to malaya garnet from Umba in East Africa.

LOCATION AND GEOLOGY

The village of Bekily is located about 200 km northwest of Taolanaro (formerly Fort-Dauphin) in southern Toliara Province (figure 2). The mining area for the color-change garnets described by Schmetzer and Bernhardt (1999) is located about 15 km north of Bekily; the malaya garnets documented in the present article were excavated in

Figure 2. Malaya garnets are mined from an area north of Bekily in southern Madagascar's Toliara Province. This area consists of high-grade metamorphic rocks that have been subdivided into six tectonic zones. The Bekily belt is composed mainly of sillimanite-cordierite-garnet gneisses. Modified from Windley et al. (1994).



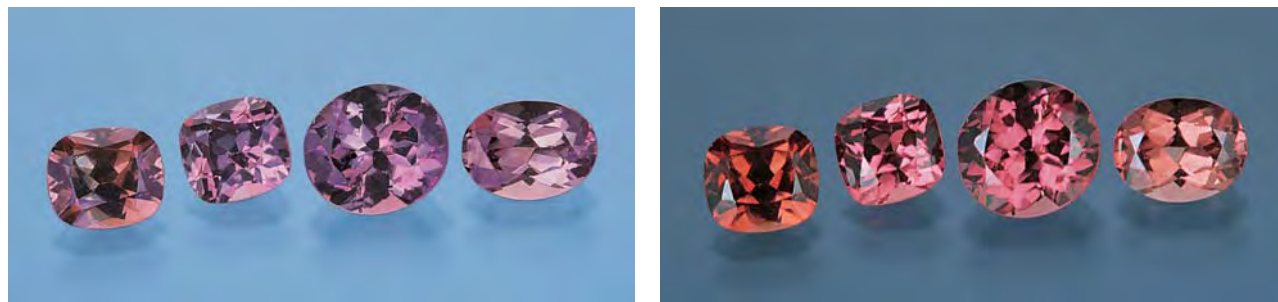


Figure 3. Malaya garnets from Madagascar (here, 0.74–1.59 ct) reveal a distinct shift of color from pink or pinkish orange in daylight (left) to a more reddish pink or reddish orange in incandescent light (right). Microprobe analyses of the four samples pictured gave FeO contents from 6.65 to 9.89 wt. %, and MnO contents from 10.39 to 15.95 wt. %. Photos by Maha Tannous.

garnet crystals as large as 3 mm. To determine the mineral assemblages of these specimens, we prepared petrographic thin sections of each for examination with a petrographic microscope. Several garnet crystals (i.e., 5–20) in each of four of the thin sections were analyzed by the Cameca electron microprobe mentioned above; a total of 77 point analyses were obtained. In addition, a garnet crystal was carefully removed from one rock sample and analyzed with the Adamas Advantage SAS 2000 spectrophotometer.

RESULTS

Characterization of the Garnet-Bearing Rock Samples. The rock samples were deeply weathered, partly decomposed gneisses consisting of the following mineral assemblage: garnet, quartz, plagioclase, sillimanite, rutile, graphite, zircon, and symplectite of unknown composition. Thus, the garnets are hosted by sillimanite gneisses. This is consistent with previous work on rocks from southern Madagascar, including the Bekily belt (Windley et al., 1994).

Visual Appearance and Gemological Properties of the Gem Garnets. Prior to cutting, the gem rough obtained by TH was visually examined to document its morphology and surface characteristics. These samples consisted mostly of irregular fragments that lacked external crystal faces. A minor fraction of the rough garnets, however, revealed a somewhat rounded surface, similar to that typically seen on rolled pebbles from alluvial deposits.

The faceted samples were predominantly pink to pinkish orange with a homogeneous color distribution. They showed distinctly variable saturation, ranging from almost colorless, very light pink or very light pinkish orange, to intense pink, pinkish orange, brownish pink, orange-red, to red in daylight. The lighter colored garnets in particular exhibited a distinct color shift from pink or pinkish

orange in daylight to a more reddish pink or reddish orange in incandescent light (figure 3). One sample revealed an unusual orange coloration.

The refractive indices and specific gravities of 15 of the 31 malaya garnets are presented in table 1 (M1–M15). The other 16 samples more or less duplicate the physical and chemical properties of the 15 samples selected for the table. The garnets revealed a distinct variation in refractive indices from 1.739 to 1.782 and in specific gravity between 3.77 and 4.04 (figure 4A). Twenty-seven garnets revealed a narrower range of both refractive indices (i.e., between 1.747 and 1.766) and specific gravities (between 3.80 and 3.96) than the full group of 31, and this color group represented 97% of the 1,000 faceted stones studied.

Chemical Properties. Faceted Malaya Garnets. The 31 faceted garnets analyzed were relatively homogeneous; they did not show any distinct chemical zoning. The analyses of the 15 representative samples (M1–M15) are given in table 1. The samples consisted of 24 to 70 mol. % pyrope and 13 to 59 mol. % spessartine. Almandine varied from 4 to 25 mol. %, and there were smaller percentages of grossular (3–5 mol. %). Calculating the garnet composition for 12 oxygens and for both Fe²⁺ and Fe³⁺, we found that iron in the trivalent state either was not present or was present in very small amounts (mostly <0.01 Fe³⁺ atoms per formula unit). This indicates a very small andradite component if present at all (cf. Spectroscopic Properties). Traces of vanadium and chromium were always present and are calculated as the goldmanite and uvarovite molecules, respectively, in table 1.

A plot of refractive index versus the sum of FeO + MnO (figure 4B) shows the variation of this optical property with chemical composition. A similar diagram (not shown) is obtained when specific gravity is plotted against the sum of FeO + MnO. These

TABLE 1. Physical and chemical properties of representative garnets from Madagascar.

Bekily ^a											
Pyrope-almandine-spessartine (malaya), faceted gems											
Property	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
Color	Light pink	Light pink	Orange	Pinkish orange	Pink	Pink	Pink	Pink	Intense pink	Pink	Pink
Refractive index	1.747	1.740	1.782	1.753	1.748	1.748	1.749	1.750	1.754	1.758	1.755
Specific gravity	3.80	3.78	4.04	3.89	3.81	3.85	3.85	3.85	3.86	3.88	3.89
Microprobe analyses (wt.%) ^b											
SiO ₂	40.96	41.24	38.68	40.97	40.69	39.94	41.91	41.33	39.93	41.29	40.34
TiO ₂	0.01	0.01	0.09	0.06	0.05	0.04	0.05	0.06	0.04	0.04	0.03
Al ₂ O ₃	23.59	23.94	22.10	23.27	23.14	22.85	23.84	23.61	23.01	23.83	23.34
Cr ₂ O ₃	0.09	0.05	0.07	0.04	0.06	0.10	0.07	0.09	0.16	0.05	0.05
V ₂ O ₃	0.11	0.08	0.08	0.04	0.05	0.07	0.08	0.09	0.16	0.03	0.05
FeO ^c	2.13	2.00	5.65	3.61	3.60	4.11	4.45	5.75	6.99	9.73	10.07
MnO	14.81	12.44	26.63	16.72	13.50	13.53	13.04	12.70	12.82	11.57	10.42
MgO	16.94	19.07	6.17	14.89	16.46	15.96	16.65	15.81	14.69	14.93	15.31
CaO	1.81	1.26	1.77	1.23	1.70	1.68	1.81	1.98	2.03	1.05	1.07
Total	100.45	100.09	101.24	100.83	99.25	98.28	101.90	101.42	99.83	102.52	100.68
FeO:MnO	0.14	0.16	0.21	0.22	0.27	0.30	0.34	0.45	0.54	0.84	0.97
Cations ^d											
Si	2.973	2.965	2.993	3.000	2.991	2.977	2.999	2.989	2.963	2.982	2.965
Ti	0.001	0.001	0.005	0.003	0.003	0.002	0.003	0.003	0.002	0.002	0.002
Al	2.018	2.028	2.016	2.008	2.005	2.007	2.010	2.012	2.012	2.029	2.022
Cr	0.005	0.003	0.004	0.002	0.004	0.006	0.004	0.005	0.009	0.003	0.003
V	0.006	0.005	0.005	0.002	0.003	0.004	0.005	0.005	0.010	0.002	0.004
Fe	0.129	0.121	0.366	0.221	0.221	0.256	0.266	0.348	0.434	0.588	0.619
Mn	0.910	0.757	1.746	1.036	0.841	0.854	0.790	0.778	0.806	0.708	0.649
Mg	1.832	2.043	0.711	1.625	1.804	1.773	1.775	1.704	1.625	1.607	1.676
Ca	0.141	0.097	0.147	0.096	0.134	0.134	0.139	0.154	0.161	0.081	0.085
Mol. % end members ^e											
Pyrope	60.8	67.7	23.9	54.6	60.1	58.8	59.8	57.1	53.7	53.9	55.3
Spessartine	30.2	25.1	58.8	34.8	28.0	28.3	26.6	26.1	26.6	23.7	21.4
Almandine	4.3	4.0	12.3	7.4	7.4	8.5	9.0	11.7	14.3	19.7	20.4
Grossular	4.2	2.9	4.5	3.0	4.2	3.9	4.3	4.8	4.4	2.5	2.5
Goldmanite	0.3	0.2	0.2	0.1	0.1	0.2	0.2	0.2	0.5	0.1	0.2
Uvarovite	0.2	0.1	0.2	0.1	0.2	0.3	0.2	0.2	0.4	0.1	0.1

^a Samples from Bekily are arranged according to increasing FeO:MnO ratio. All samples are faceted except for A–D, each of which consists of several grains in petrographic thin sections; nd = not determined.

^b Average composition of 10 analyses each, except for samples A (19), B (15), C (6), and D (37).

^c Total iron as FeO.

^d Calculated on the basis of 12 oxygens.

^e Pyrope=Mg₃Al₂Si₃O₁₂, Spessartine=Mn₃Al₂Si₃O₁₂, Almandine=Fe₃²⁺Al₂Si₃O₁₂, Grossular=Ca₃Al₂Si₃O₁₂, Goldmanite=Ca₃V₂³⁺Si₃O₁₂, Uvarovite=Ca₃Cr₂Si₃O₁₂.

results explain the variability of some optical and physical properties with chemical composition in individual samples.

The chemical variability of the Bekily garnets is revealed in figure 5. Most (27 samples) plot in a relatively small area of the pyrope-almandine-spessartine ternary diagram. These samples represent more than 97% of the 1,000 faceted malaya garnets from Bekily that we examined, that is, those with a predominantly pink or pinkish orange—but sometimes orange red or red—coloration.

Although most samples are members of the pyrope-spessartine series with smaller percentages of almandine than spessartine, six of the 31 ana-

lyzed samples have almost equal spessartine and almandine contents (samples M11, M12, and M13 in table 1, plus three samples not listed in the table). Two garnets (samples M14 and M15 in table 1) have distinctly higher percentages of almandine than spessartine. The samples in table 1 illustrate the broad range of compositions within pyrope-almandine-spessartine for the pink, pinkish orange, orange-red, or red garnets from Bekily.

Garnets from Rock Specimens. Chemical data for the garnet grains analyzed in four petrographic thin sections are also presented in table 1 (samples A–D); all were homogeneous except for small chemical

Bekily ^a				Madagascar (unspecified), faceted gems							
Garnets from rock samples				Spessartine				Pyrope-almandine			
M12	M13	M14	M15	A	B	C	D	S	PA1	PA2	R
Light pink	Orange-red	Pink	Red	Pink to red	Pink to red	Pink to red	Pink to red	Orange	Red	Red	Purplish pink (rhodolite)
1.739	1.754	1.760	1.756	nd	nd	nd	nd	1.802	1.753	1.760	1.750
3.77	3.86	3.93	3.87	nd	nd	nd	nd	4.19	3.83	3.88	3.84
41.44	39.99	39.41	40.86	38.90	39.11	39.40	39.58	35.83	40.30	40.20	42.30
0.04	0.06	0.02	0.05	0.02	0.01	0.02	0.02	0.04	0.05	0.05	0.01
23.32	23.31	22.88	23.00	22.48	22.60	22.74	22.91	20.71	23.10	23.28	24.14
0.08	0.12	0.05	0.19	0.15	0.09	0.08	0.09	0.01	0.11	0.04	0.03
0.09	0.17	0.04	0.08	0.06	0.06	0.07	0.06	0.01	0.13	0.05	0.01
6.11	9.65	12.12	11.75	17.20	16.56	16.32	16.79	3.51	14.41	19.24	16.79
6.25	9.18	10.09	7.83	8.74	8.34	8.07	5.78	38.32	3.39	1.29	0.20
19.41	15.62	14.03	15.07	10.49	11.39	11.96	13.37	0.01	16.18	15.18	18.27
2.05	1.60	1.07	1.90	1.63	1.38	1.36	1.19	0.46	1.68	1.56	1.02
98.79	99.70	99.71	100.73	99.67	99.54	100.02	99.79	98.90	99.35	100.89	102.77
0.98	1.05	1.20	1.50	1.97	1.99	2.02	2.90	0.09	4.25	14.90	84.90
2.998	2.954	2.954	2.995	2.974	2.976	2.975	2.969	2.981	2.975	2.956	2.986
0.002	0.003	0.001	0.003	0.001	0.001	0.001	0.001	0.003	0.003	0.003	0.001
1.989	2.029	2.020	1.987	2.026	2.027	2.024	2.025	2.031	2.009	2.018	2.009
0.004	0.007	0.003	0.011	0.009	0.005	0.005	0.005	—	0.007	0.003	0.002
0.005	0.010	0.003	0.005	0.004	0.004	0.004	0.004	—	0.008	0.003	—
0.370	0.596	0.760	0.720	1.100	1.054	1.030	1.054	0.245	0.889	1.183	0.991
0.383	0.575	0.640	0.486	0.567	0.538	0.516	0.367	2.700	0.212	0.080	0.012
2.093	1.720	1.568	1.647	1.194	1.292	1.346	1.494	0.002	1.780	1.664	1.932
0.159	0.127	0.086	0.149	0.134	0.113	0.110	0.096	0.041	0.133	0.123	0.077
69.7	57.0	51.3	54.9	39.9	43.1	44.8	49.6	0.1	59.1	54.6	64.1
12.7	19.1	21.0	16.2	18.9	18.0	17.2	12.2	90.4	7.0	2.6	0.4
12.3	19.7	24.9	24.0	36.7	35.2	34.3	35.0	8.2	29.5	38.8	32.9
4.8	3.4	2.6	4.3	3.9	3.4	3.3	2.8	1.4	3.7	3.8	2.5
0.3	0.5	0.1	0.2	0.2	0.2	0.2	0.2	—	0.4	0.1	—
0.2	0.3	0.1	0.5	0.4	0.2	0.2	0.2	—	0.3	0.1	0.1

variations (about 2 wt.% for FeO, MgO, or MnO). The color of the larger garnet crystals seen macroscopically in the hand specimens was almost identical to that of the malaya garnets with the highest iron contents, such as samples M14 and M15, but the crystals had distinctly higher iron contents (and, therefore, higher almandine percentages—34 to 37 mol.%) than those measured for the 31 faceted samples, as also seen in figure 5.

Spectroscopic Properties. The absorption spectra of our sample Bekily garnets revealed a series of absorption bands of variable intensity (figure 6). The intensities of some of the absorption bands directly correlated to the iron and manganese contents of the garnets determined by electron microprobe. Six typical absorption spectra are shown in figure 6A, arranged according to FeO:MnO ratio.

One rough garnet removed from sample A revealed an absorption spectrum similar to that of the

faceted garnet sample M15, which showed one of the highest iron contents of our 31 samples (figure 6B).

Features Observed with the Microscope. When examined with crossed polarizers, all samples revealed strong anomalous double refraction, occasionally parallel to growth planes that form angles of 150° to one another (figure 7). This angle occurs in garnet between faces of the most common forms, namely, the dodecahedron {110} and the trapezohedron {211}. Anomalous double refraction caused by internal strain is characteristic of pyrope-almandine-spessartine-grossular garnets (Hofmeister et al., 1998).

Most samples contained a three-dimensional network of oriented rutile needles (figure 8). Occasionally we also observed oriented platelets or elongated tabular crystals that were identified as rutile by Raman analysis (figure 9).

A variety of other mineral inclusions were identified in the 17 samples selected for Raman analysis.

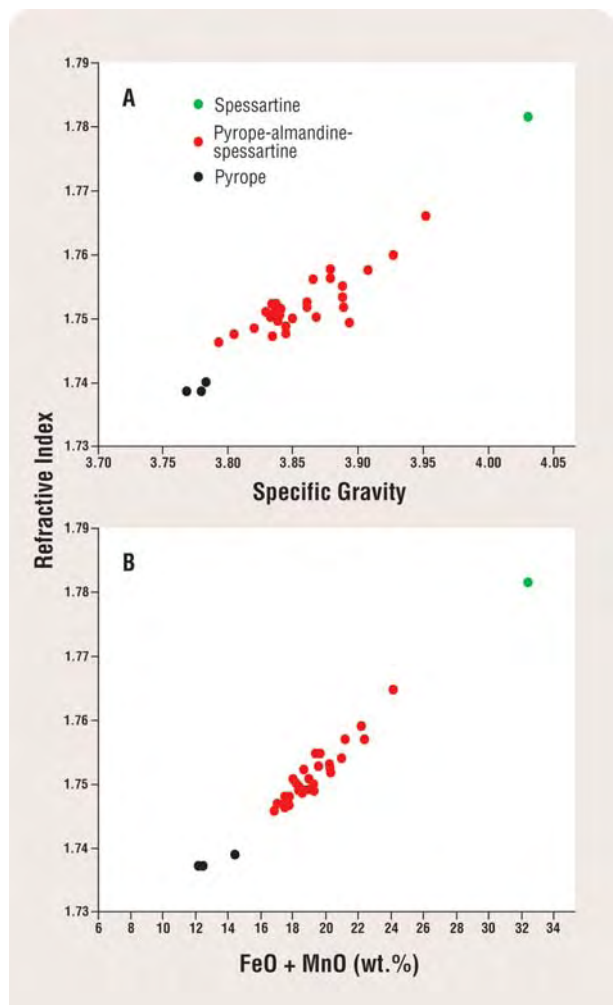
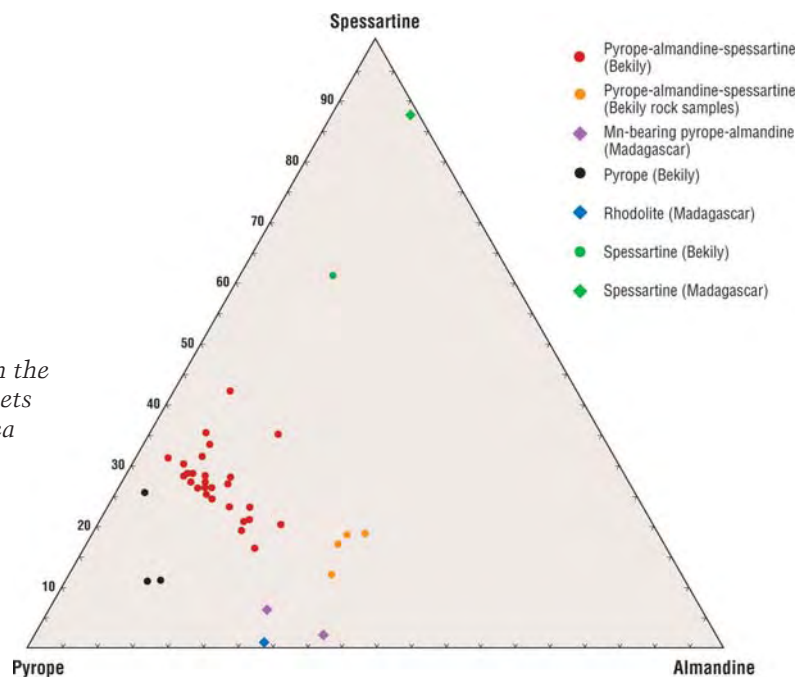


Figure 4. The 31 faceted garnet samples from Bekily showed a positive correlation between refractive index and specific gravity (A). The low Fe, Mn-bearing pyropes (e.g., M2 and M12 in table 1) showed the lowest values, and the Mg-rich spessartine sample (M3) had the highest values. A positive correlation between refractive index and FeO + MnO content was also evident (B).

Figure 5. Garnet samples from Bekily (circles), in the color range typically associated with malaya garnets from this locality, plotted in a relatively small area on this diagram that corresponded to pyrope-spessartine, with a few exceptions. The Bekily garnets from the rock samples showed significantly more almandine component. Four garnet samples from unspecified localities in Madagascar also were analyzed for comparison (diamonds).



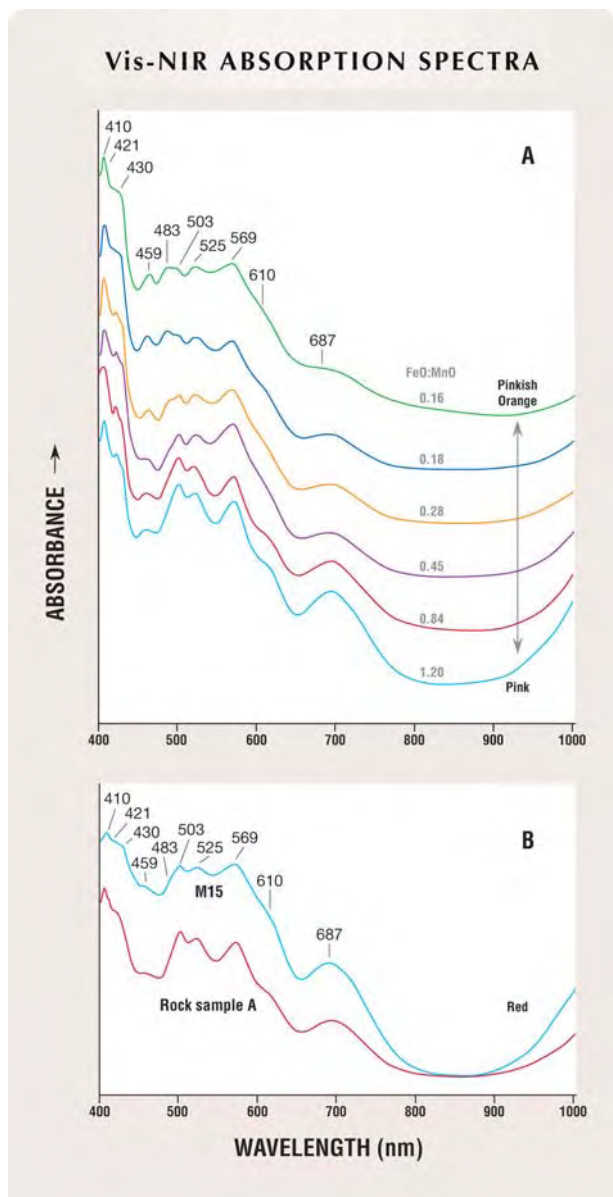
Six samples contained unoriented, irregularly shaped platelets of graphite, some surrounded by tension cracks (figure 10). Five garnets had irregularly shaped quartz inclusions (figure 11). Prismatic apatite crystals, sometimes with slightly rounded edges, were identified in six samples (figure 12). Negative crystals resembling typical garnet morphology were seen in six samples (figure 13); in transmitted light, these cavities appeared opaque (again, see figure 9). Three of the samples contained zircon inclusions with tension cracks (figure 14). Occasionally, mineral inclusions were seen at the center or at the tip of a rutile needle (figure 15); these inclusions were identified as quartz. In one garnet, oriented tabular rutile crystals were surrounded by small quartz crystals. In another sample, we identified minute needle-like to fibrous inclusions as sillimanite.

In general, the mineral inclusions reflect the mineral assemblages that were identified in the thin sections of the garnet-bearing rock specimens (i.e., graphite, quartz, rutile, zircon, and sillimanite).

DISCUSSION

Nomenclature. All samples analyzed were pyrope-spessartines or pyrope-almandine-spessartines.

Using the nomenclature proposed by Stockton and Manson (1985), most of the samples we analyzed were pyrope-spessartines (again, see figure 5). Three light pink garnets (see, e.g., M2 and M12 in table 1)



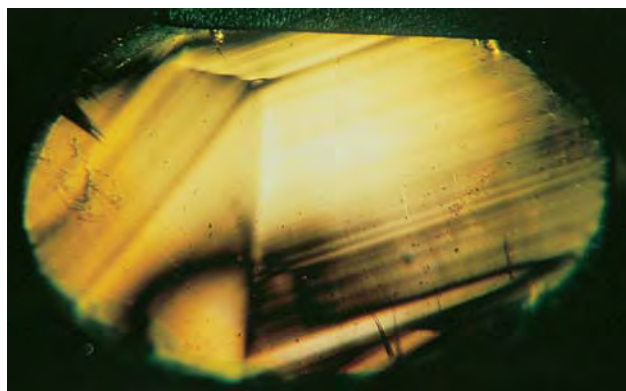
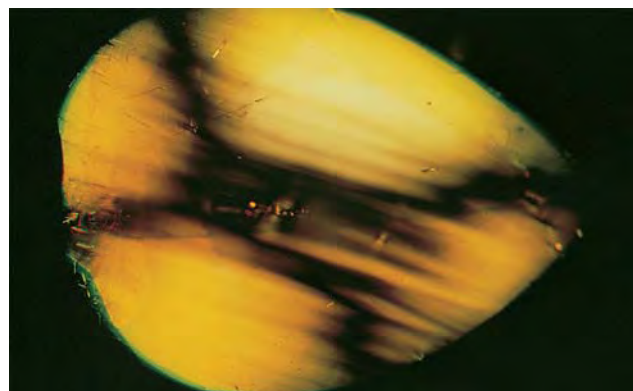
are low manganese- and iron-bearing pyropes. One orange sample (M3) was spessartine with a high magnesium (pyrope) content; in both color and chemistry, it appears to be unusual for stones from the Bekily area. Using the classification proposed by Hanneman (1997), only a few of our samples would be considered pyrope-spessartines; most would be described as pyrope-almandine-spessartines. In contrast, Lind et al. (1998) designated intermediate garnets of various colors with up to 20 mol.% spessartine as rhodolite. This nomenclature is inconsistent with both of the systems mentioned above, as well as with the purplish pink or purplish red color from which rhodolite garnet derives its name.

Interpretation of Absorption Spectra. The absorption features recorded in the Bekily garnets are due mostly to Fe²⁺ and Mn²⁺. Assignment of the bands at 503, 610, and 687 nm to Fe²⁺ and at 483 nm to Mn²⁺ (table 2) is consistent with data from the literature (see, e.g., Moore and White, 1972).

A general problem with the assignment of garnet absorption bands is an overlap of several bands from different elements in the visible range. Iron-rich gar-

Figure 6. Absorption spectra of six faceted malaya garnets from Bekily (A) show systematic variations according to their iron and manganese contents. The color of the samples varies from pink (at higher FeO:MnO ratios) to pinkish orange (at low FeO:MnO ratios). The top and bottom spectra are for samples M2 and M14, respectively (see table 1); analyses for the other spectra are not shown in table 1. One faceted sample and one garnet from a rock specimen, both with relatively high iron contents (B), show similar absorption features and color.

Figure 7. Anomalous double refraction was observed in all the Bekily garnet samples when examined between crossed polarizers (left; magnified 20×). Occasionally, internal strain parallel to growth planes was also observed. The growth planes are the most common forms for garnet: the dodecahedron {110} and the trapezohedron {211} (right; magnified 30×). Both taken in immersion with crossed polarizers.



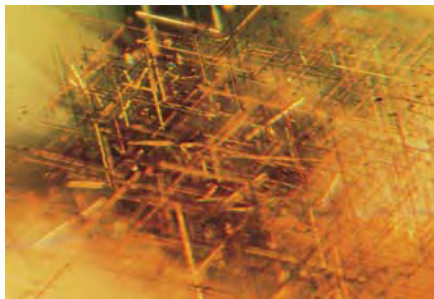
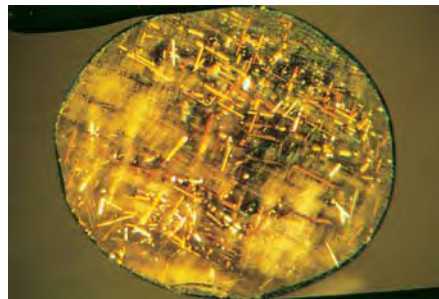


Figure 8. Anomalous double refraction is frequently observed together with rutile needles in Bekily garnet samples (left; magnified 30×). The image on the right shows the three-dimensional network of oriented rutile needles (magnified 40×). Both taken in immersion with crossed polarizers.

nets without significant manganese contents were available to researchers studying this problem in the late 1960s and early 1970s, but samples of pure spessartine were not. Consequently, in pyrope-almandine spectra those bands not previously assigned to iron were assigned to manganese.

Spectroscopic examination of synthetic iron-free spessartines and synthetic manganese-free almandines, however, revealed manganese absorption bands at approximately the same positions as some iron absorption maxima (Langer and Frentrup, 1979; Smith and Langer, 1983). These observations were later confirmed for iron-poor spessartines from Namibia and Nigeria (Lind et al., 1993, 1994; Milisenda and Zang, 1999; Lind and Henn, 2000). On the basis of these references and our own results, the bands at 459 and 525 nm can be assigned to both Fe^{2+} and Mn^{2+} . The intensities of these two bands vary only slightly in our samples with variable Fe:Mn ratios (again, see figure 6).

Another overlap may be present at 569 nm. An iron band at this wavelength is commonly observed in iron-bearing rhodolites without significant manganese, vanadium, or chromium, but this band also has been attributed to V^{3+} and/or Cr^{3+} in garnets

(Amthauer, 1976; Schmetzer and Ottemann, 1979; Schmetzer et al., 1980; Schmetzer and Bernhardt, 1999). Small amounts of V_2O_3 and Cr_2O_3 were recorded in our samples (table 1), so the absorption at 569 nm is partially due to these trace elements.

A final overlap is also possible between Mn^{2+} and Fe^{3+} at 430 nm. This band is seen in the spectra of Fe^{3+} -bearing garnet without manganese (i.e., hessonite, which is iron-bearing grossular). However, due to the intense Mn^{2+} absorption in the 410–430 nm range, it is impossible to determine if a weak Fe^{3+} band is also present.

Color and Color Causes. The intensities of the absorption maxima are related to the iron and manganese contents, and to the FeO:MnO ratio. Mn^{2+} and Fe^{2+} both replace the Mg^{2+} of “pure” pyrope garnet, which is colorless. With increasing iron (i.e., with increasing almandine content), the color intensifies from very light pink or very light pinkish orange to an intense pink, or almost red (figure 16). Traces of vanadium and/or chromium also may contribute to pink coloration. With increasing manganese, the samples appear more orange, and may attain the color of near-end-member spessartines

Figure 9. Occasionally, the network of rutile needles was associated with birefringent rutile platelets; a negative crystal in the center appears opaque in transmitted light. Immersion, crossed polarizers, magnified 30×.

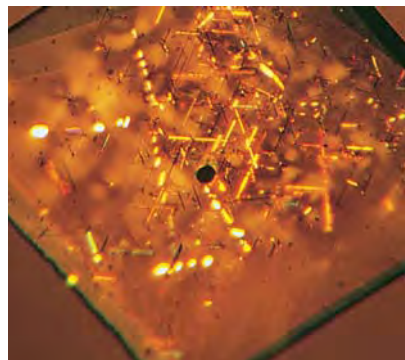


Figure 10. Tabular graphite crystals were identified in a few Bekily garnets, some surrounded by tension cracks. Magnified 50×.



Figure 11. Irregular fragments of transparent crystals seen in some of the garnets were identified as quartz. The quartz inclusion shown here is intergrown with a rutile needle. Magnified 100×.





Figure 12. Apatite crystals, some with rounded edges, were identified by Raman analysis. Immersion, crossed polarizers, magnified 80 \times .

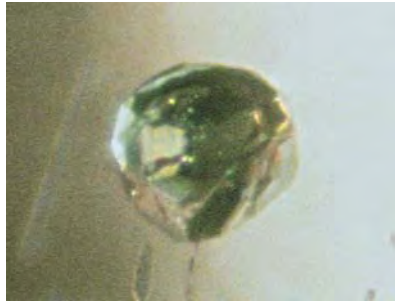


Figure 13. Negative crystals with a garnet morphology were also seen in the Bekily material. Magnified 50 \times .

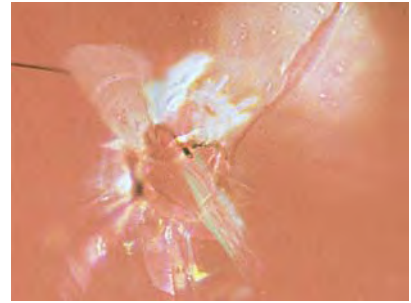


Figure 14. Zircon crystals with tension cracks were seen rarely in the samples examined. Magnified 100 \times .

when iron contents are low (figure 17; see box A).

Garnets of the pyrope-almandine series without significant manganese usually are purplish pink to purplish red (see figure 18). The absorption spectrum of sample R consists of iron-related bands (see table 2) and two distinct minima in the visible range, namely in the blue-violet and red regions. Small amounts of manganese (i.e., 1–3 wt.% MnO, samples PA1 and PA2 in table 1) are sufficient to eliminate the purple color component, resulting in an intense red. This dramatic change (again, see figure 18) is caused by the strong manganese absorption bands in the violet region (i.e., at 410, 421, and 430 nm).

The color of the Mn-bearing pyrope-almandine garnets we analyzed (samples PA1 and PA2 in table 1) resembles that of the orange-red, pink, or red garnets from Bekily with high Fe and relatively low Mn contents (e.g., samples M13 to M15). It is clear that an increase in MnO from about 3 wt.% (in Mn-bearing pyrope-almandines) to about 7–10 wt.% (in the malaya garnets from Bekily) does not strongly influence color. This also explains the similarity in color between the faceted malaya garnets with high

Figure 15. In some samples, mineral inclusions—identified as quartz—were found at the center or tip of rutile needles. Magnified 120 \times .



TABLE 2. Assignment of absorption maxima observed in malaya garnets from Bekily, Madagascar.

Absorption maximum (nm)	Fe ²⁺	Mn ²⁺	V ³⁺ and/or Cr ³⁺	Fe ³⁺
410		X		
421		X		
430		X		X
459	X	X		
483		X		
503	X			
525	X	X		
569	X		X	
610	X			
687	X			

iron contents and the relatively iron-rich garnet specimens in our rock samples.

At least two other mechanisms are known that can change the color of pyrope-almandines from purplish pink or purplish red (rhodolites) to red or orange-red: (1) the superimposition of a chromium spectrum over the iron-related absorption bands, as in Cr-bearing pyropes that contain some iron; and (2) the superimposition of absorption bands related to Fe³⁺ (which are found in the same spectral range as the strongest manganese absorption bands; see table 2) over the Fe²⁺ spectrum (see also Manson and Stockton, 1981; Stockton and Manson, 1985).

Comparison with Malaya Garnets from East Africa.

Based on our observations and photographs in the literature (see, e.g., Stockton and Manson, 1982, 1985; Rouse, 1986; Arem 1987; Dirlam et al. 1992), most malaya garnets from East Africa are intense orange, pinkish orange, or yellowish orange. Malaya garnet from Bekily also is pinkish orange, but the orange to yellowish orange material is uncommon.

The chemical compositions of malaya garnets from East Africa (see especially Stockton and Manson, 1982) showed a larger compositional vari-

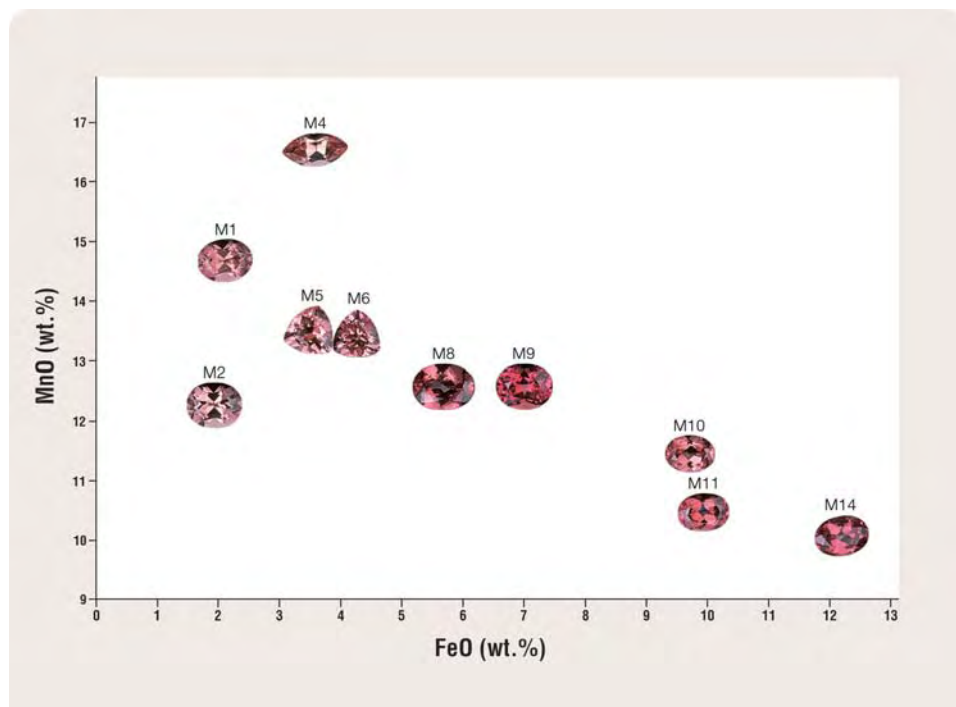


Figure 16. The color of malaya garnets is related to their chemical composition. With increasing iron, the pink component is intensified, and with increasing manganese, the orange color becomes stronger. The Bekily samples shown here weigh 0.72–1.46 ct, and were taken from a photo by Maha Tannous in incandescent light.

ation than our Bekily samples (figure 19). However, only a small fraction of the Umba samples actually fall within the compositional field of the 27 garnets that represent the color range of the majority of our samples from Bekily. Significantly, most Umba garnets contain distinctly higher amounts of manganese (i.e., a higher spessartine component). This accounts for the general differences in color seen between the two localities.

Mineral inclusions in Umba malaya garnets consist of networks of oriented rutile needles, smaller black rutile prisms, numerous tiny apatites, quartz,

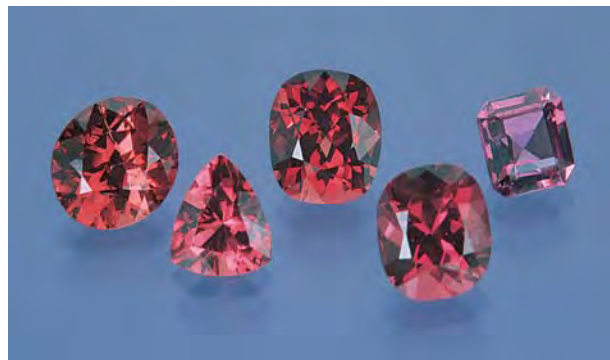
brown to reddish brown zircon, yellow to yellowish brown pyrite, black pyrrhotite, and (rarely) monazite (Gübelin, 1981). The negative crystals and graphite platelets described in the Bekily garnets have not been reported in malaya garnet from Tanzania.

Comparison with Color-Change (Blue-Green to Purple) Garnets from Bekily. As noted above, garnets with a color change from blue-green to purple are mined in the vicinity of the malaya garnets described here (Schmetzer and Bernhardt, 1999). Both types of

Figure 17. The pink malaya garnet on the left has a lower manganese content (sample M7; 13.04 wt.% MnO) than the orange malaya garnet in the center (sample M3; 26.63 wt.% MnO). A spessartine (sample S; 38.32 wt.% MnO) is shown on the right for comparison. The samples weigh 1.16–1.47 ct. Photo by Maha Tannous; incandescent light.



Figure 18. The pink and almost red malaya garnets on the left are relatively iron rich (samples M13 and M15), and have similar colors to the pyrope-almandine garnets with low manganese contents (samples PA1 and PA2, center and lower right). A rhodolite without significant manganese (sample R) is shown on the far right for comparison. The samples weigh 0.72–1.41 ct. Photo by Maha Tannous; incandescent light.



BOX A: SPESSARTINE-ALMANDINE GARNETS FROM MADAGASCAR

Spessartine from Madagascar was documented by Tisdall (1962), but until recently (see Laurs and Knox, 2001) no chemical data from gem-quality samples were published. Thus, we analyzed 12 representative spessartine and spessartine-almandine garnets from various unspecified locations in Madagascar (figure A-1). These samples were selected from several parcels totaling about 200 faceted spessartine and spessartine-almandine garnets in the orange, orange-brown, and brownish red to almost red color range. Chemical and physical properties of one spessartine sample (sample S) are presented in table 1.

Microprobe analyses revealed 34.7–39.1 wt.% MnO and 2.4–8.2 wt.% FeO. Traces of calcium were present (0.2 and 0.5 wt.% CaO), and MgO was below 0.05 wt.% in all samples. The chemical data correlate to 80.4–93.2 mol.% spessartine and 5.5–18.9 mol.% almandine. Grossular varies from 0.6 to 1.5 mol.%, and pyrope contents were ~0.1 mol.%. With increasing iron (i.e., almandine content), the color varied from

bright orange to orange brown and almost red (again, see figure A-1). Also, as iron content increased, the refractive index and specific gravity values varied continuously from 1.800 to 1.808 and from 4.15 to 4.22.



Figure A-1. These samples (0.58 to 1.42 ct) show the range of color seen in spessartine-almandine garnets from Madagascar. With increasing almandine and decreasing spessartine percentages, the colors vary from bright orange to almost red. Photo by Maha Tannous.

garnets are members of the pyrope-spessartine series, with similar features. The only significant differences are the distinctly higher vanadium (about 1 wt.% V_2O_3) and chromium (about 0.20 wt.% Cr_2O_3) contents in the color-change garnets.

CONCLUSIONS

Bekily, Madagascar, is a relatively new source of malaya garnets that are predominantly pink to pinkish orange members of the pyrope-spessartine series. Their colors are due to variable amounts of iron and manganese; in general, they contain lower amounts of manganese than most malaya garnets from East Africa. Some light pink garnets from Bekily are pyropes with relatively little manganese and iron. One orange sample from Bekily had an unusual composition: spessartine with high amounts of pyrope. Graphite platelets and negative crystals have not been reported in malaya garnets from East Africa.

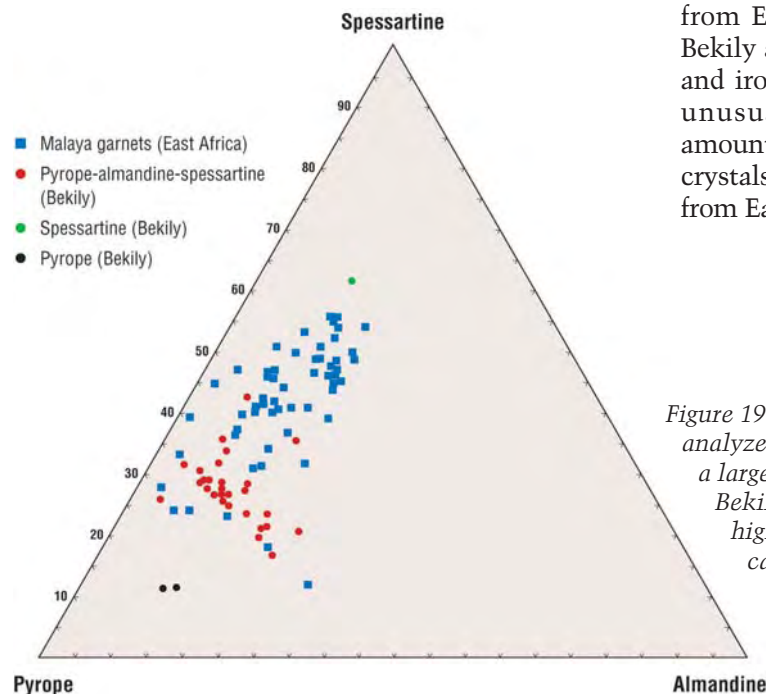


Figure 19. The malaya garnets from East Africa analyzed by Stockton and Manson (1982) showed a larger compositional variation than those from Bekily. Most of the East African samples had a higher spessartine component than the so-called malaya garnets from Madagascar.

the region between Bekily and the mines that are producing the color-change garnets.

The geology of the Bekily area is characterized by a series of Precambrian high-grade metamorphic rocks (migmatites, mica schists, and gneisses) that are locally graphite bearing (Besairie, 1964; Windley et al., 1994). Several tectonic zones are present in this region. The garnet mines are located in the Bekily belt, which consists predominantly of sillimanite-cordierite-garnet gneisses derived from metamorphosed sedimentary rocks (Windley et al., 1994).

MINING AND PRODUCTION

From the discovery of the deposit in 1997 to mid-1999, only a limited supply of rough was available. However, mining activities and production began to increase in summer 1999 and then grew until fall 2000 (producing some tens of kilograms of facet-grade material). During this time, one of the authors (TH) purchased several parcels (weighing altogether about 1 kg) of crystal fragments for cutting. Mining activities and production have declined significantly since winter 2000. This is due to the generally small size of the garnet rough recovered, as well as to the discovery of ruby deposits at Vatomandry and Andilamena in winter 2000–2001, which enticed miners away from Bekily and other mining areas.

According to local dealers, groups of four to 10 workers mined the garnets from several pits along the mineralized “vein” where it outcropped on the surface. The pits reached depths of 10 m, at which level groundwater became a major problem.

Production of facetable material was modest; neither large stones nor large quantities of rough were usually found. TH calculated that of the approximately 1 kg of mixed lots he purchased, 60% weighed less than 0.3 grams, and fewer than 4% exceeded 1 gram. The yield from this garnet rough was about 30% for the smaller sizes and up to about 40% for the larger stones. He obtained about 1,600 carats of faceted material from this 1 kg of rough.

Because the pieces of rough are typically small, faceted stones over 2 ct are scarce and, according to local dealers, only rarely are 4–6 ct stones cut. The largest fine-quality faceted stone seen by TH weighed 10.69 ct. The Umba region has produced significantly larger stones (e.g., 20–30 ct) and greater quantities.

MATERIALS AND METHODS

For the present study, we examined about 1,000 faceted garnets from Bekily. These were predomi-

nantly pink to pinkish orange, but included some orange to red samples; all were in the color range typically associated with malaya garnets. About 900 of these stones were purchased by TH directly from local dealers as rough crystal fragments mined in this area and then faceted outside Madagascar; the other approximately 100 samples were obtained from a European dealer who purchased several parcels of faceted garnets (stated to be from the Bekily area) in Madagascar in 1999 and 2000.

We selected 31 samples—representing the full range of colors we observed—for detailed gemological, chemical, and spectroscopic characterization. These samples were tested by standard gemological methods for refractive index, fluorescence to long- and short-wave UV radiation, and specific gravity. We also examined these 31 samples for inclusions and internal structural features by standard microscopic techniques using different microscopes and lighting conditions both with and without immersion in methylene iodide. In addition, we examined all samples that were not selected for extensive analytical testing to find solid inclusions other than the rutile needles noted in the 31 study samples. Finally, 17 garnets in which we found mineral inclusions were analyzed with a Renishaw 1000 laser Raman microspectrometry system.

For the same 31 samples mentioned above, we recorded UV-visible spectra with both a Leitz-Unicam SP 800 spectrophotometer and an Adamas Advantage SAS 2000 spectrophotometer. To determine the quantitative chemical composition of these 31 samples, we used a Cameca Camebax SX 50 electron microprobe, with a traverse of 10 point analyses measured across the table of each.

To compare the malaya garnets from Bekily to other colors of *pyrope-almandine-spessartine* (*pyralspite* in mineralogical nomenclature) garnets, we selected three faceted purplish pink (typical of rhodolite), three intense reddish orange to red (typical of pyrope-almandine), and 12 orange to orange-brown and almost red garnets (typical of the colors seen in spessartine). All of these were also reportedly from Madagascar (specific localities unknown). For these 18 garnets, we performed the same routine and advanced testing as for the 31 pink to orange Bekily garnets.

Several months after purchasing the gem rough, we obtained six hand specimens of a garnet-bearing rock from the Bekily area from a local dealer. These samples probably did not come from the same pits that produced the facetable rough used in this study. All six rock samples contained intense pink-to-red

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“VOICES OF THE EARTH”: TRANSCENDING THE TRADITIONAL IN LAPIDARY ARTS

By Sharon E. Thompson

Over the last 20 years, gemstone artists have demonstrated growing skill and variety. The diversity in their finished products comes not only from their unique artistic visions, but also from their ability to alter traditional tools or techniques. In the process, they are changing the way we define gemstones and jewelry. In a collection of 20 jewels entitled “Voices of the Earth,” scheduled for exhibit at the Carnegie Museum of Natural History in Pittsburgh, jewelry designer Paula Crevoshay showcases the work of some of North America’s leading lapidaries.

Since the early 1980s, the craft of lapidary has been blossoming, particularly in North America (figure 1). Although the work of German carvers such as Bernd Munsteiner inspired many cutters, including Michael Dyber and Larry Winn (McCarthy, 1996), gem art has taken its own twists in North America, where there is less of a tradition of gem carving. Due to a number of contributing factors—among them the interest in Native American jewelry in the 1970s, the fascination with crystals in the 1980s, and the search for distinctive designs in the 1990s—the buying public has become aware of gemstone carving and appreciative of its beauty. Another key factor undoubtedly has been the annual Tucson Gem and Mineral Show, and the multitude of shows that surround it. Each February in Tucson, gem carvers can find the high-quality material they need for their work, see the creations of their contemporaries, exchange information, and exhibit their own pieces to the

public. It is no coincidence that the interest in making and buying gem carvings grew as the Tucson Show grew.

One jewelry designer who is enthralled by the rebirth of lapidary art is Paula Crevoshay of Albuquerque, New Mexico. She has designed a collection of jewelry that showcases the ingenuity of some of North America’s top gem artists, and illustrates the beauty and wearability of their artwork. This collection will be on exhibit at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, for three months, beginning May 1, 2002.

By using the unique optical and physical properties of gemstones, gem artists create not only works of art, but also pieces that promote public awareness of the earth’s natural beauty. For this reason, Crevoshay asked leading gem artists from North America to create or contribute pieces that honored the earth, choosing the Greek goddess of the earth, Gaia, as the unifying theme for the collection. Ten artists responded: Arthur Lee Anderson (North Carolina), Elizabeth W. Beunaiche (Illinois), Charles Kelly (Arizona), Glenn Lehrer (California), Thomas R. McPhee (British Columbia), Nicolai Medvedev (New Jersey), Sherris Cotter Shank (Michigan), Lawrence Stoller (Oregon), Slava Tulupov (New York), and Larry Winn (Colorado). Many of them share their techniques here. While their work

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Figure 1. Lawrence Stoller's Montana agate carvings aptly illustrate the skill and creativity demonstrated by today's North American carvers. Here, in Paula Crevoshay's "Freedom's Flight," they have been transformed into a winged creature that spans almost 6 inches (15 cm). Set with a 9.72 ct topaz and a 33.94 ct Mexican opal, the necklace has a drama rarely seen since the Art Nouveau works that René Lalique created for actress Sara Bernhardt. Photo © Harold & Erica Van Pelt.

varies widely, all of these artists have transcended the traditional in their technology and skills to achieve their vision.

BACKGROUND

Historical Sources of Inspiration. In addition to the pieces created by Bernd Munsteiner and other German carvers, the work of North American gem artists has been built on a long tradition of Roman and Greek seals and mosaics (Boardman, 1985; Haswell, 1973), Chinese and South American Indian jade carvings (Zucker, 1984), Victorian cameos (Clements and Clements, 1998), Russian and Italian inlay, and the *objets d'art* that have graced palaces throughout the world. Also influential was the Art Nouveau era—from the late 19th to

the early 20th century—in which gem carvings and glass were included in pieces of fine jewelry (Misirowski and Dirlam, 1986). At about the same time, Peter Carl Fabergé was carving animals and other figures from opaque materials such as agate, onyx, and obsidian for Russian nobility (Von Habsburg-Lothringen, 1979; Becker, 1985). It is following this tradition that today some lapidary is being transformed into the fine art of gem sculpture.

Trends in Techniques. Through the centuries, certain techniques have developed to shape the very hard gem materials. Faceters, cabbers, and carvers have all used grinders, saws, and flat laps. Whether powered by muscle, water, or electricity, these tools must use harder materials to cut softer ones. Modern technology has provided lapidaries with additional



Figure 2. The 50.12 ct citrine in “Physce” is an excellent example of Arthur Anderson’s use of curved facets and frosted facet junctions to create the illusion of lace within the stone. Photo © Harold & Erica Van Pelt.

Figure 3. By using a motorized hand piece in addition to a fixed spindle, Elizabeth Beunaiche dramatically refined the lines and improved the polish in her 26.29 ct carved tourmaline face, as seen on the left in “Queen of Hearts.”

She also works in a mosaic style with abstract-shaped gem materials. In “First Light” (right, 4.3 cm total length), Beunaiche has incorporated chloromelanite to represent a mountain shape, striated hematite as a night sky, and a dark drusy quartz to imply the city lights of Phoenix, Arizona. Photo © Harold & Erica Van Pelt.



tools to make the work faster or more accurate—sandblasters for etching (Thompson and McPhee, 1996a), programmable faceting machine heads for accuracy, motor tools for speed, and diamond grits for a higher polish—but the basic techniques and equipment have remained largely unchanged (Thompson, 1995).

Not entirely, though. North American lapidaries of the late 20th and early 21st centuries are artists, and artists have always been tinkerers, trying different painting media and surfaces, as well as drawing and sculpting tools—even combining processes. These gem artists also tinker with their techniques and materials, constantly refining them to get closer to their artistic vision. Often it is only a slight shift in approach that allows them to break barriers; other times the cutters must immerse themselves in engineering, or reshape their world view, to make that vision a reality.

ARTHUR LEE ANDERSON

The excessive “play” in the head of Arthur Anderson’s first rickety faceting machine meant that he was unable to count on the accuracy of the facet angles unless he controlled the cutting by touch, much like working with an old-fashioned “jam peg” machine. This serendipitous discovery allowed him to incorporate convex facets into his work. Had he been able to afford better equipment, he never would have learned this style (A. Anderson, pers. comm., 2001). Anderson also discovered that by locking the faceting arm in a free-wheeling position, he could sweep the lap with the stone to create curved facets (Anderson, 1991).

Because Anderson’s desire is to focus the viewer’s attention on the shape and interplay of facets on the pavilion, the crown of the stone is cut flat, with only a few facets at the edge. This allows the viewer to look into the stone as if through an open window. It also means that Anderson must use exceptionally clean rough—any inclusions would be reflected and magnified.

Fascinated by the optical properties of the various gems, Anderson combines facets and their reflections so that they appear to float above the surface of the stone, in what he terms his “holographic style” (Anderson, 1991; Weldon, 2001). By frosting facet junctions, he can create a look similar to a spider’s web or lace (as with the citrine used in Crevoshay’s “Physce,” seen in figure 2) when the stone is viewed from above.

ELIZABETH W. BEUNAICHE

Obsessed with drawing horses, Elizabeth Beunaiche became convinced she could carve them after seeing an exhibit of Russian art from the period of the Czars. At first she worked with soft stones such as turquoise, shaping the material with any tools she could find, including sandpaper and carbide bits. As her equipment improved, so did the range of her work (E. Beunaiche, pers. comm., 2001).

For 15 years, Beunaiche created reverse intaglios with a fixed spindle machine, often used as a grinder or polishing unit. (Unlike a cameo, which is a sculpture *raised above* the surface of a stone, an intaglio is a carving *cut into* the surface of the stone; in ancient times, intaglios were used as seals. A reverse intaglio is cut into the back surface of a transparent stone so that the image can be seen from the front.) Then in Tucson several years ago, Charles Kelly convinced her to try the Lab Air-Z, a high-speed, air-powered mini-motor tool originally manufactured by Shofu for the dental industry, which she now uses for raised carvings as well. By using this motor tool to rework the carved tourmaline face she provided for Crevoshay's "Queen of Hearts" (figure 3, left), Beunaiche was able to refine the lines and improve the polish dramatically. While she prefers the motorized hand piece for delicate work, she returns to the fixed-spindle machine when working on symmetrical elements such as circles, because it provides easier control.

Beunaiche has worked in a variety of styles. Another piece she provided to Crevoshay is a mosaic of three minerals: striated hematite, chloromelanite, and drusy quartz (figure 3, right). The work is part of Beunaiche's landscape series; occasionally she mounts these mosaics behind her reverse intaglios of horses to give the animals context. For the mosaics, she trims the stones with the rotary diamond tool in the hand piece or with a saw blade until the pieces fit tightly together. She sometimes uses a diamond file to sharpen corners. Applying an industrial two-part epoxy marketed by Smooth-on Corp. under the name EA 40, she bonds the pieces edge to edge. For greater adherence, Beunaiche uses a knife-edged diamond tool to carve the edges with extra lines where the stones will come into contact. If the piece is to be set into metal, she advises leaving the surface of the metal rough where it touches the stone to promote a better bond (E. Beunaiche, pers. comm., 2001).



Figure 4. Glenn Lehrer's Torus™ cut is a variation on the round brilliant with a hole through the center into which other gemstones may be set. The back of the 31.12 ct amethyst set in "Ishtar's Cross" has been cut with lines that spiral out from the center like the winds in a cyclone. This helps impart a feeling of movement in a static material. Photo © Harold & Erica Van Pelt.

GLENN LEHRER

Interested in the processes that take place in the natural world, from wind and wave to crystal structures, and intrigued by the challenge of creating the illusion of movement in a static material, Glenn Lehrer took another look at the standard round brilliant cut. Through the simple but revolutionary expedient of putting a hole through the center of the table, and carving rather than faceting the surface, Lehrer was able to create a form that represents many of the earth's basic shapes, such as the iris of an eye or the eye of a hurricane. He called the shape Torus™, patented the form, and trademarked the name. A Torus™ forms the center of Crevoshay's "Ishtar's Cross" (figure 4).

The incisions on the back of this stone are curved, so they appear to spiral out from the center hole like the winds in a cyclone; when the stone is seen from the front, these curved cuts impart a feeling of movement to the color in the stone. This



Figure 5. Thomas McPhee's 173.16 ct carved quartz, shown here in "Mari Ana," illustrates the detail and classical beauty for which his gem sculptures are known. Photo © Harold & Erica Van Pelt.

technique is particularly effective in stones such as ametrine or bi-colored tourmaline.

Lehrer uses an arsenal of equipment: a series of diamond saws, three fixed carving spindles, faceting and flat laps, and diamond tools in a variety of

shapes and diameters. His primary concern is being able to duplicate the angles and curves he creates with his first cuts.

THOMAS R. MCPHEE

Some of the artists featured in this exhibit were inspired to try gem carving as a result of historical influences. Thomas McPhee was fascinated by ancient stone seals; some of his pieces, such as the carved emerald "1492," reflect that interest (Thompson, 1994). In the beginning, though, McPhee was unable to pursue his vision due to the lack of proper equipment. Like other gem artists, he has adapted tools to meet his needs. Using a dental motor tool for its speed, he has developed a system that uses air and water to flush the dust from the grinding process (Thompson and McPhee, 1995b). In addition, McPhee makes or modifies just about all of his own burrs (Thompson and McPhee, 1995a).

McPhee applies a traditional sculpting approach to his pieces, first making a detailed "maquette," or model, of exact size in clay (Thompson and McPhee, 1996c). This allows him to work out proportion and design problems that could ruin his highly accurate, figurative work. By carefully measuring the maquette with calipers and continuously transferring these measurements to the rough as he works, McPhee creates pieces of great classical beauty (figure 5; Thompson and McPhee, 1996b). McPhee is also extremely safety-conscious, wearing a respirator whenever he works on hard stones.

NICOLAI MEDVEDEV

Often working with tiny slivers of stone, Nicolai Medvedev creates intarsia boxes and pendants (figure 6; Elliott, 1986). Over the last 20 years, he has developed a palette of colored gem materials—malachite, azurite, rhodochrosite, sugilite, lapis, opal, turquoise, and gold-in-quartz—that appear constantly in his work, accented occasionally by more unusual finds. Working with such slim slabs of often fragile material, he has had to develop techniques to protect the stone during cutting. He encases his rough, which often weighs tens of kilograms, in plaster. The plaster is thicker on one side so that the saw blade passes through the rough and the bulk of the plaster, but the plaster still supports the slab. This prevents a fragile slab from falling onto the floor of the saw and possibly being broken or crushed by the blade (N. Medvedev, pers. comm., 2001). He also places a

piece of glass in front of the slab to help stabilize it during cutting (Berk, 1988). Because of the immense care he takes in preparing and cutting slabs, this is the most time-consuming part of his work; it can take weeks or months to cut a single chunk of rough into the pieces Medvedev will use.

The tiny elements of each mosaic are assembled into panels and then glued with epoxy. When constructing boxes larger than 6 inches (approximately 15 cm) across, Medvedev creates and finishes each side and then assembles the panels. He attaches the panel pieces to supporting material, grinds the pieces flat, and then polishes them. After the panel is completed, he grinds away the supporting material. When working with smaller boxes, Medvedev creates the entire box, then finishes it all at one time.

By working with combinations of stones so intensively, Medvedev has developed a deep understanding of them. Rhodochrosite has to be cut in thicker slabs for maximum color—4 to 5 mm compared to a slender 3 mm for malachite (Berk, 1988). Its translucency also means that rhodochrosite must be placed over a white material, such as marble. Dark wood or stone lining the box behind it makes the rhodochrosite turn brown. Behind opal, however, he can use a dark material that emphasizes its play-of-color. The gem materials at the edges of Nikolai Medvedev's pendants also form the back, acting as a frame for the mosaic.

When polishing opal, Medvedev must bring the heat up gradually and then reduce it slowly. This is challenging when the opal is set next to lapis, as in Crevoshay's "Czarina" (figure 6, left), since the latter material requires a certain amount of heat on the flat lap to give it a nice polish (N. Medvedev, pers. comm., 2001). Malachite too is delicate and will turn brown with too much heat. The gold in gold-in-quartz may pull out during the polishing process. If individual slivers of a stone are damaged during cutting, grinding, or polishing, the entire panel must be scrapped. It cannot be taken apart and reworked.

SHERRIS COTTER SHANK

Sherris Cotter Shank was a bench jeweler when she saw the lapidary work of Henry Hunt in a series run by *Metalsmith* in 1981 and 1982. She later read his books (Hunt, 1993, 1996) and was inspired to begin experimenting with the methods he taught (S. C. Shank, pers. comm., 2001). Shank loves the contours



Figure 6. In "Czarina" (left, 2.9 cm × 8.0 cm), Nikolai Medvedev had to gradually build up and reduce the heat to ensure that the opal survived polishing. In "Om tara" (right, 3.6 cm × 6.0 cm), Medvedev tightly controlled the thickness of the rhodochrosite "frame" to ensure the most attractive depth of color. The artist's signature palette also includes turquoise, sugilite, lapis lazuli, and azurite/malachite. Photo © Harold & Erica Van Pelt.

of the land and recreates the undulating curves, deep grooves, and swirling lines of a wind- and water-shaped hillside, or the rolling surface of an ocean.

Recognizing the very basic concept that light entering standard faceted stones is reflected back through the crown by the angled pavilion facets, Shank developed her "pavilion cut," an example of which is seen in Crevoshay's "Summer's Cup" (figure 7, left). On the back of the stone, Shank carves grooves of varying depths, each of which opposes a cut on the top. These grooves return light through the surface just as the facets of a round brilliant or step cut return light in a standard faceting style. It is the two opposing cuts that create the illusion of swirling movement, together with the optical mix-



Figure 7. Adapting the angled pavilion facets of traditional faceted stones, Sherris Cotter Shank cut grooves of varying depth into the base of this 66.63 ct ametrine, set in Crevoshay's "Summer's Cup" (left). With opposing curved lines on top, these cuts give the illusion that the colors in the ametrine are moving. Larry Winn also uses carefully chosen pavilion cuts in combination with traditional facet angles to produce dramatic reflections, as illustrated by this 11.86 ct carved beryl in "Sol's Jewel" (right). Photo © Harold & Erica Van Pelt.

ing of the colors of a multi-colored gem material such as ametrine.

Shank does all her cutting with a fixed-spindle machine into which she has fitted a Jacobs chuck, which has adjustable jaws to hold grinding tips with shanks of varying dimensions. The chuck allows her to change her diamond-tipped tools as needed. She also relies on a Crystalite phenolic wheel, a precision-surfaced, hard plastic lap that stands up to the heavy pressure she uses when cutting—wood points and wood laps are too soft for her (S. C. Shank, pers. comm., 2001). When she wants to inscribe fine details in her work, she uses a Lab Air-Z mini-motor tool.

LAWRENCE STOLLER

Lawrence Stoller is best known for the work he has done shaping crystals that weigh hundreds of kilograms. He has had to invent much of the equipment he uses to hold and move the material securely and accurately during the cutting and carving process. He also has borrowed equipment from the memorial monument industry (Stoller, 2000). Yet even when creating relatively small pieces, Stoller's work overwhelms most jewelry-size gemstones. In concept, Stoller's carvings often push the boundaries of jewelry until the work occupies the gray area between jewelry gemstone and art object.

The large wing-shaped carvings of Montana agate that Stoller provided for Crevoshay's "Freedom's Flight" (figure 1) were fashioned with a fixed spindle, the method Stoller prefers to use when working on his smaller pieces. The wings are joined in a neck-piece that spans almost 6 inches long (14 cm). The theatricality of such a piece is rarely seen, and is reminiscent of the jewelry designed by René Lalique for Sarah Bernhardt (Becker, 1985; Thompson, 1987). In the Lalique tradition, work such as this expands the concept of what jewelry can be, and at the same time it displays the beauty of a material that many would consider "just agate."

LARRY WINN

Larry Winn began faceting in the 1980s, but soon grew bored with it. Then in 1989, he saw an article in *Lapidary Journal* on Lew Wackler's work that inspired him to try cutting another way (Zeitner, 1989). Like Bernd Munsteiner, Arthur Anderson, Michael Dyber, and Wackler, Winn became interested in reflections and their distortions in gemstones (figure 7, right). Using a milling machine set horizontally as a fixed spindle, a contemporary faceting machine, and a battery of tools, he cuts grooves and dimples in the pavilion surface of transparent materials. An intricate array of crown facets breaks up the pavilion reflections even further. Unlike Munsteiner, Winn chooses symmetrical outlines for his stones, as they are easier to set and thus more appealing to jewelers (McCarthy, 1996).

Winn often cuts the pavilion deeper than may be considered ideal for a particular gem material to avoid leakage of light. He then cuts shallow grooves into the pavilion to provide the reflections he wants. He may also engrave dimples into the pavilion, using a motorized hand piece and a round, 1/8-inch diamond burr. Some facets are left matte for

contrast, while other surfaces are polished so that they act like mirrors. Winn cuts the crown into a complex of intricate facets, terminating in a slight point, much like a rose cut (McCarthy, 1996).

Winn's cuts often bear biological names: "Prophase," a term that refers to cell division, is one, as he felt the pavilion cuts, which move in different directions, were like cells splitting. "Synapse" is designed to reflect light from facet to facet the way an electrical impulse jumps from one nerve to another.

PAULA CREVOSHAY

Once the pieces arrived in her studio, Crevoshay was faced with a variety of challenges. Stoller's wings, for example, were relatively large and long (again, see figure 1). Crevoshay had to design a piece that would hold the weight of the wings over their span and also the shield-shaped center stone that would join them. Crevoshay used a base in pierced gold to support the weight of the wings and allow light to penetrate the Montana agate. Because the shield stone was shallower than the two wings, Crevoshay built a bezel that lifts the stone to the height of the wings; it too is pierced to allow light in and to reduce the visual weight of the piece.

While the Stoller piece was the largest, every piece in the collection challenged Crevoshay, to a greater or lesser degree, to design individualized mountings that would hold the stones securely without interfering with the carving or cutting. She had to accommodate differences in cutting styles, weights, shapes, and sizes, yet still be functional, wearable jewelry.

"VOICES OF THE EARTH"

From figurative forms to abstract designs, from faceting to intarsia to carving, the works of the North American gemstone artists featured in "Voices of the Earth" demonstrate that today's lapidary art plays as vibrant and vital a role in adornment as it has for centuries. By combining such a diversity of styles and techniques in one collection, jewelry designer Paula Crevoshay underscores the appropriateness of using such varied pieces in contemporary designs. In fact, she compels us to reexamine the connection between jewelry and gemstone art and to transcend our own traditional views. "Voices of the Earth" will be exhibited at the Carnegie Museum of Natural History in Pittsburgh, Pennsylvania, from May 1 to July 31, 2002.

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An Interesting CHAROITE Cabochon

A cabochon of charoite with an interesting inclusion was recently sent to the West Coast lab by gemologist Leon M. Agee of Agee Lapidary in Deer Park, Washington. Mr. Agee told us that the cabochon was cut from a slab discovered in a bin of cutting scraps at the 2001 Tucson gem show. The finished stone weighed 292.14 ct and measured 85.78 × 56.57 × 6.70 mm (figure 1).

While charoite is relatively well known as an ornamental gem material, it was the X-shaped pattern and length (79 mm) of the orangy brown inclusion that made this cabochon interesting. Other inclusions visible with a gemological microscope were transparent and near-colorless, or greenish black. Since all of these inclusions had been exposed on the surface and were nicely polished during lapidary preparation, they presented ideal targets for GIA's laser Raman microspectrometer.

The Raman spectrum of the large orangy brown inclusion matched that of the rare mineral tinaksite. We determined that the greenish black inclusions were aegirine, whereas the transparent to translucent near-colorless inclusions proved to be feldspar or quartz, depending on where the testing was done on the polished surface. Although we have examined many objects fashioned from charoite since it was first described as a new mineral in 1976—and encountered aegirine, feldspar, quartz, and tinaksite as inclusions—none of those inclusions had approached this tinaksite in size and unusual shape.

JIK and Maha Tannous

Figure 1. This 292.14 ct charoite cabochon is host to a large X-shaped spray of tinaksite.



High-Iron Cat's-Eye CHRYSOBERYL

Gem-quality chrysoberyl typically shows consistent optical and physical properties. Although variances in its refractive indices have been reported in the literature—with values sometimes so high that the material could be confused with corundum—such chrysoberyls actually are quite rare. Most gemologists have never seen one.

The West Coast lab recently examined a green chatoyant cabochon that was represented as chrysoberyl from Orissa, India. It was sent to us by K & K International of Falls Church, Virginia. The saturated, slightly yellowish green color of the



Figure 2. This 4.58 ct cat's-eye chrysoberyl cabochon had extremely high R.I. and S.G. values.

4.58 ct cabochon was very unusual for chrysoberyl, but the eye was strong and typical in appearance of the chatoyancy seen in this species (figure 2). However, when we put the stone on a refractometer, the spot reading was 1.78, much too high for chrysoberyl (usually 1.746–1.755). The specific gravity of the stone, measured hydrostatically, was also high, at 3.81. There was no fluorescence to long- or short-wave ultraviolet radiation, which would be typical for this color of chrysoberyl. The only feature seen with the desk-model spectroscope was a cutoff at about 480 nm.

These properties were somewhat perplexing, so we obtained permission from our client to polish a small flat facet on the back of the stone in order to get a more precise R.I. reading. Accurate refractive indices of 1.780 and 1.793 (birefringence 0.13) were then obtained on the flat polished surface. We were unable to find any reference to a mineral that fit both the physical appearance and the measured properties of the stone in question.

Moving to more sophisticated tests on the cabochon, we obtained a Raman spectrum that matched chrysoberyl exactly. Energy-dispersive X-ray fluorescence (EDXRF) qualitative chemical analysis showed strong peaks for aluminum and iron with minor peaks for

titanium, gallium, and tin. Beryllium is too light an element to be detected by EDXRF, so aluminum would be the only major element we would expect to find using this method. Therefore, the presence of a much higher iron content than expected confused the issue further.

However, X-ray powder diffraction also confirmed the mineral to be chrysoberyl. Because this cat's-eye chrysoberyl was the most unusual one we had ever seen, we obtained further permission from the owner to submit it to quantitative chemical analyses by electron microprobe.

The microprobe analyses were carried out by Drs. William "Skip" Simmons and Alexander Falster at the University of New Orleans in Louisiana. In addition to the expected major aluminum content, analyses of 11 different spots on the stone revealed 8.92–10.27 wt.% Fe_2O_3 (as total Fe). Traces of titanium were also detected (up to 0.18 wt.% TiO_2), but all other elements analyzed were at or below the detection limit. The large amount of iron (as compared to 0.5–2 wt.% Fe_2O_3 typically recorded) was clearly the cause of the extremely high R.I.'s and S.G.

Although we were not able to find any reference to a chrysoberyl with comparable refractive indices, birefringence, or S.G., we did note one reference to a cat's-eye chrysoberyl with very similar chemistry in a report by M. Hayashi ("Iron-rich chrysoberyl cat's-eye," *Journal of the Gemmological Society of Japan*, Vol. 19, No. 1–4, 1994, pp. 31–32). That stone had approximately 9.90 wt.% Fe_2O_3 (as determined by EDXRF) with an R.I. of 1.77 and an S.G. of 3.75. Although its iron content was similar to that of the chrysoberyl we examined, the R.I. and S.G. values of that stone were somewhat lower.

Coincidentally, while the anomalous cat's-eye was in the laboratory, we also examined two transparent faceted greenish yellow 0.80 and 1.05 ct chrysoberyls from Joeb Enterprises in Solana Beach, California, that fit the data most often quoted in the litera-

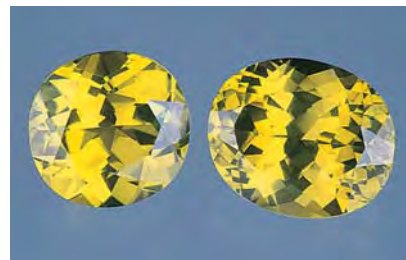


Figure 3. These 0.80 and 1.05 ct greenish yellow chrysoberyls also displayed unusually high properties, but they were still significantly lower than the cat's-eye in figure 2.

ture for high-property chrysoberyl (see, e.g., R. Webster, *Gems*, 5th ed., Butterworth-Heinemann, Oxford, UK, 1994, p. 134; figure 3). Reported to be from Malawi, both of these stones had R.I.'s that nearly matched those of corundum: 1.759–1.769. Although we did not obtain microprobe data on these stones, EDXRF analysis indicated that they also had an iron content that was relatively high for chrysoberyl, although not as high as in the cat's-eye. *SFM*

DIAMOND, with Unusually Large Laser Drill Holes

The East Coast lab recently received for grading a 3.30 ct near-colorless round brilliant cut diamond. Using a standard gemological microscope and overhead reflected light, we observed three unusual cavities—two on the pavilion and one on the crown. Both were irregular in shape, with the outline of one resembling a flower (figure

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Figure 4. In reflected light, the lower cavity in the pavilion of this 3.30 ct diamond breaks the surface in a flower-like shape. Feathers can be seen extending from both cavities. A “spatter ring,” a remnant of laser drilling, is also visible around the lower cavity. Magnified 160×.

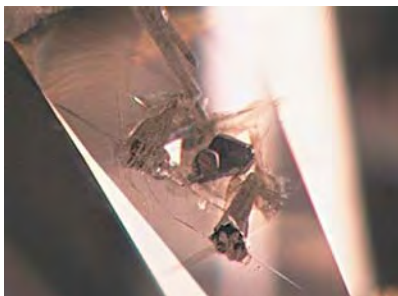


Figure 5. At 100× magnification with darkfield illumination, it is evident that the pavilion cavities in the diamond shown in figure 4 are cone shaped and reach a feather surrounding an included crystal.



Figure 6. The entry point on the crown best illustrates the fact that these cavities are the result of multiple laser drillings. Note the minute feathers extending off these tubes, which give them a “hairy” appearance. Magnified 100×.

4). Several feathers extended from both cavities on the pavilion, so that they appeared to be chips.

With darkfield illumination, magnification revealed that the two pavilion cavities extended into the stone in an inwardly tapering conical shape, and both touched a feather surrounding the same included crystal (figure 5). The roughness of the surfaces made the cavities look like indented naturals. However, our suspicions were aroused when we discovered that the cavity on the crown extended into the diamond via three separate conical tubes, two of which touched an internal feather surrounding a green crystal (figure 6). Along the length of each tube, and extending out from it, were minute feathers that gave the tubes a “hairy” appearance.

Our next task was to confirm that these conical tubes were laser drill holes and not natural etch channels. Etch channels in diamonds probably result from dissolution by corrosive fluids along weaknesses in the crystal structure (see, e.g., L. Orlov, *Mineralogy of the Diamond*, John Wiley & Sons, New York, 1977, pp. 98–100). Most commonly, their shape at the surface of the diamond, as well as the shape of the tube, is rhombic, square, rectangular, or hexagonal, due to the

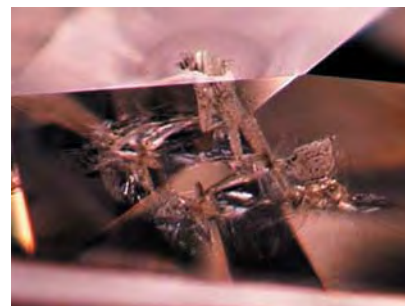
cubic crystal structure of diamond. In rare instances, such channels are triangular. The internal surfaces of etch channels may be smooth, or they may show transverse growth steps or parallel grooves (see, e.g., M. Johnson et al., “When a drill hole isn’t,” *Rapaport Diamond Report*, December 4, 1998, pp. 1, 19, 21, 23, 25–26).

Several features suggested that these tubes were not natural. They were oriented haphazardly to one another, and did not have any obvious relationship to the crystallographic orientation of the stone. Their shape was irregular at the surface of the diamond, and they narrowed into cones as they extended into the diamond, without any obvious growth steps. Also, their internal surfaces were rough, with a frosted appearance, and they contained small black spots. The last and most convincing piece of evidence was apparent only with high magnification: All three of the cavities were surrounded by “spatter rings” where they reached the surface of the diamond. These were created by carbon that was vaporized during the drilling process and redeposited around the outside of the drill hole (see, e.g., J. Koivula, “Micro evidence of natural diamond enhancement,” *MicroWorld of Diamonds*, GemWorld

International, Northbrook, IL, 2000, p. 110). This effect is best seen in figure 7 around the cavity in the crown. In our experience, these rings are not commonly seen due to the post-drilling repolishing of facets, but when present on a polished diamond they offer definitive evidence of laser drilling.

The unusual surface expressions of the cavities resulted from groups of drilled holes being aimed at a single point from slightly different angles.

Figure 7. When the laser-drilled diamond was examined with a combination of darkfield and reflected light, all three tubes could be seen associated with the crown cavity, as well as a “spatter ring” on the surface. Magnified 100×.



The flower-shaped cavity best illustrates this. The question remains: Why would someone do this to a diamond? Creating inclusions of this size hurt the clarity grade more than the crystals they were trying to reach. Perhaps the manufacturer was intentionally trying to make the laser drill holes look like indented naturals in a deceptive effort. Unfortunately, we will never know.

Wendi Mayerson

GLASS Sold as Quartz

A group of five faceted 8.0×4.8 mm translucent light blue button-shaped beads (figure 8) were sent to the West Coast lab by Patricia Gray of Graystone Enterprises in Missoula, Montana. She was suspicious of their nature, and curious about the inclusions they contained. The five beads, removed from a single-strand necklace, were purchased at the September 2001 Denver gem and mineral show, and were sold to Graystone as “natural blue quartz from a new undisclosed locality in China.” Routine gemological testing proved that all five beads were manufactured glass.

When the beads were examined with magnification, numerous transparent rod-shaped to needle-like crystals were clearly and immediately visible (figure 9). In cross-section, these inclusions appeared to be diamond-shaped. When the crystals extended throughout the entire bead, they transmitted light—just as individual fiber-optic fibers would do—and they appeared colorless when examined down their length. This provided evidence that the beads derived their blue color from the glass body, not the inclusions. When examined with cross-polarized light, these inclusions responded in a manner consistent with doubly refractive crystals (figure 10).

Those inclusions exposed to the surface during polishing were raised above the surrounding glass, which indicates that they had a hardness greater than their host. The gas bub-

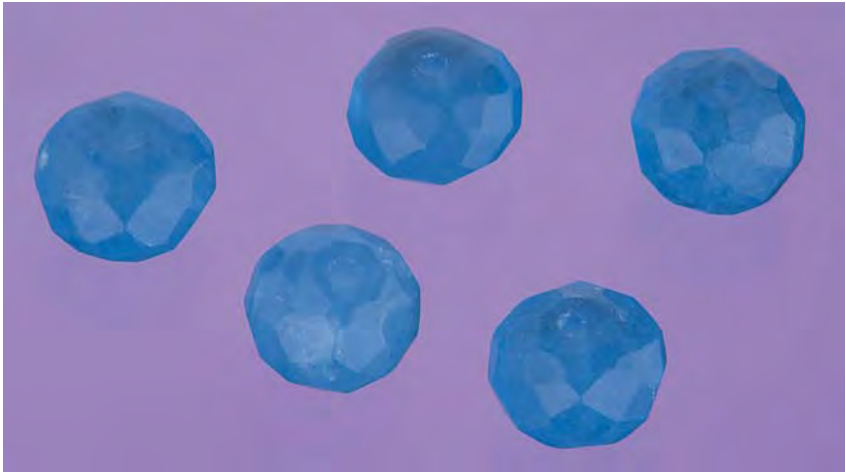


Figure 8. These five 8.0×4.8 mm faceted beads proved to be manufactured glass. They were represented as natural quartz from a “new locality” in China.

bles commonly associated with glass were scarce, although we observed occasional tiny individual bubbles between the rod-shaped inclusions or along grooves in their length (again, see figure 9). Laser Raman microspectrometry of the inclusions exposed to the surface gave a pattern for wollastonite (which has a reported hardness of $5-5\frac{1}{2}$ on the Mohs scale).

Wollastonite is a naturally occurring mineral, but in this instance the inclusions were undoubtedly a prod-

Figure 9. All of the glass beads contained numerous inclusions identified as synthetic wollastonite. Note the tiny gas bubble trapped along a groove in one of the crystals (centered in the photo). Magnified 40 \times .



uct of induced devitrification of the glass. This is not the first time synthetic wollastonite has been identified as inclusions in glass. For example, tabular crystals of synthetic wollastonite in glass are pictured in the *Photoatlas of Inclusions in Gemstones* (E. Gübelin and J.I. Koivula, ABC Edition, Zurich, 1986, p. 439); and, more recently, H. A. Hänni et al. reported on synthetic wollastonite inclusions in a glass that appears to be similar to the beads we examined (“A

Figure 10. Cross-polarized light shows that the synthetic wollastonite inclusions are anisotropic. A first-order red compensator was used to shorten the exposure time. Magnified 35 \times .

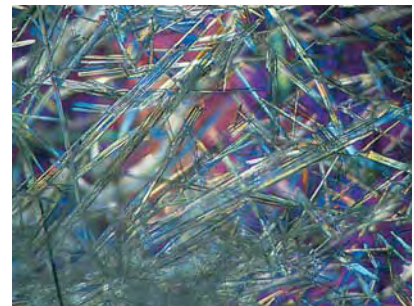




Figure 11. The animal figures (longest, 42.95 mm) in this necklace were represented as being carved from fossil ivory.

glass imitation of blue chalcedony," *Journal of Gemmology*, Vol. 27, No. 5, 2001, pp. 275–285). Whereas Dr. Hänni and his colleagues obtained their samples in Taiwan, represented as chalcedony, it appears that this material is now being sold—and misrepresented as quartz—in the U.S.

JIK and Maha Tannous

Fossil IVORY

Very little ivory has been submitted to the GIA Gem Trade Laboratory since importation of the material into the U.S. was banned in 1989. Therefore, it was interesting to receive for identification a necklace fashioned of numerous small carvings of animals (figure 11) that clearly exhibited the "engine-turned" structure (i.e., intersecting curved lines) characteristic of elephant ivory. The client's primary concern, however, was whether the necklace was recent or fossil ivory.

Fossil ivory typically comes from the woolly mammoth, an early relative of the modern elephant. Many of these mammoths, which became extinct about 10,000 years ago, died in the far northern latitudes, including Siberia, Alaska, and northern

Canada. Because their ivory has been preserved in the continually frozen ground, this ancient material is often almost unchanged from the time it was buried; thus it can be cut, polished, and used in jewelry. Trade in fossil ivory is not regulated, as it poses no threat to the welfare of living elephants.

The challenge of separating modern ivory from mammoth ivory is that both materials exhibit the characteristic engine-turned structure (figure 12), and their gemological properties are virtually identical. However,

Figure 12. This sample slab of mammoth ivory clearly shows the engine-turned effect in the darker internal layer of the tusk. The outer layer is cementum. Magnified 10×.



John Koivula, GIA's chief research gemologist, recalled that several years ago he and former director of Gem Identification C. W. Fryer identified (using X-ray powder diffraction) a blue encrustation on some mammoth ivory as vivianite. This iron phosphate mineral formed via a chemical reaction with the phosphate in the ivory over an extended period of time. It is not present in recent ivory, so blue vivianite discolorations should prove that ivory is of ancient origin.

Fortunately, we were able to purchase a section of mammoth tusk, reportedly found in Canada's Yukon Territory, shortly after the necklace arrived in the lab. Readily visible on the weathered surface of this tusk section were several dark gray-blue smudges (figure 13). Closer inspection revealed a similarly colored encrustation on a broken surface and within several tiny cracks. Small pieces of the encrustation were scraped off and analyzed by laser Raman microspectrometry. The spectra were a perfect match for vivianite, confirming the results obtained years before by Koivula and Fryer. Consequently, we inspected our client's necklace for these blue smudges. We observed them, to some degree, in almost all the carved animals that made up the necklace, proving that this ivory was not of recent origin, but rather was fossil ivory. With magnification, the appearance of the vivianite ranged from small dots

Figure 13. Note the irregular blue areas on the weathered surface of this section of mammoth tusk.



spread out or in dense groups to larger solid areas of a medium-blue to dark blue-gray color (figure 14).

We also noticed on the sample tusk section that there was a very thick (approximately 7 mm) layer on the outside of the tusk with a structure very different from its interior (again, see figure 12). This outside section, which is called "cementum," did not show the engine-turned effect, but instead had a layered structure that ran parallel to the length of the tusk. We found a layer of cementum in a section of modern elephant tusk, but it was very thin and difficult to see. Although additional research is needed, it is possible that the presence of a thick layer of cementum could also indicate mammoth ivory.

A paper published on the Web site for the National Fish and Wildlife Service (www.lab.fws.gov) described yet another way to distinguish recent elephant ivory from mammoth ivory. This paper states that the angles between the lines in the engine-turned effect (which they refer to as "Schreger lines") are different in these two types of ivory. Unfortunately, the process of obtaining these measurements is somewhat involved and requires a flat cross-section of a tusk, so this test would have limited value for ivory that has been carved or used in jewelry. Another advanced technique that has proved effective in separating elephant from mammoth ivory (as well

Figure 14. Vivianite in fossil ivory may appear as large areas with a fibrous structure that follows the structure of the host. Magnified 20×.



as other ivory-like materials) is FT Raman (H. G. M. Edwards et al., "Fourier transform-Raman spectroscopy of ivory: A non-destructive diagnostic technique," *Studies in Conservation*, Vol. 43, No. 1, 1998, pp. 9–16). However, this technology is not readily available to most gemologists or gemological laboratories.

SFM

Hornbill "IVORY"

Recently, the West Coast lab was asked to identify a single 16.5 mm round bead that was semi-translucent to opaque light brownish yellow with a few "carmine" red to dark brown areas that gave it a marbled appearance (figure 15). Also eye-visible was a distinct difference in texture between: (1) an opaque, dense, featureless mass; and (2) a semi-translucent fibrous layered area. Closer observation with a standard gemological microscope revealed that the opaque mass contained very small particles that resembled granules of red pigment (figure 16). These particles were closely packed in the highly colored areas. Such characteristics can usually be found in various types of ivory and the rarely encountered hornbill "ivory."

Because the bead did not have a smooth finish, we had to check various areas before we were able to obtain a vague refractive index reading in the mid-1.50s, which is consistent with the reported values for hornbill "ivory." However, the fibrous area showed a slightly higher R.I., in the low 1.60s. When the bead was exposed to short-wave UV radiation, the light brownish yellow portion fluoresced chalky bluish white and the red area fluoresced strong red. The reaction to long-wave UV was even more intense. In addition, we noticed an odor similar to that of burnt hair when we touched the bead with a thermal reaction tester. Combined, these findings confirmed that the bead was fashioned from an organic material.

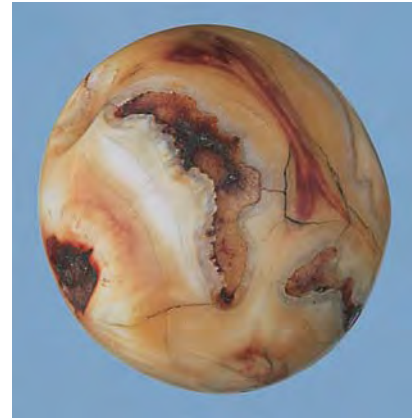
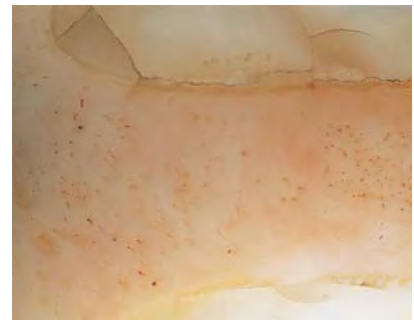


Figure 15. This 16.5 mm round bead was identified as hornbill "ivory."

The presence of the dark red area further proved that the bead had been carved from hornbill "ivory." This material is obtained from the casque of the helmeted hornbill, an exotic bird native to Borneo and Southeast Asia (see, e.g., R. E. Kane, "Hornbill ivory," Summer 1981 *Gems & Gemology*, pp. 96–97; G. Brown and A. J. Moule, "Hornbill ivory," *Journal of Gemmology*, Vol. 18, No. 1, 1982, pp. 8–19; and Lab Notes, Spring 1997, pp. 57–58, including the "editor's note" on trade restrictions). KNH

Figure 16. The "marbled" bead contained particles of red pigment that helped establish its organic nature and proved that it was hornbill "ivory." Magnified 15×.



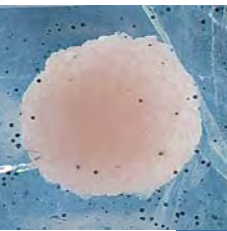


Figure 17. Almost centered in its 4.13 ct quartz host, the 3 mm mass of pink rhodochrosite makes this colorless gem very interesting. The faceted quartz also contains numerous tiny black crystallites of pyrrhotite, as shown in the inset.

QUARTZ with Rhodochrosite

As a faceted gemstone, rock crystal quartz is not particularly exciting unless it contains interesting inclusions. Such was the case with a 4.13 ct square emerald cut that was sent to the West Coast lab by gem dealer Elaine Rohrbach of Pittstown, New Jersey.

This 10.04 × 9.49 × 7.26 mm near-colorless gemstone contained an obvious pink, nearly spherical 3 mm mass under its table facet (figure 17). Even with the unaided eye, numerous tiny black crystallites were also clearly visible. The large pink mass was very close to the surface of the table, and a few of the black grains had been exposed to the surface during faceting. The near- or at-surface locations of these inclusions made them ideal for testing with the laser Raman microspectrometer. The Raman spectra revealed that the pink material was composed of the manganese carbonate rhodochrosite. The two tiny black grains that were analyzed individually proved to be the iron sulfide pyrrhotite.

Because the rhodochrosite inclu-

sion was relatively large and close to the surface, we used EDXRF analysis to confirm its manganese content. With the aid of a masking technique to isolate the inclusion from the host quartz, this testing showed that the inclusion did indeed contain manganese as a major element. While the source of this unusual quartz is not known, we believe that it may have come from Mexico, specifically from the Gibraltar mine in Naica. As shown in figure 18, beautiful colorless crystals with rhodochrosite inclusions have been recovered from this locality.

JIK, Maha Tannous,
and Sam Muhlmeister

SAPPHIRES with Diffusion-Induced Stars

The East Coast lab recently received for identification two asteriated dark blue oval cabochons that weighed 31.64 ct and 15.26 ct, and measured 19.70 × 16.31 × 8.64 mm and 14.88 × 12.49 × 6.68 mm, respectively. In overhead reflected light, both cabochons appeared to be evenly colored and nearly opaque. The stars appeared white, with straight arms of equal length that seemed to float over the surface of the stones (figure 19).

Figure 19. These semi-translucent to opaque dark blue star sapphires (31.64 and 15.26 ct) came into the East Coast lab for identification.



Figure 18. It is possible that the gem in figure 17 was cut from rough similar to this 35.23-mm-long quartz cluster from the Gibraltar mine in Naica, Chihuahua, Mexico.

Typically, a six-rayed star forms as the result of reflections off three sets of oriented needles that are present

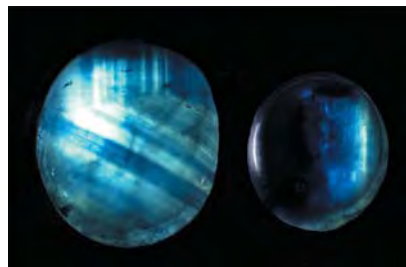


Figure 20. The straight, angular color zoning visible in transmitted light indicates that the dark blue color of these cabochons is natural.

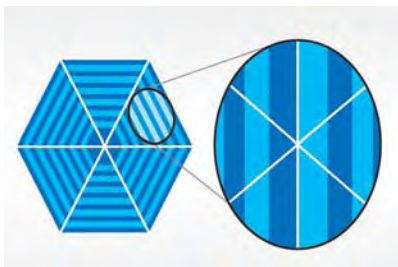


Figure 21. This line drawing illustrates the relationship between asterism and color zoning in a natural star sapphire (shown in both a rough crystal section and a polished cabochon). Note that two of the six rays are always parallel to the color zoning.



Figure 22. With combined transmitted and overhead lighting, it was evident that none of the rays of the stars was parallel to the hexagonal color banding. This was a strong indication that the stars were not natural.

throughout a large portion of the stone. Although examination in transmitted light revealed opaque and translucent areas along with straight, angular color banding (figure 20), we did not see any oriented needle-like inclusions with magnification. Aware that diffusion-induced asterism has been around since Linde Air Products Company patented the process in 1954 (as described in K. Nassau, "Heat treating ruby and sapphire: Technical aspects," Fall 1981 *Gems & Gemology*, pp. 121–131), we suspected that the two stones had been treated.

Standard gemological testing produced the following information on both stones: spot refractive indices of 1.76, no fluorescence to either long- or short-wave UV radiation, and a solid, heavy band from 450 to 470 nm that was visible in the desk-model spectroscope and was probably due to trace amounts of iron. Standard magnification (10×–60×) revealed melted fingerprint-like inclusions, polysynthetic twinning nearly parallel to the bases of the cabochons, and (as noted above) straight, angular bands that were either a very saturated dark blue or colorless—but no oriented needle-like inclusions. This combination of

properties and features indicated that the stones were natural sapphires but the stars were manufactured.

In a sapphire with a natural star, the orientation of the asterism-causing needles is directly related to the crystallography of the host stone. Because color zoning is also related to the hexagonal crystal structure, the rays of the stars are always parallel to the six sides of the hexagon created by the growth/color zoning (see figure 21). Even if only one section of zoning is visible, as seen in the smaller of the two cabochons, two of the star's six rays would still be parallel to the visible banding. As is evident in figure 22, however, that was not the case for the stars on these cabochons. Therefore, we were not surprised when fiber-optic lighting revealed a very shallow hazy, whitish surface layer on both stones. Such a layer, composed of tiny individual needles too small to be detected at standard gemological magnification, previously has been associated with diffusion-induced stars (see, e.g., Lab Notes—Summer 1982, pp.106–107;

Summer 1985, pp. 112–113; Fall 1985, pp. 171–172; Spring 1991, pp. 44–45; and Spring 1995, pp. 56–57; and *Gem News*—Summer 1996, pp. 136–137; and Winter 1997, pp. 308–309). Combined, the above findings allowed us to conclude that the stars on these cabochons had been artificially applied by means of a surface diffusion process.

It is particularly interesting that the treatment in these two cabochons consisted only of the creation of the stars, since the Gem Trade Laboratory more commonly sees this process on cabochons in which the color also has been diffusion-induced.

Wendi Mayerson

PHOTO CREDITS

Maha Tannous—figures 1, 2, 3, 8, 11, 13, 15, 17, and 18; Wendi Mayerson—figures 4, 5, 6, 7, and 21; John I. Koivula—figures 9, 10, 16, and 17 (inset); Shane F. McClure—figures 12 and 14; Elizabeth Schrader—figures 19, 20, and 22.



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SPECIAL REPORT

U.S. Postal Service irradiation process may affect some gemstones. The jewelry industry relies heavily on the USPS to ship gems and jewelry throughout the United States. As most are aware, the recent incidences of people being infected by anthrax spores sent through the mail has caused the postal service to seek ways to protect their employees and the public from this potential threat. One part of this effort is to use a technique that actually kills anthrax spores (and other biological agents) in the mail as it is being processed.

One company with which the postal service has contracted, SureBeam (a subsidiary of Titan Corp.), makes equipment designed to destroy food-borne pathogens such as salmonella. SureBeam uses a type of linear accelerator that creates a beam of high-energy electrons. This is the same type of ionizing radiation that is often used intention-

ally to change the color of some gem materials—and could produce an undesirable result as well. We at GIA and others in the trade immediately recognized the potential impact of this development on the jewelry industry and the consuming public, so we decided to test the effect of the proposed postal irradiation process on several gem materials.

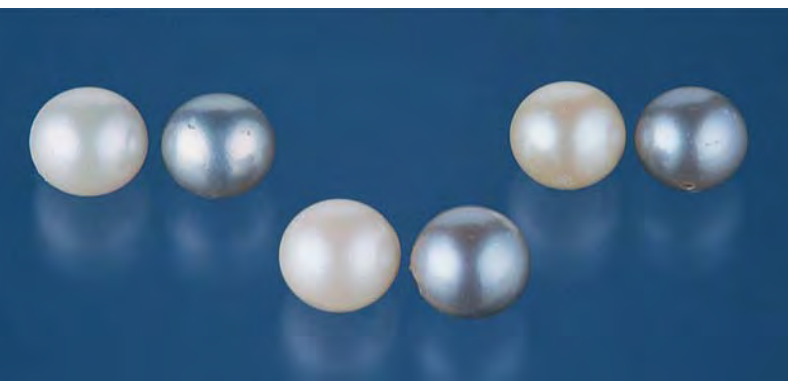
The Process. For these initial tests, we chose gem materials that, based on our many years of experience and discussions with experts in the field, we know may be significantly affected by irradiation. This group consisted of two types of cultured pearls plus 14 gem varieties from eight different gem species—all of which were natural—for a base of 16 sample types (table 1). We also included a 14 karat yellow gold ring, to reassure the industry that gold jewelry would not retain any residual radioactivity from this process.

We made up three sets of this sample group and placed them in boxes that were packaged in the same manner that we routinely use to ship gems from the GIA Gem Trade Laboratory. Because stones are often shipped through the mail more than once (e.g., sent out on memo, returned or sent to a manufacturer for mounting, and then returned or sent to someone else), we asked to have one package scanned just once, another scanned twice, and the third scanned four times—to see if the cumulative effect of multiple scans caused any significant difference.

The contents of the boxes were identical, except that there was only one heavily included gray diamond. We placed this in the package that was to receive four scans to determine whether it would retain any residual radioactivity, as is often detected in irradiated black diamonds.

A spokesman for SureBeam told us that the dosage being used by the postal system is 56 kilograys (kGy), which is equivalent to 5.6 megarads. This figure was later confirmed by Laura Smith, quality assurance manager for Titan Scan Technologies, another Titan Corp. subsidiary, who agreed

Figure 1. All of the white cultured pearls turned gray with irradiation. One in each of these pairs of bead-nucleated saltwater cultured pearls (approximately 6.5 mm) was irradiated, while the other was retained as a control sample. Photo by Maha Tannous.



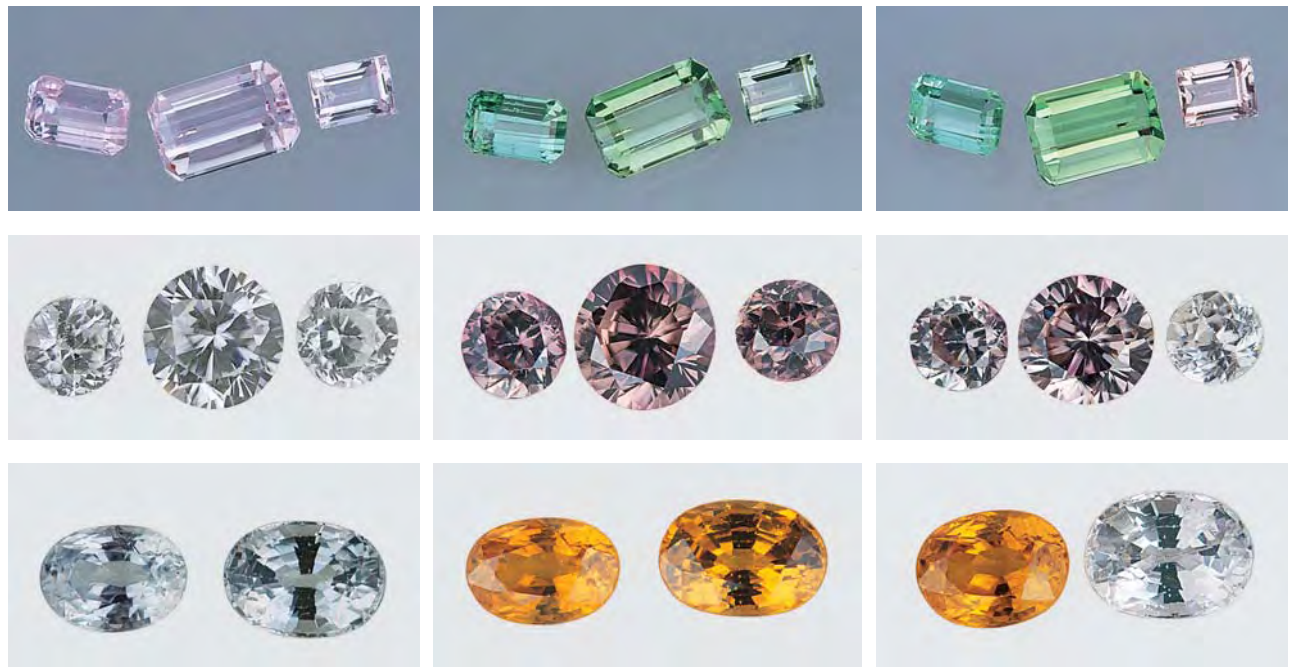


Figure 2. Distinct changes were seen in the color appearance of spodumene (top row, 1.13–4.24 ct), zircon (middle, 0.51–1.39 ct), and sapphire (bottom, 0.60 and 0.72 ct) following simulated USPS irradiation and subsequent fade-testing experiments. For each gem variety, the photo on the left shows the material before irradiation, the middle photo was taken after irradiation, and the image on the right shows the final result of fade testing (far right stone only). Photos by Maha Tannous.

TABLE 1. Gem materials exposed to irradiation conditions used by the USPS.

Gem material	Before	After
Diamond	Near colorless	Near colorless; <i>no change</i>
Diamond	Gray (due to inclusions)	Gray; <i>no change</i>
Spodumene	Pink (kunzite)	Green
Beryl	Brownish orange pink (morganite)	Yellow
Cultured pearl: bead-nucleated saltwater	White	Gray
Cultured pearl: tissue-nucleated freshwater	White	Gray
Quartz	Colorless	Brown
Quartz	Yellow (citrine)	Brown
Sapphire	Light blue	Yellowish orange
Topaz	Colorless	Brown
Tourmaline	Near colorless	Light pink
Tourmaline	Light pink	Darker pink
Tourmaline	Bicolored green and pink	Green; <i>no change</i> Pink; darker
Zircon	Colorless	Pinkish brown
Zircon	Yellow	Yellowish brown
Zircon	Green	Greenish yellowish brown

to run tests for us under the same conditions being used by the U.S. Postal Service. Ms. Smith confirmed, however, that the figure is approximate, as our three packages were exposed to the following doses:

Package A – one scan – 51.0 kGy

Package B – two scans – 113.5 kGy total

Package C – four scans – 251.7 kGy total

Results. After we retrieved the packages, we first checked for the presence of residual radiation with a Victoreen model 290 radiation survey meter. No residual radiation was detected from the unopened packages or any of the individual samples.

Next, we examined each stone for obvious changes in appearance. (Changes in absorption spectra and analytical data will be addressed in future research.) All of the gem materials other than diamond showed a dramatic change in color (see table 1; figures 1 and 2).

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For most of the samples, the changes were just as dramatic in the box that went through only one scan as in the box that went through four. However, the degree of change was different for some stones. For example, the colorless quartz in the box that was scanned once came out a medium brown; a similar sample in the box scanned twice turned dark brown; and the third sample, scanned four times, became almost black.

Some of the color changes produced by radiation exposure are known to be unstable to light or heat. (For more on the color stability of irradiated gems, see K. Nassau, *Gemstone Enhancement*, 2nd ed., Butterworth-Heinemann, Oxford, 1994.) Therefore, we performed some simple experiments on selected samples to try to return them to their original, pre-irradiation color. The stones included sapphire, kunzite, and (originally colorless) zircon. In each case, we tested one of the three irradiated samples and saved the others for comparison.

In an attempt to fade these stones under realistic conditions, we taped them to a south-facing window on a sunny day in December, and checked their color periodically. After approximately 2.5 hours, the green color that had been induced in the kunzite and the pinkish brown in the zircon had completely disappeared, and the stones had returned to essentially their original colors. It is interesting to note that the other two zircons showed noticeable color fading even though they had been kept in the stone paper and were removed only briefly for photography.

The sapphire slowly lost color and became more yellow than orange. After 36 hours, the stone had faded to light yellow and was removed from the window to be photographed. In an attempt to return the stone to its original light blue color, we gently heated it in the flame of an alcohol lamp. This method was successful in removing the remaining yellow color. However, the original blue hue did not return, and the stone was left colorless (again, see figure 2). According to Dr. John Emmett (pers. comm., 2002), if the stone were heated to significantly higher temperatures in a reducing atmosphere, the blue color should be restored.

Implications for the Future. Currently, the USPS is scanning only a small portion of the mail and only letters and flat envelopes. John Dunlap, manager of Materials Handling and Deployment for the USPS Engineering Group (pers. comm., 2001), which oversees mail sanitization operations, told us that "Probably nothing will be done to packages that are sent registered or certified [the preferred method for the jewelry industry], since we now require information from the sender." Other postal authorities have commented that the cost and time required to sanitize all mail would be prohibitive.

We also contacted the U.S. Customs Service, Brinks, Malca Amit, UPS, and FedEx, and learned that no irradiation procedures were being used or were planned by them at this time. Nevertheless, it is important that members of the trade and the consuming public alike be aware that some

gem materials could be affected by the procedure, and every effort should be made to ship such materials by methods that are not likely to be exposed to the irradiation process.

We recognize that other gem species or varieties, including ruby and emerald, may be affected to lesser degrees by this radiation dosage. Also, not all members of the same species or even the same variety should be expected to react similarly. For example, according to Dr. George Rossman of the California Institute of Technology (pers. comm., 2001), it is less likely that blue sapphires from basaltic deposits (e.g., Thailand or Australia) will show a change in color. In the second phase of our testing, which is already underway, we will investigate these and many more questions about this newest concern to the gem industry.

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CONFERENCE REPORTS

28TH INTERNATIONAL GEMMOLOGICAL CONFERENCE

Held in Madrid, Spain, on October 8–12, 2001, the 28th IGC attracted 38 delegates and 25 observers from 22 countries. The participants consisted of gemologists (laboratory and academic), gem cutters and dealers, geologists, archaeologists, instrument designers, museum curators, physical scientists (e.g., spectroscopists), synthetics manufacturers, editors, educators, and more. An abundance of information was exchanged, and new ideas were germinated that should help advance many aspects of gemology, from exploration for new deposits to new approaches to protecting the consumer.

The IGC is a biennial event, and this year's conference was organized by the Instituto Gemológico Español, with Cristina Sapalski as the executive secretary. The 51 presentations (44 oral and seven posters) covered a variety of topics. This report, prepared by IGC participants Dr. Alfred A. Levinson, Robert E. Kane, and Michael E. Gray, is a summary of selected presentations that provide a significant amount of new information for *G&G* readers.

Update on Piteiras emeralds, Minas Gerais, Brazil. Dr. Jan Kanis, a consulting geologist from Veitsrodt, Germany, provided an update (as of May 2001) on the exploration, geology, and recovery of emeralds at the Piteiras property, which is part of the Itabira emerald belt (see Spring 2001 GNI section, pp. 68–69). A 140-m-long tunnel with a 12% decline has been completed to access the emerald-bearing zones, from which further bulk sampling is taking place. An automated plant is used to process the emerald-bearing schist and associated quartz-feldspar veins, and 24 workers hand-pick the emeralds from the concentrate along three conveyor belts. Fine facet- and cabochon-grade rough has been recovered, and most of the stones

range from 3 to 12 mm. However, some large (more than 2 kg), mostly non-gem-quality emerald crystals also have been recovered (figure 3). Electron microprobe analysis of four emerald crystals revealed an average of 0.60 wt.% FeO, 0.33 wt.% Cr₂O₃, and 0.03 wt.% V₂O₃.

Update on jadeite mining in Myanmar. In February 2000, Robert E. Kane of Fine Gems International, Helena, Montana, visited the Nansibon jadeite mines in northern Myanmar (see also R. W. Hughes et al., "Burmese jade: The inscrutable gem," Spring 2000 *Gems & Gemology*, pp. 14–15). These mines are located within the Hkamti region, which is arguably the most important source of green jadeite in the world today. The two main mining areas—Natmaw and Nansibon—are separated by about 32 air km (20 miles).

At Natmaw, the jadeite occurs in two types of deposits: (1) primary—as dikes and veins in serpentinite, and (2) secondary—as jadeite pebbles and boulders in conglomerate. The primary deposits are mined using conventional pneumatic drilling and blasting; the pebbles and boulders found usually come from the Natmaw River. At Nansibon, an area of jadeite-bearing conglomerates is divided into nearly 175 one-acre cooperative joint-venture mining claims that are worked by both traditional hand methods and modern mechanized mining techniques (figure 4).

The Myanma Gems Enterprise, a subsidiary of the government's Ministry of Mines, oversees jadeite mining in the Nansibon and Natmaw areas, and has a valuation facility in the town of Hkamti. The jadeite is categorized according to three grades: (1) Gem Quality, (2) Commercial, and (3) Utility. Valuation is based on standardized pricing guidelines. After valuation, the jadeite is sent to trading and cutting centers directly or via Mandalay.

Figure 3. This large (18 × 9 cm) emerald crystal was recently recovered from the Piteiras property in Minas Gerais, Brazil. Photo courtesy of Jean-Marc Lopez.



Figure 4. The Nansibon region of northern Myanmar is an important source of fine-quality Imperial jadeite. This is the largest jadeite mining operation in the area, the Hjar Maw joint venture. Photo by Robert E. Kane.

The structure of opals. The structure of play-of-color opal of sedimentary origin (e.g., Australia) is classically described as a three-dimensional stacking of silica (SiO₂) spheres. However, Dr. Emmanuel Fritsch of the University of Nantes, France, explained that this is an oversimplification applicable only to highly porous, hydrophane opal. In opals typically encountered in the gem trade, the spheres coalesce to the point that the structure is best described as a network of holes (i.e., the spaces remaining between the spheres) in a solid silica matrix.

In opals of volcanic origin (e.g., Mexico), no such spheres are observed on freshly broken surfaces of play-of-color material. Only after etching with dilute hydrofluoric acid is a network of spherical holes observed. These holes are about 200 nm in diameter, in a residual "honeycomb" composed of small siliceous grains (20–40 nm each). These grains appear to be the true elementary building blocks of many opals. Because of their small size, they are best observed with an atomic-force microscope (figure 5). In volcanic opals without play-of-color, these small grains are disordered. They sometimes coalesce to form fibers (in pink opal) or platy crystals of disordered cristobalite in opal CT (in most volcanic opals). The ~200-nm-diameter spheres observed in play-of-color sedimentary opals from Australia or Brazil are on rare occasions built of concentric layers of small grains.

Transparent green orthoclase feldspar from Vietnam. Dr. Johann Ponahlo of the Natural History Museum, Vienna, Austria, described green orthoclase that first appeared in gem markets at Luc Yen, in northern Vietnam, in 1997. The material is predominantly opaque, but some translucent and transparent pieces have been sold as polished gems, represented as jadeite or amazonite. Mineralogical studies have established that the material is orthoclase

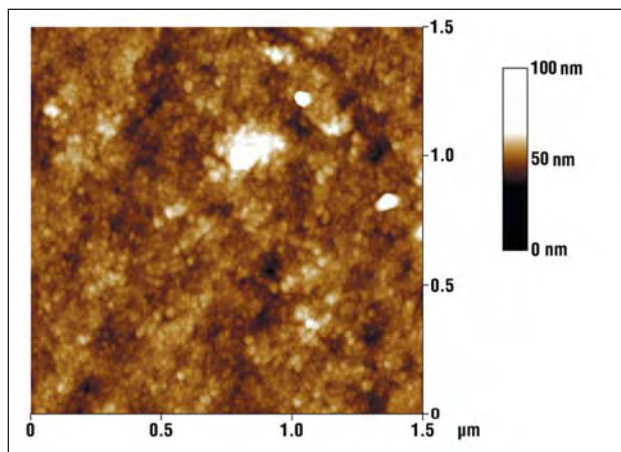


Figure 5. Atomic-force microscopy of the freshly broken and etched surface of a volcanic fire opal from Kazakhstan shows that it is composed of an agglomeration of small silica grains that are typically about 20 nm (0.02 μm) in diameter. The field of view is 1.5 × 1.5 mm, and the colors correspond to the topographic relief of the broken surface. Micrograph by David Albertini.

because it is a monoclinic K-feldspar (amazonite is a green Pb-bearing triclinic K-feldspar). Unique to this locality, the orthoclase contains inclusions of small ruby crystals, which were identified by their strong red cathodoluminescence (CL) and characteristic CL spectrum. A strong CL band at 822–834 nm also is characteristic of orthoclase from this locality. The green color is attributed to an unusually high lead content (0.5 wt.% PbO), which is also unique to orthoclase from the Luc Yen area.

Cultured mabe pearls from North Queensland, Australia.

Dr. Grahame Brown of Brisbane, Australia, reviewed the culturing process, production, and quality characteristics of the bead-nucleated mabes that are cultured by Indian Pacific Pearls Ltd. in subtropical waters off Orpheus Island, 80 km north-northwest of Townsville. When they reach approximately 120 mm long, one-year-old *Pteria penguin* oysters (also known as penguin or black wing oysters) are implanted with five polymer nuclei of various shapes. After 18 months the mabes are harvested, with a nacre thickness of ~0.5 mm. After processing, about 40% of the cultured mabes are marketable (figure 6).

The cultured mabe pearls are 12–16 mm in diameter. Their nacre is highly iridescent, in colors that range from white-“silver” to “silver”-brown, and a most desirable slightly brownish “gold.” Some are attractively patterned by the intergrowth of black calcite that lines the outer margin of the mollusk’s shell. When exposed to long-wave UV radiation, the white to “silver” nacre fluoresces a strong blue and the brown and black material is inert.

“Young” and “old” sapphires from Australia and Southeast Asia. Australia and Southeast Asia have been the sources of large amounts of sapphire associated with

basaltic rocks. It is universally accepted by geologists that the sapphires did not crystallize directly from the basalts; rather, the basalts merely were the transporting mechanism that brought the sapphires to the surface. Over the past decade, two types of sapphires associated with basalts from these areas have been recognized, based on variations in their trace-element contents. Dr. F. L. Sutherland of the Australian Museum, Sydney, postulated that sapphires with a $\text{Cr}_2\text{O}_3/\text{Ga}_2\text{O}_3$ ratio less than 1 crystallized from a magma, whereas those with a $\text{Cr}_2\text{O}_3/\text{Ga}_2\text{O}_3$ ratio greater than 1 formed by a metamorphic process.

To help prove this hypothesis, Dr. Sutherland and co-workers have obtained information on the age of sapphires from both inferred origins. Sapphires of such different geological origins should show discrete differences in their crystallization ages. Syngenetic zircon inclusions (figure 7) in both types of sapphire were dated by uranium-lead isotope methods. Vastly different ages (ranging from 2.8 to 900 million years) were obtained in a study of Australian sapphires of both types, from Queensland and New South Wales. The younger ages correspond to sapphires with a magmatic origin, while the older sapphires have trace-element ratios that indicate a metamorphic origin. The youngest ages obtained so far (1.1–1.5 million years) were found in magmatic-type sapphires from Laos.

Spanish gem deposits. Cristina Sapalski gave an overview of gem and mineral localities in Spain (see also J. C. Guinea and E. G. Huertos, “Mapa Gemológico y Previsor de España,” Instituto Gemológico Español and Instituto Geológico y Minero de España, Madrid, 1986). These include: sapphire and spinel in marble deposits at Villanueva de Bogas (Toledo); cinnabar and mercury at the world-famous Almadén deposits; topaz from greisens at the Valle de la Serena mine (Badajoz); hematite and mala-

Figure 6. These cultured mabe pearls were harvested from *Pteria penguin* oysters near Orpheus Island, North Queensland, Australia. Photo by Grahame Brown.



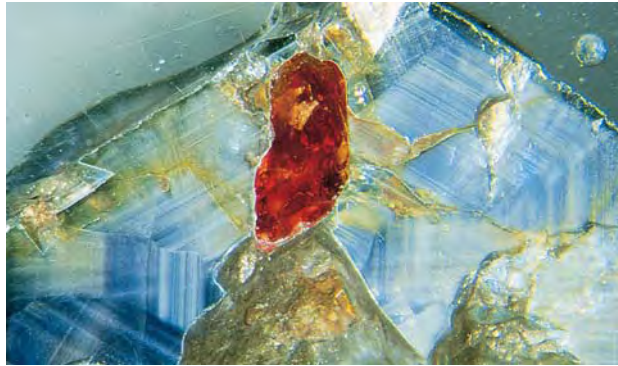


Figure 7. Uranium-lead isotopic dating of this 3-mm-long red-orange zircon inclusion in an Australian sapphire from Lava Plains, Queensland, suggests a crystallization age of 3 million years and a magmatic origin. Photo by Gayle Webb, Australian Museum.

chite at the Jayona mine; scapolite, sphene, and other minerals in skarns at Burguillos del Cerro and Jeréz de los Caballeros (Badajoz); turquoise from hydrothermal veins at Valdeflorez (Cáceres); rose quartz from a pegmatite at Oliva de Plasencia (Cáceres); goshenite in cavities within the Pereña pegmatite; and variscite at Palazuelo de las Cuevas. Currently, there is little or no commercial production of gem-quality material from these occurrences.

Tsavorite from Tanzania and elsewhere. Menahem Sevdernish of the European Gemological Center and College, Ramat Gan, Israel, reviewed currently known localities for tsavorite and recounted the cutting of a 192 ct piece of tsavorite that was recovered from the tailings of the old Titus tsavorite mine in Tanzania (see Spring 2001 GNI, pp. 72–73). Tsavorite was originally found and described from the Tsavo National Game Park in Kenya. However, over the last few years Tanzania has surpassed Kenya in production of this gem. Today, there are five main sources of tsavorite in Tanzania (see figure 8), each of which produces gems with slightly different color characteristics. However, their gemological characteristics (e.g., R.I. and S.G. values) are essentially identical.

Advanced spectroscopic methods applied to gem materials. Drs. Jean-Marie Dereppe and Claudette Moreaux of the University of Louvain, Belgium, reviewed a variety of nonconventional spectroscopic methods such as neutron activation analysis (NAA), Mössbauer spectroscopy, nuclear magnetic resonance (NMR), and X-ray photoelectron spectroscopy (XPS, also called electron spectroscopy for chemical analysis [ESCA]). These different methods can be used to help determine the locality of origin of natural gemstones and detect new synthetics or treatments.

Synthetic and enhanced gems from Russia. An update on synthetics, simulants, and gem treatments from Russia was provided by Dr. Vladimir S. Balitsky of the Institute of

Experimental Mineralogy, Russian Academy of Science, Chernogolovka, Russia. Several government institutes and about 30 companies have succeeded in manufacturing almost all known gems, whether their natural counter-

Figure 8. This map shows the five major tsavorite-producing localities in Tanzania (Komolo, Merelani Hills, Ruangwa, Tunduru, and Uмба) and one in Kenya (Voi, near the Tsavo National Game Park). The characteristic colors of the tsavorites from each locality also are illustrated. Courtesy of Menahem Sevdernish.

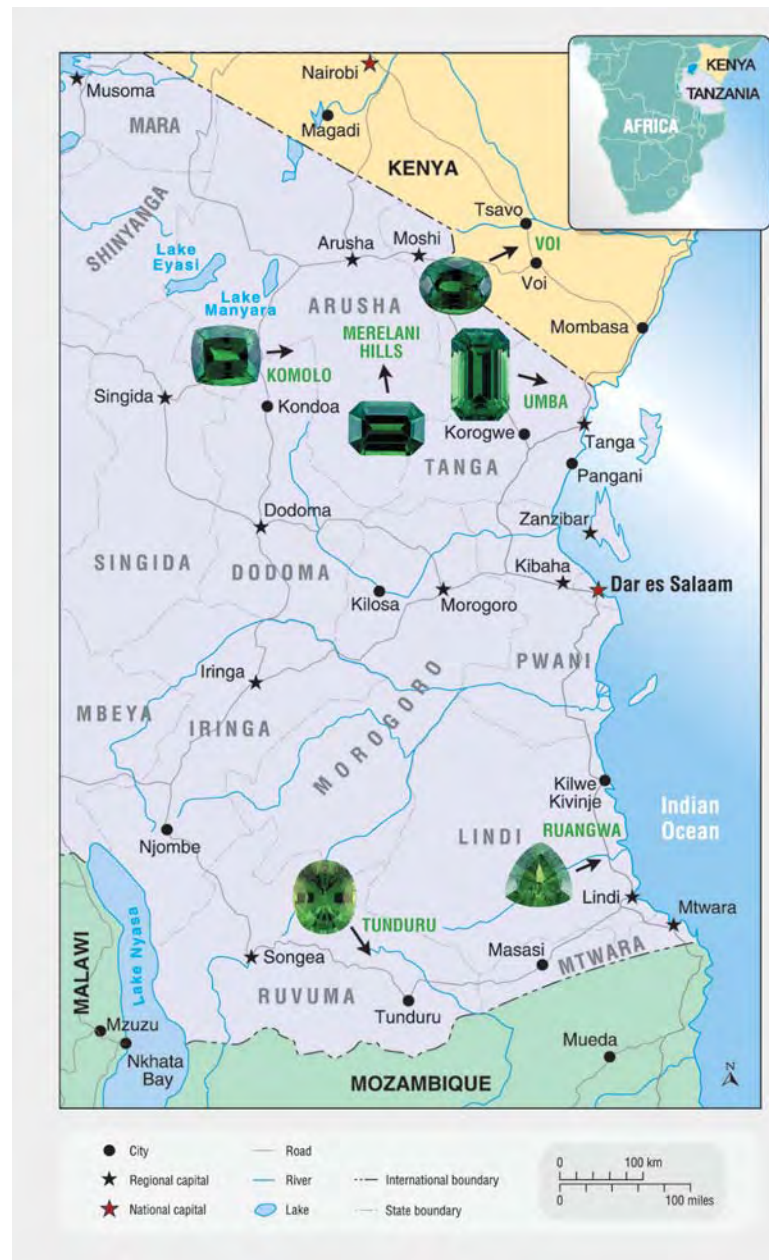




Figure 9. Russian gem treaters are experimenting with surface-coloring technologies using a high-temperature process in the presence of cobalt and other metals and their oxides. This 1.17 ct reddish orange sapphire and 2.62 ct orangy yellow topaz were treated in this fashion. Courtesy of Vladimir S. Balitsky; photo by Maha Tannous.

parts are abundant (e.g., some varieties of synthetic quartz) or relatively uncommon (e.g., synthetic alexandrite, morganite, and moissanite), and representing a broad value range (e.g., synthetic emerald, play-of-color opal, malachite, and turquoise). In some cases, they are being manufactured in huge amounts—such as a few thousand kilograms annually of synthetic amethyst, ametrine, ruby, and sapphires of various colors—by every major method of synthesis (including hydrothermal, flux, Czochralski, and floating zone). Also being manufactured are large quantities of simulants, such as YAG, GGG, and CZ.

The Russians are enhancing the appearance and/or physical characteristics of several natural gems, including: agate, amazonite, amber, charoite, corundum, danburite, demantoid garnet, heliodor, lazurite, nephrite, quartz, topaz, and turquoise. A variety of techniques are used, such as heat treatment, impregnation, and dyeing. Gem treaters are also developing new surface-coloring technologies. For example, they are using a high-temperature process that chemically alters the surface of stones to turn colorless and pale-colored sapphires an attractive blue. Quartz and topaz are also enhanced by this process (see, e.g., figure 9).

The future will likely see increased production of larger and better synthetics (e.g., diamonds), as well as advances in enhancement techniques. Clearly, Russia is a leader in these fields.

Recent observations at CISGEM. Dr. Margherita Superchi of the Centro Informazione e Servizi Gemmologici (CISGEM), Milan, Italy, focused mainly on the recent discovery of gem-quality rhodizite from Antetetzantsio in central Madagascar, which she compared to the new gem mineral londonite, $(\text{Cs}, \text{K}, \text{Rb})\text{Al}_4\text{Be}_4(\text{B}, \text{Be})_{12}\text{O}_{28}$. The latter was discovered at nearby Antsongombato (see W. B. Simmons et al., "Londonite, a new mineral species: The Cs-dominant analogue of rhodizite from the Antandrokomby granitic

pegmatite, Madagascar," *Canadian Mineralogist*, Vol. 39, 2001, pp. 747–755). The Antetetzantsio rhodizite ranges from colorless to yellow-green or very light bluish green (figure 10). Preliminary chemical data reveal a relatively high content of rubidium.

Dr. Superchi also discussed a new bead that is being manufactured in Australia for pearl culturing. The bead is made from sintered dolomite, $\text{CaMg}(\text{CO}_3)_2$, and spheres from 13 to 15 mm in diameter have been used to nucleate South Sea cultured pearls on at least one Indonesian farm. The material has an S.G. of 2.84 and is opaque to X-rays.

A code of ethics for gemologists and jewelers. Dr. Roger Harding of the Gemmological Association and Gem Testing Laboratory of Great Britain (GAGTL), discussed an important matter for gemologists and jewelers—a general code of practice and behavior in business. This topic has particular relevance today because business practices have changed significantly in recent years. For example, via the Internet, traders are more often dealing with people they do not know. Also, the need to disclose enhancements and synthetics is more important than ever before to safeguard the future of the gem and jewelry industry.

Dr. Harding reviewed the codes of conduct, practice, and/or ethics, as well as disciplinary procedures and remediations, of four professional organizations in Great Britain: the National Association of Goldsmiths, the Geological Society, the Registered Valuers, and the London Diamond Bourse and Club. He noted large differences, especially in detail, among them, even though all operate within the same region. Based on these preliminary findings, Dr. Harding concluded that it would be difficult to compile a detailed "code of practice" that would be both applicable and acceptable to all segments of the gem and jewelry industry. Accordingly, GAGTL is considering a general code of conduct, and would welcome input from similar organizations worldwide.

Hardness testing of gemstones. It is well known that some gems show variations in their hardness according to crystallographic orientation. For example, the Mohs hardness of kyanite ranges from 4.5 to 7, and diamond must be oriented in specific directions during cutting. Michael Gray of Coast-to-Coast Rare Stones Intl., Missoula, Montana, reported that *every* mineral species should have some variation in hardness according to crystallographic orientation. Hand-held testers have been developed that use traditional (scratch) techniques to accurately measure hardness in a matter of seconds. These instruments could be used to help confirm the identity of gem materials, even when mounted, because the mark they leave is imperceptible without magnification. Mr. Gray proposed using this technique to reexamine the accepted hardness of various mineral species; to determine if there are differences in directional hardness between heat-treated gems (such as corundum) and synthetics, as compared to their natural counter-

parts; and to investigate whether gems from different localities show differences in hardness.

Diamond presentations at the annual AusIMM and Australian Diamond Conferences. The annual Australasian Institute of Mining & Metallurgy (AusIMM) meeting, held November 6–8 in Melbourne, was attended by 650, down from 2,000 the previous year. Meanwhile, attendance at the Australian Diamond Conference, held December 3–4 in Perth, was 240, which exceeded the attendance three years ago at 180.

Many presentations at the two meetings overlapped. The highlight of both conferences was the address given by Miles Kennedy, chairman, and David Jones, exploration manager, of Kimberley Diamond Co. (KDC), which in 2000 purchased the mining rights to the Ellendale project in the West Kimberly region of Western Australia. The area contains two large (78 and 45 ha) diamondiferous lamproites, and evaluation by KDC has shown that parts of their western peripheries have enriched surface zones down to 3 m (10 feet) that contain 470,000 tonnes at 26 carats/tonne (pipe 4) and 500,000 tonnes at over 12 carats/tonne (pipe 9). During evaluation, good-quality diamonds weighing 8.04 ct, 7.90 ct, and 6.88 ct were found. Mining is scheduled to start in April or May 2002. With a projected production of 400,000 carats per year, Ellendale will be Australia's third diamond mine after Argyle and Merlin.

Gordon Gilchrist, managing director of Argyle Diamonds, remarked that diamonds now comprise about 10% of Rio Tinto's business. With the recent completion of development work for enlarging the open pit at Argyle, annual production will climb back to 30 million carats (Mct), up from its present 24 Mct. The Merlin mine produces 70,000 carats annually, and Canada's Diavik mine will go on-line in mid-2003 with 2.6 Mct projected for the year. Diavik's planned full production of 7.8 Mct annually will be reached in mid-2005. Other Rio Tinto projects include the Murowa pipes in Zimbabwe, which may start production in 2003 with an initial output of 400,000

carats per year, and an unnamed venture in Brazil.

Bill McKechnie, group manager of exploration for De Beers South Africa, gave a diamond industry overview from the De Beers perspective. Production among the three largest producers stands as: De Beers—31% by weight, 44% by value; Russia—18% by weight, 20% by value; and Rio Tinto—43% by weight, 4% by value. De Beers's new producers will be Snap Lake, starting in 2005 with 1.7 Mct annually; the new small pipe east of Orapa (Botswana), starting in 2002 with 170,000 carats per year; Mwadui (Tanzania) redeveloped and in full production in 2003 at 250,000 carats per year; and the Premier C-cut (South Africa), in full production by 2008 at 3 Mct per year. The company's exploration in Canada centers on three areas: the Victor pipe in the James Bay Lowlands (with diamonds valued at US\$160/ct), the Fort à la Corne area in Saskatchewan, and the Kennady Lake area in the Slave province of the Northwest Territories (NWT).

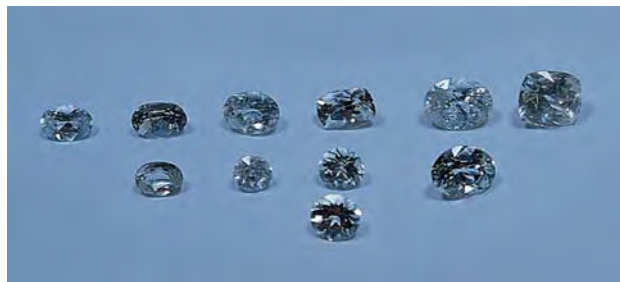
Elsewhere in Canada, Tahera Corp.'s Joseph Gutnick described the discovery of the new Coronation district of diamondiferous kimberlites, 120 km northwest of the company's Jericho project in Nunavut. Jericho may become Canada's third diamond mine, ahead of De Beers's Snap Lake.

Stephen Cooper, Wolf Marx, and Leon Daniels of Orogenic Exploration and Tawana Resources discussed the Flinders Island prospect off the west coast of South Australia, where drilling will begin in January 2002. Linda Tompkins, technical director of Elkedra Diamonds, outlined the geologic merits of exploring the Aljtawarra craton in the southeastern part of the Northern Territory. Various companies presented case histories of discovery, sampling, and exploration at other Australian projects, but they did not include any new mine feasibility studies.

Presentations on diamond projects elsewhere included: Namakwa Diamond Co.'s development of onshore diamondiferous beach deposits, 12–47 km north of the Olifants River in Namaqualand, South Africa; African Mining & Petroleum Resources' Bobi diamond project in the Ivory Coast, which aims to start mining an alluvial deposit in January 2003 at a rate of up to 50,000 carats per year of diamonds valued at US\$100/ct; and an alluvial deposit in Brazil's Abaete River that is shared by Australia's Kimberley Diamonds and Black Swan Minerals of Toronto. Namibia's mining minister, Jesaya Nyamu, pointed out that the country has profited from developing its own diamond cutting and polishing industry. Richard Russell, speaking for Mount Burgess Mining, announced the intersection of kimberlite at their Tsumkwe prospect, in northeastern Namibia. The contributor of this GNI entry, acting as technical director of Australian Indian Resources, indicated that there are still many undiscovered diamond deposits in India.

In other presentations, David Fardon, manager of polished sales at Argyle Diamonds, showed the variations in color and intensity of pink diamonds. Garry Holloway of

Figure 10. The Rb-rich rhodizites shown here (up to 1.15 ct) were recently mined from the Antetezantsio pegmatite in central Madagascar. Courtesy of Margherita Superchi.



Precious Metals discussed how small manufacturers and retailers can shorten the pipeline by making direct arrangements with producers and establishing their own brand.

The atmosphere in Melbourne among the metal miners and explorers was subdued, but in Perth the mood was different. Despite the present poor economic climate, diamond explorers remain optimistic. The success of the initial prospectus offer for Elkedra Diamonds showed that it was still possible to raise capital for a new project. Many junior diamond exploration companies are still venturing into Africa and India. Rio Tinto and De Beers are each investing millions annually for exploration in Australia and Canada. The biggest challenge will be to increase demand for diamonds in order to keep up with increasing production.

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COLORED STONES AND ORGANIC MATERIALS

Gem resources of Afghanistan. If wars and tribal conflicts were not tearing the country apart, Afghanistan could produce as much as \$300–\$400 million in colored gemstones yearly, according to *Gems & Gemology* author Gary Bowersox, of GeoVision Inc., Honolulu, who has been working with Afghan miners and dealers for 30 years. Bowersox says the country could be a major source for numerous gemstones, including emerald, aquamarine, morganite, tourmaline, kunzite, pink sapphire, ruby and, of course, lapis lazuli.

As Mr. Bowersox indicated in the Winter 1985 issue of *G&G* ("A Status Report on Gemstones from Afghanistan," pp. 192–204), most of the country's gem deposits are located in the eastern region within the Hindu Kush Mountains, relatively close to the border with Pakistan. Many of the mines are in remote, mountainous areas, and some are accessible for only a few months of the year. Since miners have already exploited the surface deposits, now they must go deeper to find the gems, which will require more sophisticated equipment than the primitive digging and blasting typically used there.

Mr. Bowersox feels that the strongest potential is for emeralds from the Panjshir Valley, which was also the home base of the recently assassinated Northern Alliance leader General Ahmed Shah Massoud, who was heavily involved in emerald mining. Mr. Bowersox maintains that the best gems are "comparable to the finest emeralds of the Muzo mine in Colombia." Despite the primitive mining methods, as much as \$10 million worth of emeralds have been produced annually since 1994.

Pegmatite gems (see, e.g., figure 11) are mined in the Nuristan-Laghman region, which is east of the main emerald deposits. In his 1985 *G&G* article, Mr. Bowersox wrote that since the early 1970s "literally hundreds of thousands of carats of gem-quality tourmaline and fine kunzite" had



Figure 11. Even in times of war, Afghanistan has produced an abundant supply of gems, such as this tourmaline (12.1 cm tall, with stilbite and cleavelandite) from a pegmatite in Paprok, Nuristan Province. Courtesy of Steve Neely; photo © Jeff Scovil.

been cut from this area. Morganite and large aquamarine crystals have been mined in the same region. The ruby and sapphire deposits are the most accessible, located near the road between the capital, Kabul, and the city of Jalalabad to the east. Because this has been one of the country's most embattled areas, production has been sparse, although Mr. Bowersox believes it could be a major deposit.

Lapis lazuli, for which Afghanistan is the primary source, has been mined for centuries in Badakhshan Province, north of the country's other gemstone deposits. In July–August 2001, Mr. Bowersox escorted a film crew to the lapis mines. Although there was little activity or production at the mine, the group saw more than 18 tons of lapis lazuli for sale in Peshawar, Pakistan. Apparently the miners were occupied with the war against the Taliban, as numerous lapis veins could still be seen in the mine tunnels.

Mr. Bowersox is optimistic that, if peace and stability return to the country (which has known neither for some 20 years), "gems from Afghanistan will be flowing onto the market for many years to come."

Update on amethyst, citrine, and ametrine from the Anahí mine, Bolivia. Since the publication of "The Anahí ametrine mine, Bolivia" by P. M. Vasconcelos et al. (Spring 1994 *G&G*, pp. 4–23), there have been some significant changes in the processing and marketing of gem material from this mine. The following update was provided by Ramiro Rivero, owner of *Minerales y Metales del*

Oriente S.R.L. (Santa Cruz, Bolivia), which has mined the deposit since 1990.

The company currently employs a full-time team of three mining engineers and geologists, as well as more than 120 miners. Exploration is conducted simultaneously with mining to help assure a steady supply of material in the future. They are now exploiting seven areas within the Anahí mining concession (see, e.g., figure 12), in search of cavities that are lined with the amethyst-citrine crystals. The miners extract about 30–40 tonnes of amethyst, citrine, and ametrine (bicolored amethyst-citrine; see figure 12 inset) every month, which is processed at the company's facility in the city of Santa Cruz (figure 13). The processing plant employs approximately 60 workers, who are involved in washing, cobbing, sawing, and pre-forming the rough. Calibrated pre-forms are sent to Hong Kong for faceting—together with examples of finished gemstones with the desired proportions and facet designs—and the polished gems are then returned to Santa Cruz for sorting and quality control before distribution to the international market.

To avoid problems created by the widespread practice of mixing synthetic quartz into parcels of amethyst, citrine, and ametrine, the company sells about 80% of their gemstones directly to overseas jewelry manufacturers. Sales of rough material to selected high-end designers and cutters will continue at the Tucson gem show. The company aims to maintain the combined production of faceted material (sold directly and cut from rough) at 3 million carats per year, as they have since 1998. The proportion of each gem variety produced is adjusted according to market requirements; today it is approximately 40% amethyst, 20% citrine, 20% ametrine, and 20% "anahite" (pale amethyst with no brown overtones). Every year, about 100 tonnes of nonfacetable material is sold to manufacturers of spheres, cabochons, and beads in Brazil and Hong Kong. The company also sells about 10 tonnes of mineral specimens annually.

Research and development on gem cutting and jewelry manufacturing is ongoing. The company is investigating the logistics of developing large-scale lapidary capabilities in Santa Cruz, and they are test marketing silver jewelry that is being manufactured in Bangkok.

"Copal" resin from Madagascar. In recent years, attractive polished specimens sold as copal from Madagascar have become widely available. The material's transparency, interesting inclusions, and availability in large sizes and quantities have contributed to its popularity. GNI editor Brendan Laurs recently received some information on the origin and characteristics of this Malagasy "copal" from Dr. Federico Pezzotta, of the Museo Civico di Storia Naturale, Milan, Italy.

Dr. Pezzotta has followed this attractive resin since 1994–95, when the first production arrived in the capital city, Antananarivo. At that time, the material was scarce,



Figure 12. A miner uses a wheelbarrow to remove material from the Anahí mine in Bolivia; photo courtesy of Ramiro Rivero. The free-form ametrine carving in the inset is by Michael Dyber and weighs 25.60 ct; photo by Sena Dyber.

commanded high prices, and was sold as amber. Soon buyers classified it as "copal" when they realized that it was of recent origin. In fact, this material should actually be called *resin*, since it is generally just several years (or tens of years) old, according to Dr. Pezzotta. (Conversely, *copal* is defined

Figure 13. At a processing facility in Santa Cruz, Bolivia, mine-run material from the Anahí mine is washed, cobbled (center and right side), sawn, and pre-formed (left side). Courtesy of Ramiro Rivero.



as “barely fossilized tree resins between 100 and 1,000 years old,” according to GIA’s *Colored Stones* course.) The hard resin is collected in rain forests that lie principally along the east coast of the island; it is taken directly from certain trees or from the ground beneath them. Dr. Pezzotta reported that the resin forms on the trees annually, and he has seen masses weighing several kilograms on the market, with part of the wood still attached in some cases.

In 1997–98, large stocks of medium- to low-quality “copal” showed up in gem markets in Antananarivo and Antsirabe, and local dealers began working with the material—in a process that involved controlled heating of the surface during polishing—to produce attractive transparent forms that contained spectacular inclusions. Dr. Pezzotta has seen not only a wide variety of insect species in the hardened resin, but also small lizards (including chameleons), leaves of various trees, and even feathers (see the following entry for more detail on these inclusions). It is not known if all of these inclusions were trapped in the resin naturally.

The stability of the resin is unknown at this time. From 1996 to 1998, Dr. Pezzotta collected a significant number of polished samples with interesting inclusions for his museum, and some of these have started to develop a network of thin cracks on the surface. The stability may depend on the age, location, or species origin of the resin, or it may be influenced by the polishing procedure used.

More interesting inclusions in copal resin from Madagascar.

In the Spring 2000 Gem News section (pp. 67–68), one of these contributors (JIK) documented some unusual fluid inclusions in what was represented to him as copal from Madagascar. This attractive resin was widely available at the 2001 Tucson gem show, and Le Minéral Brut (Hauterive, France) had a good selection of well-polished specimens that contained a wide variety of arthropod

inclusions such as ants, spiders, beetles, termites, and two- and four-winged flies, as well as plant matter. Some of these polished pieces were more than 25 cm long and weighed several hundred carats. The clarity of the resin and the high quality of the polish provide an excellent showcase for viewing the various inclusions (figure 14).

One of these contributors (JIK) obtained a sample that contained a spider, a large beetle, and several small flies, as well as a number of bubbles trapped along a flow plane. Microscopic examination of the bubbles revealed a watery liquid of low viscosity, possibly encapsulated droplets of rain or dew; most of the bubbles also contained a small gas phase (figure 15). In a few of these fluid inclusions, the gas bubbles moved freely.

The variety and type of inclusions, together with the apparent quality of the resin, make this material interesting to anyone who appreciates nature. According to the literature provided by the dealer, the resin comes from *Hymenaea verrucosa* trees in forests on the northeastern part of the island.

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Iolite and corundum in Wyoming. In 1995, this contributor led the Wyoming State Geological Survey (WSGS) field reconnaissance for gems in the central Laramie Range of southeastern Wyoming, at which time he discovered samples of cordierite (iolite) and corundum—many of gem quality—in the Palmer Canyon area west of Wheatland. Recently, some Palmer Canyon iolites and pink to purplish pink sapphires were cut by claim owner Vic Norris of Lyons, Colorado, as part of ongoing investigations into the commercial viability of the deposit. These samples were provided to the WSGS and examined by Elizabeth Quinn at the GIA Gem Trade Lab in Carlsbad for this report.

The iolite is hosted by quartzofeldspathic gneiss that crops out over a distance of 60 m and averages about 3 m wide (W. D. Hausel, “Field reconnaissance of the Palmer Canyon corundum-kyanite-cordierite deposit, Laramie Mountains, Wyoming,” WSGS *Mineral Report* MR98-1, 1998, 7 pp.). This outcrop disappears under soil, and the presence of detrital iolite up-slope suggests that the deposit may exceed 500 feet (152 m) in length. The iolite typically forms rounded transparent to translucent grains or larger nodules. Samples of fractured iolite as large as 600 grams, with areas that could cut jewelry-quality stones, were collected from the gneiss during the initial field investigation. A similar piece found recently measures 10.8 × 6.4 × 3.2 cm, and is believed to be the largest iolite known from Wyoming.

The three samples (0.36–1.33 ct; see figure 16) examined at GIA had the following properties: color—grayish violet to violet, with moderate to strong pleochroism in violet and very light brownish yellow; R.I.—from 1.531–1.533 to 1.540–1.542; birefringence—0.009; S.G.—

Figure 14. A variety of arthropods, plant matter, and fluid inclusions can be found in “copal” resin from Madagascar. This polished specimen is 130.38 mm long and weighs 306.72 ct. Photo by Maha Tannous.



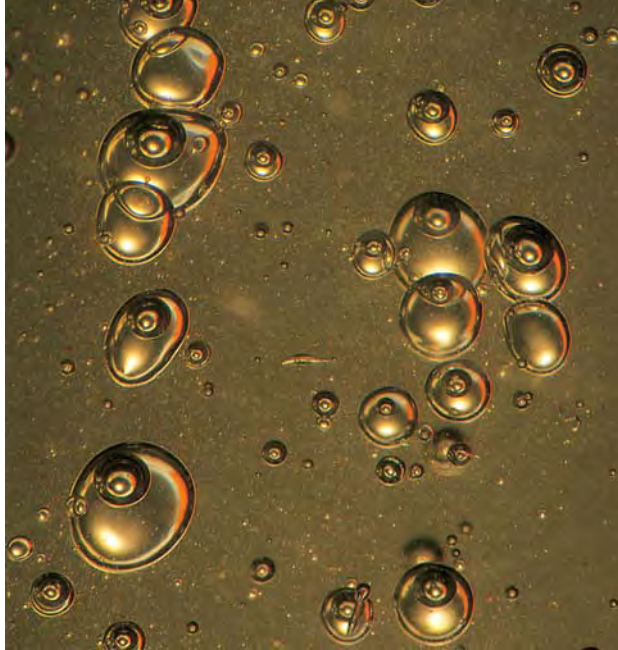


Figure 15. The bubbles in this resin, trapped along a flow plane, are partially filled with a watery fluid; several also contain free-floating gas bubbles in the fluid portion. Photomicrograph by John I. Koivula; magnified 10 \times .

2.59–2.60; inert to long- and short-wave UV radiation; and no features visible with the desk-model spectroscope. These properties are consistent with those reported for iolite in the literature (see, e.g., R. Webster, *Gems*, 5th ed., revised by P. G. Read, Butterworth-Heinemann, Oxford, 1994). Microscopic examination revealed dark hexagonal crystals (probably biotite), colorless and milky-looking crystals, fractures (some partially healed), patchy clouds, and broken lines of “silk.”

The corundum from Palmer Canyon is found near the iolite occurrence in chlorite-biotite schist and mica-kyanite gneiss that has been traced for nearly 300 m (see Hausel, 1998, cited above). The corundum forms hexagonal prisms and platelets that are locally abundant in the schist. The crystals are translucent to transparent, and vary from white to pink to (less commonly) purplish pink. Most crystals average about 1 cm long and 0.5 cm in diameter; the largest specimen collected thus far measures 2.5 \times 0.7 cm.

Ms. Quinn examined a 1.15 ct transparent faceted purplish pink sapphire and a 1.47 ct opaque brownish purplish pink sapphire cabochon from Palmer Canyon (again, see figure 16). The faceted sapphire showed the following properties: pleochroism—moderate, in purplish pink and orangy pink; R.I.—1.760–1.768; birefringence—0.008; S.G.—3.99; fluorescence—moderate orangy red to long-wave, and very weak red to short-wave, UV radiation; and chromium lines and a 470 nm doublet visible with the desk-model spectroscope. Microscopic examination revealed fractures (most partially healed), twin planes, white needles (probably boehmite), colorless crystals, and fine “silk” composed of minute short needles, stringers, and clouds. No evidence of heat treatment was observed. The following properties

were recorded for the cabochon: no pleochroism observed; R.I.—1.76 (spot method); S.G.—3.89; fluorescence—very weak red to long-wave and inert to short-wave UV; and chromium lines in the red region plus absorption due to iron around 450 nm in the blue region. Microscopic examination revealed numerous needles (probably rutile) and reddish orange crystals, abundant twin planes and fractures, and a yellowish substance in some fractures.

Several other minerals with potential as gems or ornamental materials have been identified in Wyoming, many within the last two to three decades. These include diamond, aquamarine, chrome diopside, jade, labradorite, peridot, opal, pyrope garnet, variscite, and many unusual agates and jaspers (see W. D. Hausel and W. M. Sutherland, *Gemstones and Other Unique Minerals and Rocks of Wyoming—A Field Guide for Collectors*, WSGS Bulletin 71, 2000, 268 pp.). Further field investigations will likely lead to additional gem discoveries in the Cowboy State.

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Green kyanite from Bahia, Brazil. Although kyanite is typically blue (see, e.g., Spring 1999 Gem News, pp. 51–52), recently a large discovery of green material was made in Bahia, Brazil. According to Steve Perry of Steve Perry Gems, Davis, California, the find occurred in March–April 2001. Last June, he saw 16 kg of rough in Governador Valadares. Lightly to moderately included faceted gems averaging about 6–10 ct (and up to 30 ct) were also seen by Mr. Perry in Brazil. Many of the stones contain a blue stripe that appears similar to material mined in Brazil’s Goiás State about 13 years ago. The blue area is variable in width and ranges from very pale to saturated.

Figure 16. The iolites (0.36–1.33 ct) and pink sapphires (1.15 and 1.47 ct) shown here are from the Palmer Canyon area in the central Laramie Range of southeastern Wyoming. Courtesy of Vic Norris; photo by Maha Tannous.



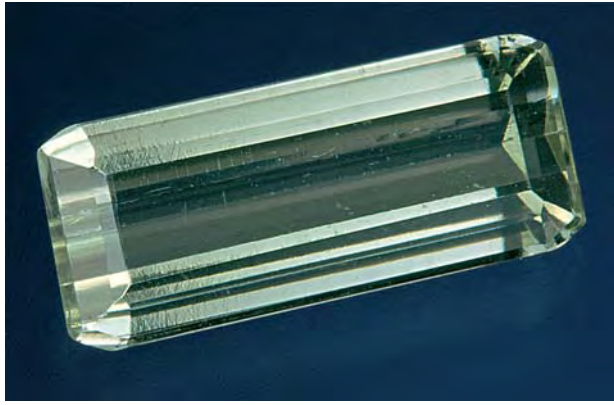


Figure 17. This 3.45 ct kyanite was reportedly mined in spring 2001 in Bahia, Brazil. Courtesy of Steve Perry; photo by Maha Tannous.

Mr. Perry sent a 3.45 ct light yellowish green kyanite (figure 17) to GIA for examination. Cheryl Wentzell of the GIA Gem Trade Lab in Carlsbad recorded the following properties: R.I.—1.711–1.739; birefringence—0.019; S.G.—3.69; fluorescence—inert to short- and long-wave UV radiation; and two absorption bands in the blue region at approximately 435 and 445 nm. Microscopic examination revealed minute crystals and pinpoints, and a cluster of tiny cleavage breaks. The properties are consistent with those reported for gem kyanite, except that this stone showed a larger range in R.I. values and a greater birefringence (compare to $n=1.716-1.731$ and $d=0.012-0.017$ reported in the *GIA Gem Reference Guide*). Raman analysis gave a perfect spectral match for kyanite.

“Ruby Rock” cabochons. In early 2001, this contributor first saw cabochon doublets that were created by attaching quartz domes to thin slices of Ruby Rock from New Zealand. Also referred to as goodletite, this ornamental stone comes from the Southern Alps (near the coastal town of Hokitika on the South Island), and is composed of ruby or pink-to-blue sapphire with green chromian mica or tourmaline (see, e.g., G. Brown and H. Bracewell, “Goodletite—A beautiful ornamental material from New Zealand,” *Journal of Gemmology*, Vol. 25, No. 3, 1996, pp. 211–217). Microprobe analysis of the tourmaline in one sample at the University of Manitoba in Winnipeg proved that it was chromian dravite, with 1.90 wt.% Cr_2O_3 (Dr. F. Hawthorne, pers. comm., 2001).

According to Gerry Commandeur of New Zealand Ruby Rock Ltd., Hokitika, all of the Ruby Rock found to date has been in glacial moraine; none of the material has been found *in situ*. In thin slices, the material becomes translucent and shows vivid red and green colors that mingle in a variety of patterns. Some of the doublets have been set in jewelry to make distinctive pendants and rings (see, e.g., figure 18).

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A new find of tourmaline in Warner Springs, California.

An unusual discovery of pink tourmaline was made recently at the Cryo-Genie mine, approximately 3 km northwest of Warner Springs in north-central San Diego County (see map accompanying the spessartine article in this issue, p. 280). Formerly known as the Lost Valley Truck Trail prospect, the pegmatite was first located in 1904, and has been worked in a series of trenches, small pits, and short tunnels. In 1974, the property was claimed as the Cryo-Genie mine by Bart Cannon of Seattle, Washington, who worked it occasionally until the mid-1980s. Since 1994, the claim has been held by Dana Gochenour of Tustin, California, and worked intermittently by the Gochenour family and their associates. The main production from the pegmatite has consisted of mineral specimens of beryl (morganite and aquamarine), tourmaline (green and, rarely, pink or blue), and typical associated pegmatite minerals. GNI

Figure 18. The vivid colors in “Ruby Rock” from New Zealand are due to ruby and green chromian mica or tourmaline. The Ruby Rock doublet in this pendant has a quartz dome. Courtesy of Gerry Commandeur.



editor Brendan Laurs visited the mine in October 2001 for this report.

In spring 2001, the Gochenours intensified their mining activities, bringing in additional partners and investors including Jim Clanin (El Cajon, California), John Klenke (Las Vegas, Nevada), Cal Kalamas (Eugene, Oregon), and others. The group excavated the entire outcrop with a backhoe and extended the main tunnel in the central-eastern part of the pegmatite by drilling and blasting. A series of cavities or gem “pockets” encountered along this tunnel contained nonfacetable blue-to-green and pink tourmaline.

In early October, however, Ken Gochenour recovered some large, well-formed crystals of pink tourmaline from a pocket measuring $1.2 \times 1.0 \times 0.4$ m (figure 19). The largest crystal weighed 2.2 kg (16.3 cm tall), and had both prism terminations intact (figure 20). Two other notable crystals approached 17 cm in length and up to 10 cm in diameter, with distinctly flared pinacoidal terminations. The crystals are predominantly of carving quality, but contain small transparent areas that are facetable. However, most will be sold to collectors as mineral specimens, since the crystals are unusual for their size and color, as well as their morphology. Large pink tourmalines (similar in color to those found in the famous Pala pegmatite district 45 km to the west) were previously unknown from the Warner Springs area, and the flared shape is not typical of tourmalines from any of the southern California pegmatites. Rather, the shape resembles that of some tourmalines from east-central Afghanistan.

Figure 19. In October 2001, large crystals of pink tourmaline were found at the Cryo-Genie mine, near Warner Springs in San Diego County, California. Jim Clanin, a partner in the mining project, displays one of the crystals in front of the large cavity from which it was mined. Photo by John Klenke.



Figure 20. This doubly terminated 16.3-cm-tall crystal is the largest of the tourmalines recovered recently at the Cryo-Genie mine. Photo © Jeff Scovil.

SYNTHETICS AND SIMULANTS

Synthetic topaz crystals. Topaz is one of the few popular gems that—until recently—had not been grown successfully in the laboratory. This is undoubtedly because topaz has few physical properties that make it industrially useful, and there is an adequate supply of gem-quality brown (“smoky”) or blue topaz for the jewelry market. In addition, topaz is difficult to grow by ordinary hydrothermal growth techniques. In early 2000, however, synthetic topaz was successfully manufactured at the Institute of Experimental Mineralogy in Chernogolovka, Russia, by one of these contributors (VSB). The experiments were undertaken to gain a better understanding of the crystal morphology, color formation, and crystal growth mechanism of natural pegmatitic topaz. The growth technique, experimental conditions, and gemological properties of the synthetic topaz crystals are reported here.

The hydrothermal growth method used a supercritical fluoride-bearing aqueous fluid under conditions of a direct thermal gradient (see V. S. Balitsky and L. V. Balitskaya, “Experimental study of coincident- and opposite-directed simultaneous transfer of silica and alumina in supercritical aqueous-fluoride fluids,” *High Pressure Research*, Vol. 20, 2001, pp. 325–331). The growth experiments were carried out at temperatures of 500°–800°C and pressures of

20–200 MPa, using an autoclave made from a heat-resistant Cr-Ni alloy with a volume of 100 cm³.

The autoclave was heated in a vertical electric furnace with two independent heaters. Water with added AlF₃ was used as a solvent. The resulting acidic fluoride-bearing aqueous fluid had a pH of 1–2, as measured after the experimental run. A mixture of equal quantities of crushed natural quartz and topaz was placed in the upper zone of the autoclave in a perforated basket. Topaz seed plates were suspended in the lower zone of the autoclave; they were separated from the perforated basket by a diaphragm. The seed plates were cut in a rectangular shape with a ZX-orientation (i.e., the plate was elongated in the prism [110] direction). The temperature difference between the upper and lower zones of the autoclave ranged from 20° to 100°C. The duration of the experimental runs was between 20 and 30 days.

Light gray to near-colorless single crystals of synthetic topaz were grown in dimensions ranging from 2.5 to 4.0 mm thick, 20.1 to 40.8 mm long, and 8.0 to 15.0 mm wide; they weighed up to 20 g. About half of each crystal consisted of the seed, with the other half formed by the synthetic topaz overgrowth. Growth rates varied depending on crystallographic orientation, characteristics of the seed plate, and the growth conditions used. The maximum growth rate of a few tenths of a millimeter per day occurred in the [101] direction, while the minimum rate of a few thousandths of a millimeter per day occurred in the [001] direction.

Various heating and irradiation experiments were performed to alter the color of the synthetic topaz crystals. As

Figure 21. These synthetic topaz crystals were grown at the Institute of Experimental Mineralogy, in Chernogolovka, Russia. The semi-transparent light gray crystal weighs 23.66 ct (36.40 × 12.90 × 3.92 mm), and the semi-translucent brown crystal weighs 27.48 ct (36.70 × 11.52 × 4.41 mm). The latter has been treated by gamma-ray irradiation. Photo by Maha Tannous.



Figure 22. Conspicuous growth hillocks were observed on the as-grown surfaces of the synthetic topaz crystals. Photomicrograph by Taijin Lu; magnified 50×.

is the case with natural topaz, the synthetic material can be changed from light gray or near-colorless to “smoky” brown by gamma-ray irradiation (figure 21), and to light blue using high-energy electron irradiation and heat treatment. The stability of the brown color in the synthetic topaz has not been investigated yet. In one of the synthetic topaz crystals, one of us (VSB) observed a narrow zone of red-violet color along the seed plate. This coloration could be related to the presence of a chromium impurity from the autoclave walls that was captured during growth.

The two synthetic topaz crystals in figure 21 (23.66 and 27.48 ct), were examined at GIA by one of these contributors (TL) and Dino DeGhionno of the GIA Gem Trade Lab in Carlsbad. Three colorless crystal sections of synthetic topaz cut perpendicular to the c-axis and mount-

Figure 23. Two-phase inclusions were observed in the synthetic topaz, along the boundary with the seed plate, as shown in this crystal section. The synthetic topaz overgrowth is on the bottom and right, and the seed plate is on the upper left. Photomicrograph by Taijin Lu; magnified 10×.



ed on a glass slide also were examined. The light gray crystal was as-grown, while the brown one had been treated by gamma-ray irradiation. The morphology of these synthetic crystals resembled that of natural topaz, although a more detailed crystallographic study is underway. The crystal faces were well developed and had abundant concentric growth hillocks (figure 22). These hillocks often contained tiny black spots (possible impurities) at their centers. There was a roughly proportional relationship between the sizes of the growth hillocks and the sizes and numbers of these black spots. In addition, the larger the growth hillocks were, the more irregular their shapes were. The largest growth hillock was 3 mm in diameter.

The refractive indices of the two crystals ranged from 1.610 to 1.620, which is slightly lower than the values seen for typical pegmatite-derived topaz. Specific gravity (measured hydrostatically) was about 3.57 for these samples (which still contained portions of the steel wires used to suspend the seed); this value is slightly higher than that of natural OH-poor topaz. In addition to the steel wires, two-phase inclusions and fractures were observed. The two-phase inclusions were usually distributed in the region close to the boundary with the seed plate, and were typically elongated along the growth direction (figure 23).

The FTIR and Raman spectra of the synthetic overgrowths were very similar to those of natural topaz. Sharp absorption peaks in the near infrared were found at 2317 cm^{-1} and in the range of $3478\text{--}3680\text{ cm}^{-1}$, together with a small peak at 4798 cm^{-1} and a broad peak around 3970 cm^{-1} . Qualitative chemical analysis by EDXRF spectrometry detected traces of iron, nickel, and germanium in the two synthetic topaz crystals.

Although the basic growth technology for synthetic topaz has been developed, more work is needed before production becomes commercially viable. Research is ongoing to refine the growth technique and find the appropriate conditions for producing pink and yellow-orange colors.

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EXHIBITS

A visit to the Pearls exhibit at AMNH. What has been described as the most comprehensive exhibition ever presented on pearls opened at the American Museum of Natural History in New York on October 13, 2001. The dazzling display (see, e.g., figure 24) includes all types of natural and cultured pearls, as well as calcareous concretions. Among the most interesting in the latter category are the multitude of conch and melo "pearls," including an enormous (27 mm) red conch "pearl" in a tarantula



Figure 24. The Queen Victoria Brooch is one of the historic pieces featured at the AMNH "Pearls" exhibit. This gold brooch (approximately $6.4 \times 4.4\text{ cm}$), an 1843 anniversary gift from Prince Albert to Queen Victoria, is set with four Scottish freshwater pearls and accented by amethyst, garnet, and chrysoberyl. On loan from the collection of Mr. and Mrs. G. C. Munn; photo by Denis Finnin, © American Museum of Natural History.

brooch. Other stand-outs include a collection of American freshwater pearls used by the Native American Hopewell culture, which date from 200 B.C. to 500 A.D. A later addition to the exhibition was perhaps the most famous single pearl, "La Peregrina." Currently owned by Elizabeth Taylor, its lineage has been traced back to Mary Tudor (1516–1558), daughter of England's King Henry VIII.

Lead Curator Dr. Neil Landman and his staff have done exceptionally well in covering the entire scope of pearls. In an informative display on pearl formation, the exhibit traces the growth and harvesting of many varieties of cultured and natural pearls. Their historic use in decorative and religious objects is well illustrated, and several magnificent pieces, both jewelry and art, are shown. An interactive display allows visitors to observe the surface features of four specimens, as seen with a scanning electron microscope.

A comprehensive 232 page book has been prepared by Mr. Landman and coauthors to accompany the exhibit, called *Pearls: A Natural History* (reviewed in this issue of

G&G). The exhibit runs through April 14, 2002, and will move to the Field Museum in Chicago from June 28 to January 5, 2002.

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Gems at the Bowers Museum. "Gems! The Art and Nature of Precious Stones" will be on display at the Bowers Museum of Cultural Art in Santa Ana, California, February 16–May 12, 2002. Curated by museum president Dr. Peter Keller together with Mike Scott, this exhibit will feature extraordinary gems such as a 480 ct golden sapphire, a 10 ct Burmese ruby, a 60 ct blue sapphire, a 250 ct tanzanite, and a 5,500 ct star rose quartz (figure 25). The show will answer basic gemological questions, present a variety of rare gems, and portray gemstones as art. Featured artists include Bernd Munsteiner and Gerd Dreher of Idar Oberstein, John Marshall of the U.S., and several Asian master carvers. Visit www.bowers.org or call 714-567-3600.

GIA Museum exhibits. The Museum Gallery at GIA in Carlsbad is featuring "The Glitter Merchants" photo essay of diamond cutters and dealers, and an educational display about GIA's role in the diamond industry titled "From Trading to Grading"; both exhibits will be on display through May 2002. In the rotunda at GIA in Carlsbad is "Jeweled Zoo," a fascinating array of more than 100 pieces of animal-motif jewelry, on display through March 2002. Contact Alexander Angelle at 800-421-7250, ext. 4112 (or 760-603-4112), or e-mail alex.angelle@gia.edu.

ANNOUNCEMENTS

GIA's new Graduate Retail Management program. GIA has launched a new business-oriented diploma program called Graduate Retail Management. Available at GIA's Carlsbad campus, it consists of three 60 hour courses in Retail Management, Marketing, and Entrepreneurship that integrate jewelry-industry specifics into fundamental business practices. The courses are taught over 10-week terms, and students may take them concurrently or individually. The interactive format will include guest speakers, panels, and video presentations, and students will develop practical, industry-related term projects. In 2002, the program will be offered in a Summer Quarter (May 30–August 9) and a Fall Quarter (October 10–December 20). Enrollment is limited and on a first-come, first-served basis. For details, contact Taryn Reynolds at 800-421-7250, ext. 7306 (or 760-603-4000, ext. 7326), or visit www.gia.edu/education.

Trip to Idar-Oberstein, Germany. On April 21–27, 2002, the Gemmological Association and Gem Testing Laboratory of Great Britain will lead their eighth trip to Idar-Oberstein. Highlights will include visits to mineral and gem museums, historic and modern gem-cutting facilities, and a mine with agate and amethyst. Visit www.gagtl.ac.uk/gidar.htm or



Figure 25. "Dynamic Symmetry," by John Marshall (1990), features a 5,500 ct star rose quartz; note the 1 ct diamond placed to the right of the base for scale. Photo © Erica & Harold Van Pelt.

contact Douglas Garrod at 44-0-20-7404-3334 (phone), 44-0-20-7404-8843 (fax), or e-mail gagtl@btinternet.com.

CONFERENCES

International Bead Expo 2002. This show will celebrate its 11th year in Santa Fe, New Mexico, March 6–10. Expanded bazaar locations, additional workshops, and a multitude of educational events will be offered for an estimated 6,000 artists, scholars, vendors, and buyers. The 65 workshops will cover a variety of media, techniques, and skill levels. "Glass Beadmaking Through the Ages" is the Expo theme, with morning lectures and afternoon discussions scheduled March 8–10. Visit www.beadexpo.com, e-mail info@beadexpo.com, or call 800-732-6881.

PDAC 2002. The annual convention of the Prospectors and Developers Association of Canada will take place March 10–13, in Toronto, Ontario, and will include presentations on diamonds from Canada and Brazil, as well as diamond pricing. Visit www.pdac.ca, or call 416-362-1969, fax 416-362-0101, or email info@pdac.ca.

19th Colloquium of African Geology. Held in El Jadida, Morocco, March 19–22, 2002, this colloquium will include a symposium titled *Ore Deposits and Gem Minerals*. Visit www.ucd.ac.ma/geologie/cag19.html.

Basel 2002. The World Watch, Clock, and Jewellery Show will be held April 4–11 in Basel, Switzerland. GIA will host GemFest Basel 2002 from 4:00 to 6:00 p.m. April 6, which is open to the public and will highlight critical issues in the gem and jewelry trade in a panel discussion and keynote speech on "Doing Business in a Changing Economy." A pre-

sensation of GIA's latest research activities will round out the program. During the show *Gems & Gemology* editor Alice Keller will be available at the GIA booth in Hall 2, Stand W23. Visit <http://www.baselshow.com> or call 800-357-5570.

Workshop on Diamond and Diamond-like Carbon. On April 8–10, 2002, this workshop will be held in Brighton, U.K., during the Institute of Physics' Annual Congress. Topics will include the nucleation, growth, and characterization of diamond, diamond-like carbon, and other "high performance" crystals. Visit <http://physics.iop.org/IOP/Confs/Congress/Diamond> or e-mail registrations@iop.org.

Global Exploration 2002. As a sequel to their 1993 conference, the Society of Economic Geologists will convene Global Exploration 2002—Integrated Methods for Discovery, on April 14–16, in Denver, Colorado. The technical program will include presentations on diamond exploration, and post-meeting activities will include a workshop "Diamonds—from Source to Sea" (April 17–18) and a field trip to the Kelsey Lake diamond mine in the State Line kimberlite district of Colorado (April 19). Visit www.seg2002.org, call 720-981-7882, fax 720-981-7874, or e-mail SEG2002@segweb.org.

AGS Conclave. On April 24–27, the 2002 AGS International Conclave will take place in Vancouver, British Columbia, Canada. Several high-profile speakers have been scheduled, including De Beers's Nicky Oppenheimer. Visit <http://www.ags.org>.

Gemmological Association of Australia conference. The Queensland Division of the GAA will present the 56th Annual Federal Conference May 16–19, 2002, in Brisbane, Queensland. Invited speakers will cover Australian gem and pearl sources; the geology of Australian opals; inclusions in agates; Aurias diamonds; sapphires from Subera, Queensland; rhodonite from Broken Hill, New South Wales; and quartz coloration. The program also will include a Raman spectrometer workshop and presentation of the *Australian Gemstones in Jewellery Design* awards at the Queensland Museum. Visit www.gem.org.au/news, or contact Hylda Bracewell at 07-3355-5080 (phone), 07-3355-6282 (fax), or hyldab@gil.com.au.

Santa Fe Symposium. The 16th annual Santa Fe Symposium will take place May 19–22, 2002, in Albuquerque, New Mexico. Presentations will cover cutting-edge jewelry manufacturing technology, business acumen, and gem treatments. Visit www.santafesymposium.org, call 505-839-2490, or fax 505-839-3248.

GAC–MAC Saskatoon 2002. The joint annual meeting of the Geological Association of Canada and the Mineralogical Association of Canada will take place May 27–29 in

Saskatoon, Saskatchewan, Canada. A session on diamondiferous kimberlites from central Saskatchewan and elsewhere in Canada will be followed by a one-day workshop with Canadian kimberlite drill core. Visit www.usask.ca/geology/sask2002, call 306-966-5708, fax 306-966-8593, or e-mail karen.mcmullan@usask.ca.

16th Australian Geological Convention. The Geological Society of Australia is presenting this conference in Adelaide, South Australia July 1–5, 2002. Gems will be discussed in a symposium titled "World-Class Australian Ore Deposits," and a pre-conference excursion—"Kimberlites and Diamonds in South Australia"—will take place June 26–30. Visit www.16thagc.gsa.org.au or call 618-8227-0252, fax 618-8227-0251, or e-mail 16thagc@sapro.com.au.

IAS2002 Congress. The 16th International Sedimentological Congress will take place July 8–12, in Johannesburg, South Africa. Diamonds will be included in a special session on placer sedimentology and a short course titled "Modern and Ancient Placers—Sedimentological Models for Exploration and Mining." A pre-meeting field trip (June 29 to July 7) will follow diamonds from Kimberley (South Africa) to the Namibian coast, with several stops along the Orange-Vaal drainage system. Visit <http://general.rau.ac.za/geology/IAS2002>, or contact Dr. Bruce Cairncross at 27-11-489-2313 (phone), 27-11-489-2309 (fax), or e-mail bc@na.rau.ac.za.

8th International Conference New Diamond Science and Technology 2002. On July 21–26, at the University of Melbourne in Victoria, Australia, this conference will cover all aspects of diamond science and technology including growth and processing, characterization, and methods of detecting HPHT diamonds in gemology. Visit www.conferences.unimelb.edu.au/icndst-8, call 61-3-8344-6389, fax 61-3-8344-6122, or e-mail icndst-8@unimelb.edu.au.

ERRATA

1. In box B on p. 176 of the Fall 2001 article "Modeling the Appearance of the Round Brilliant Cut Diamond: An Analysis of Fire, and More About Brilliance," the acronym AGA should have referred to Accredited Gem Appraisers, a subsidiary of D. Atlas & Co., Inc. We thank David Atlas for bringing this error to our attention.
2. In the Fall 2001 Gem News International entry "Vanadium-colored beryl from China" (pp. 226–228), the location of the deposit should have been reported as Yunnan Province. We thank Ron Tsai for this correction.
3. Harold Dupuy (Baton Rouge, Louisiana) and Johanne Jack (Algarve, Portugal) were inadvertently omitted from the list of 2001 Challenge Winners in the Fall 2001 issue (p. 220). We apologize for this error.

EDITORS

Susan B. Johnson
Jana E. Miyahira-Smith

Gemstones: Symbols of Beauty and Power

By Edward Gübelin and Franz-Xaver Erni, with photographic contributions by Erica and Harold Van Pelt, 240 pp., illus., publ. by Geoscience Press, Tucson, AZ, 2000. US\$49.95*

Whereas most coffee table books feature popular impressions of the subject, this attractive book combines factual information by probably the best-qualified living gemologist and an experienced scientific writer with photographic contributions by the famed team of Erica and Harold Van Pelt. To find a beautifully illustrated volume with such an erudite discussion of gemstones is remarkable.

This book, a German edition of which appeared in 1999, is intended for a broad audience. It aims to "guide the layperson . . . into one of nature's most fascinating puzzles without any need for a specialist's knowledge." The opening chapters, by Dr. Gübelin, cover such topics as gem characteristics, origin, extraction, and processing. The essence of the book, though, is a 100 page section on gemstones and portraits fashioned from ornamental gems. It is a welcome surprise that in addition to covering the important so-called precious stones, the authors have added many lesser-known species such as spodumene, charoite, rhodochrosite, rhodonite, and sugilite.

Famous jewels and the magical attributes popularly assigned to gems are described by Dr. Erni in another interesting section. Dr. Gübelin, the eminent figure in the study of gemstone inclusions for over 60 years, also contributes a chapter titled "The Fascination of Internal Life."

Altogether, *Gemstones* is a valuable and beautiful addition to the gemstone literature.

RICHARD T. LIDDICOAT
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The Jeweled Menagerie: The World of Animals in Gems

By Suzanne Tennenbaum and Janet Zapata, 216 pp., illus., publ. by Thames & Hudson, New York, 2001. US \$45.00*

The Jeweled Menagerie grew out of a passion for jewelry and a love of animals on the part of co-authors Suzanne Tennenbaum and Janet Zapata. The delightful result of combining these two widely divergent subjects is a book that layers text and photos like a luscious confection, delicious to the last bite.

Animals have long been subjects for jewelry, and their jeweled images have appeared in every culture from antiquity to the present day. In the introduction to *Jeweled Menagerie*, Ms. Zapata touches on the amuletic power of animal imagery in jewelry from Ancient Egypt to the Renaissance. The body of the book then focuses on the use of animals as subjects for jewelry during the 19th and 20th centuries in Europe and the U.S. Six chapters explain the prevalence of certain animal motifs during different eras, describe the popularity of various gem materials, and delineate the design styles that became fashionable during these time periods.

Chapter 1 looks at the 19th century, covering animal jewels in the Revivalist, Victorian, and Edwardian

styles. Subsequent chapters showcase Art Nouveau, Art Deco, the 1930s–40s, the 1950s–60s, and the 1970s to the present. This broad spectrum of history is deftly condensed into a few pages of insightful text at the beginning of each chapter, followed by a dazzling panoply of photos with captions that are packed with information, including the designer, gems used, and date of manufacture.

Richly diverse, the illustrations incorporate photos of actual pieces, design renderings, and jewelry advertisements in layouts that are innovative and amusing. While a few of the jewels are old friends—such as Lalique's dragon-fly corsage ornament, and Cartier's diamond and enameled snake necklace made for the Mexican actress Maria Felix—most of the pieces illustrated have not appeared previously in books on jewelry history.

Creative placement of the photos often brings these creatures alive: A tiger jewel crouching on the bottom of one page stalks a flying crane on another, while snakes and lizards slither and skitter across adjacent pages. Several jeweled animals are placed opposite their original design renderings or laid over their vintage advertisements. Large spreads show these precious creatures superimposed on photos of natural environments: five Sterlé birds perched in the spreading branches of a tree, two

**This book is available for purchase through the GIA Bookstore, 5345 Armada Drive, Carlsbad, CA 92008. Telephone: (800) 421-7250, ext. 4200; outside the U.S. (760) 603-4200. Fax: (760) 603-4266.*

Victorian spiders on a lichen-covered rock wall, or a pair of Cartier crocodiles in a lily pad-covered lake. Close-ups allow the reader to see details of how the pieces are fabricated and the gems are set.

The Jeweled Menagerie isn't comprehensive in terms of information about designers or jewelry history, but the authors never intended it to be. They have provided a good index to find references to the various animals, jewelers, and personalities covered, and there is an impressive bibliography for the reader who wants to go deeper. This book is, however, appealing, entertaining, informative, and a feast for the eyes.

ELISE B. MISIOROWSKI
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Diamond: A Journey to the Heart of an Obsession

By Matthew Hart, 276 pp., illus., publ. by Walker & Co., New York, 2001. US\$26.00

Matthew Hart, a Canadian journalist who contributes to the *Rapaport Diamond Report*, offers a lively read through various bits of diamond lore, intrigue, and history—recent and ancient. The work opens with the tale of a mysterious 81 ct pink diamond unearthed by two *garimpeiros* in the Brazilian state of Minas Gerais that introduces many of the players who appear later in the book. In the second chapter, the scene shifts to outer space, where cosmic rivers of diamonds may be swirling through the universe. Later in the book, Hart moves far beneath the earth's crust, where the diamonds mined today were formed by intense heat and pressure before they were blasted to the surface through volcanic pipes.

In subsequent chapters, his tale shifts to diamond exploration, as he retells the story of the South African rush, describes newer methods of prospecting for diamonds, and provides a detailed discussion of Canadian Charles Fipke's trek through the

barren north that resulted in the discovery of the Ekati mine. The middle of the book describes De Beers and the company's recent evolution from a near-monopoly producer of rough diamonds to a competitive player with the likes of BHP Minerals, Rio Tinto, and other mining concerns, as well as how De Beers has built diamond demand through advertising. It also includes an account of the moral battles over illicit and conflict diamonds. Hart then uses the history of the giant firm Rosy Blue to trace the rise of India, and profiles a master diamond cutter with William Goldberg in New York.

Unfortunately the book's chief asset, Hart's engaging and accessible writing style, is also its chief liability, for the author often oversimplifies things, wrapping his story around a nucleus of a few interesting personalities, to the point of being wrong. For example, in the section on diamond exploration, the author strongly implies that South African geologist John Gurney was the first to identify garnet as an indicator mineral for diamond, when, in fact, a mantra of South African prospectors of the 1870s was "where garnets lie, you'll find diamonds." (Gurney narrowed the indicator mineral to a particular type of pyrope garnet.) And, in the chapter on Rosy Blue, the author appears to suggest that this billion-dollar company has carried India's diamond trade to its current world-class status on its coattails. Rosy Blue may be the largest Indian diamond firm, but it is hardly the only major player.

In general, the book has a hurried air about it, as if it were the biography of some important celebrity that had to make the bookstores before the limelight dimmed. Yet there's nothing so urgent here to justify the lack of proper editing (like any good storyteller, Hart has to be reined in from time to time, but the editors at Walker & Co. have not done so) and the clumsy, obvious typos that distract throughout the book.

In the past 20 years, the diamond industry has been besieged by books and documentaries attempting to

debunk the value of these gems (notably Edward J. Epstein's *The Rise and Fall of Diamonds* in 1981) or associate them with wars and furtive conspiracies. There is a need for an honest, objective story about diamonds, but unfortunately Hart fails to deliver his promised journey.

RUSSELL SHOR
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Barren Lands: An Epic Search for Diamonds in the North American Arctic

By Kevin Krajick, 442 pp., illus., publ. by Times Books (Henry Holt and Co.), New York, 2001. US\$26.00

"Barren Lands" is the name given to the vast (roughly 500,000 sq. mi. [1.3 million km²]), bleak, and remote areas of northern Canada beyond the tree line. The region is characterized by bare rocks and lakes, as well as extreme cold in the winter. Yet it also hosts the major discoveries of diamond-bearing kimberlite that have propelled Canada into the spotlight as a significant source of diamonds. This four-part book documents in vivid detail the search by two indefatigable (and lucky!) maverick geologists, Charles E. Fipke and Stewart L. Blusson, that eventually resulted in the discovery of kimberlites despite almost impossible odds.

Part I is a brief history of the Barren Lands, beginning with Jacques Cartier's initial exploration in 1534 and continuing with the exploits of Martin Frobisher, Samuel Hearne, and Sir John Franklin over the next ~300 years. It also describes the inhospitable characteristics of the area, which made geologic exploration essentially impossible, except along the shorelines and main rivers, until after World War II, when float planes and helicopters became reliable. Part II is a history of diamond finds in North America, starting with the discovery of diamonds in the 1830s in the Appalachian Mountains

of the United States. The section continues with their discovery in the glacial tills of the Great Lakes states, which led Prof. W. H. Hobbs to suggest (in 1899) that primary diamond deposits would be found in Canada; the discovery of diamonds in Arkansas (1906); and the initial exploration by De Beers in the 1960s, primarily in Ontario. An added bonus is an interesting summary of the role played by Dr. George F. Kunz in the early history of diamonds in America. Although the discussion is peripheral to the main theme of the book, to my knowledge this is the only publication where these topics are assembled in one place.

Part III is the backbone of the book. Here we follow the exploits of Fipke and Blusson during the 1980s, in their decade-long quest for diamonds across roughly 1,000 km of desolate northern Canada, from the Mackenzie Mountains in the west to the Lac de Gras region in the middle of the Barren Lands. We experience the great physical, emotional, and financial stresses these two geologists faced, and follow the logic of their changing geologic concepts (e.g., the sampling of eskers for "G10" pyrope garnets and other indicator minerals), which were clearly ahead of their time. During this entire period they were competing with—and only one step ahead of—other well-financed diamond exploration programs, mainly that of De Beers. Krajick masterfully portrays the multitude of personalities (e.g., eccentric, ruthless, paranoid, deceptive) evident in several individuals who were prominent in the search. Part IV covers the period after the discovery of diamonds in the Lac de Gras area was announced in late 1991 until the opening of the Ekati mine in October 1998. Emphasis is on the greatest staking rush the world has ever seen for any (solid) mineral and the rapid discovery of hundreds of kimberlite pipes.

To reconstruct the history of diamond exploration in the Barren Lands since the early 1980s, Krajick interviewed at least a dozen major personalities; this alone was an achieve-

ment, as those involved in diamond exploration are notoriously secretive. Since many of these individuals are reaching retirement age or otherwise dispersing, it is unlikely that an account of such depth and quality will ever be possible again. Further, an extensive list of references—some with annotations that make for interesting reading in themselves—adds credibility and utility for the researcher. My only disappointment is that the book contains only two illustrations (both of which are maps). It lacks any illustrations or photographs of the landscape, important geologic features, exploration parties, mines, diamonds, and (especially) Fipke, Blusson, and other key individuals.

Nevertheless, this book is extremely well written, and it is clearly the most authoritative single source on the history of the discovery of diamonds in Canada for both the layperson and the professional.

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Pearls: A Natural History

*By Neil H. Landman, Paula M. Mikkelsen, Rudiger Bieler, and Bennet Bronson, 232 pp., illus., publ. by Harry N. Abrams, New York, in association with The American Museum of Natural History and The Field Museum, 2001. US\$49.50**

If you are a pearl aficionado, then this is a book for all seasons. For the novice especially, this is a splendid educational experience that weaves science, history, literature, and magnificent jewelry into the story of pearls, both natural and cultured.

As a pearl importer and wholesaler, I am ever searching for a book to recommend on this subject. *Pearls* not only has captivated my attention, but it also has expanded my information cache both visually and intellectually. I particularly appreciate how the science is consistent with GIA's *Pearls* course, and that *Ge&G* articles are

acknowledged in the "Notes," an informative collection of footnotes on many subjects.

This book supplies a vast compilation of pearl arcana. If you are interested in archeology, the chapter on "Non-European Traditions" will tantalize you with sites where pearl and mother-of-pearl usage was evidenced. As you read poetic allusions to pearls from classic literary sources from the first millennium B.C., you will learn that a very high value was placed on pearls even then. From the Neolithic period to the rise of the Persian Empire in the sixth century, the authors chronicle the recognition of pearls as status symbols.

Woodcuts, photos, charts, and paintings all lavishly illustrate and clearly document how pearls have been a part of human history. Portraits of pearl-laden queens and kings abound. Parures of seed pearl jewelry, coronals and headdresses, and a pearl diadem worn by Princess Diana are but a few items of provenance that will engage the antique collector's interest.

Sprinkled throughout the full text are satisfying tidbits of information that are self-contained on one or two pages. For example, "Pearls in Medicine and Cosmetics" will enlighten you to the marvels of the gem's many purported medicinal properties, both curative and beautifying.

Although there is no glossary, the index is so thorough that you can personalize and construct your own definitions. References abound if one wants to explore any topic further.

Last but not least, should you be even the least bit curious about what the visuals in the book look like in three dimensions, go see the *Pearls* exhibition at the American Museum of Natural History in New York City. The show is on exhibit there until April 14, after which it travels to the Field Museum in Chicago. At this exhibition you will experience firsthand the essence of what the book is all about.

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King's Ransom
Sausalito, California

Diamonds: Famous & Fatal

By Leo P. Kendall, 236 pp., illus., publ. by Barricade Books, Fort Lee, NJ, 2001. US\$30.00

The author clearly states in his preface that you will not find “information about the technical or geological aspects of the diamond” in this book. Rather, the book is a compilation of the known history, as well as the lore and legend, of many famous diamonds and the people associated with them. Of particular interest is the detailed chapter on Jean-Baptiste Tavernier’s fascinating life and travels. In other chapters, the author recounts the tales of the famous robbery of the French Crown Jewels in 1792 and of the amazing Peacock Throne of the Persians. In keeping with the title of the book, Kendall also relates legends of bad fortune connected with the Hope diamond, the Koh-i-Noor, and others. Are these diamonds cursed? Readers are left to decide for themselves.

Also discussed are historical references to diamonds, such as in the Bible and in Pliny’s writings. Kendall does a fine job of describing the evolution of diamond cutting and historical diamond sources. The book is quite enjoyable to those who admire diamond. There are a few typographical errors and some questionable statements. (For example, I have trouble agreeing with the assertion that, “it is one of the most common of all gemstones.”) Overall, though, this book is recommended reading for any diamond enthusiast.

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OTHER BOOKS RECEIVED

Proceedings of the International Workshop on Material Characterization by Solid State Spectroscopy: Gems and Minerals of Vietnam, edited by Wolfgang Hofmeister, Nguyen Quy Dao, and Vu Xuan Quang, 334 pp., illus., publ. by Vien Khoa hoc Vat lieu, Hanoi, US\$20.00 [e-mail:

quangvx@hn.vnn.vn]. This book represents the published proceedings of an international scientific conference held in Hanoi, Vietnam, April 4–10, 2001. The conference brought together researchers interested in applying various spectroscopic and other analytical techniques to characterize gem materials. The meeting was organized by the Institute of Materials Science, Laboratory of Applied Spectroscopy and Gemmology of the National Centre of Science and Technology in Hanoi, among others. This volume contains 34 short articles, many of which focus on gems of Vietnamese origin. Characterization techniques include optical spectroscopy, thermoluminescence, particle-induced X-ray emission (PIXE) spectroscopy, photoluminescence, X-ray powder diffraction analysis, cathodoluminescence, electron paramagnetic resonance (EPR) spectroscopy, and inductively coupled plasma-atomic emission spectroscopy (ICP-AES). Data—including gemological properties, chemical compositions, and visible and Raman spectra—are presented for Vietnamese ruby, sapphire, spinel, topaz, aquamarine, tourmaline, peridot, zircon, quartz, feldspar (orthoclase), and pyroxene (diopside). Articles on more general topics discuss geologic environments of gemstone formation or occurrence, heat treatment of corundum, cultured pearl identification, irradiated topaz, gem corundum from Madagascar, and gem deposits of Sri Lanka, as well as types of gem deposits in Vietnam. This volume provides an important compilation of data on Vietnamese gems and gem localities.

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Shinju no Kagaku [Science of the Pearl], by Koji Wada, 339 pp., illus., publ. by Shinju Shinbunsaya (Pearl News Press), Tokyo, 1999 [in Japanese], ¥8,500. Those who begin to learn about pearls—both natural and cultured—soon encounter many ques-

tions. How is pearl formed in an oyster? Why do pearls have so many different colors? How are surface imperfections produced? How does one learn about the quality and care of pearls? *Science of the Pearl* provides most of the answers. It consists of 11 chapters on such topics as the function of the piece of mantle tissue and the pearl sac in the culturing procedure, the calcification process of shell and pearl, pearl processing, imitation pearls, pearl identification, the pearl culturing industry, and pearls in jewelry. Dr. Koji Wada, a world-famous biomineral researcher, provides revealing insight on all of these topics and more.

SHIGERU AKAMATSU
*K. Mikimoto & Co. Ltd.
Tokyo*

Minding the Store, by Stanley Marcus, 383 pp., illus., publ. by University of North Texas Press, Denton, TX, paperback edition 2001, US\$19.95. Founded in Dallas, Texas, in 1907, Neiman Marcus became famous as a retail store specializing in upscale apparel, accessories, and jewelry. Leading the way for much of the 20th century was Stanley Marcus, who joined the family firm in 1926 and guided its growth until he retired in 1977. With his memoir *Minding the Store*—first published in 1974 and now available for the first time in paperback—Marcus shares decades of retail wisdom as he recounts the Neiman Marcus success story.

In Marcus’s companion book *Quest for the Best* (227 pp., illus., paperback, University of North Texas Press, 2001, US\$14.95), the legendary retailer outlines his standards of quality in luxury goods and services. He describes how consumers can develop a taste for and locate “the finer things,” including jewelry (pp. 120–123), fashion, food and wine, accommodations, fragrances, and more. Originally published in 1979, this revised edition offers an updated “Best Things List.”

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COLORED STONES AND ORGANIC MATERIALS

Fibrous nano-inclusions in massive rose quartz: The origin of rose coloration. J. S. Goreva, C. Ma, and G. R. Rossman, *American Mineralogist*, Vol. 86, No. 4, 2001, pp. 466–472.

In the past 75 years, numerous explanations have been offered for the origin of the pink color of massive rose quartz. It has been attributed, for example, to a chromophore (Mn^{3+} or Ti^{3+}), to light scattering by rutile needles, and to fibrous inclusions presumed to be aluminosilicates. In this study, the authors extracted pink nanofibers (0.1 to 0.5 mm in width) from massive rose quartz from 29 pegmatite and vein localities worldwide. On the basis of optical and absorption spectra of the fibers and the massive rose quartz, they concluded that the fibers are the cause of the pink coloration in this material.

Heating and other experiments show that the pink color of the fibers is due to an Fe-Ti intervalence charge transfer that produces an optical absorption band at 500 nm. Based on X-ray diffraction and pleochroism characteristics, the best match for these inclusions is dumortierite, $Al_7(BO_3)(SiO_4)_3O_3$. However, infrared and Raman spectra do not exactly match standard dumortierite patterns, which suggests that the fibrous phase may be a material closely related to dumortierite. Rare euhedral pink quartz does not contain the fibers; rather, its color is explained by hole centers induced by radiation. TL

From mastodon ivory to gemstone: The origin of turquoise color in odontolite. I. Reiche, C. Vignaud, B. Champagnon, G. Panczer, C. Brouder, G. Morin, V. A. Solé, L. Charlet, and M. Menu, *American Mineralogist*, Vol. 86, No. 11–12, 2001, pp. 1519–1524.

Odontolite (also known as “bone turquoise” or “fossil turquoise”) is derived from heating fossilized bones and/or teeth, and is

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

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

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known to have been used in medieval art objects. The "turquoise"-blue color of the material has been attributed to the mineral vivianite, $\text{Fe}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$, which is thought to have formed during the heating process. This study of Miocene age (13–16 million years) mastodon ivory from the classic locality in southern France shows that both the fossil material and odontolite consist of well-crystallized fluorapatite, $\text{Ca}_5(\text{PO}_4)_3\text{F}$, with trace amounts of Fe (230–890 ppm), Mn (220–650 ppm), Ba (160–620 ppm), Pb (40–140 ppm), and U (80–210 ppm). No vivianite was found, so the previously accepted origin of the "turquoise"-blue color in this ivory is incorrect.

To identify the coloring agent(s) in odontolite, various apatite compounds were synthesized. It was found that small amounts of manganese had a major effect on the color of the synthesized compounds after they were heated. Analysis by various types of spectroscopy revealed that the "turquoise"-blue color is due to Mn^{5+} , which results from the oxidation of Mn^{2+} during heating. The authors propose a two-stage process for the formation of odontolite: (1) fossilization of the bone material to apatite accompanied by the uptake of Mn^{2+} ions, and (2) a heating process in air above 600°C that oxidizes Mn^{2+} to Mn^{5+} . [Abstracter's note: The color of this heated Miocene mastodon ivory apparently has a different origin than the blue spots in more recent fossil ivory, which are thought to be vivianite (see the Lab Notes entry on pp. 322–323 of this issue, which provides an example of vivianite causing the blue color in mammoth ivory that is ~10,000 years old).]

AAL

The nature of "rights" in the Western Australian pearling industry. H. G. Brayford and G. Paust, *FAO [Food and Agriculture Organization of the United Nations] Fisheries Technical Paper*, No. 404/2, 2000, pp. 338–342.

Western Australia produces most of the world's fine South Sea cultured pearls. The pearl oysters are mainly harvested from the wild, although hatchery technology also has been developed for the propagation of pearl oysters. The industry operates under a complex set of management arrangements governed by the state's *Pearling Act of 1990*, under which three categories of "rights" have emerged.

1. *The right to harvest wild pearl oysters.* A quota system sets limits on the number of pearl oysters that can be taken from the wild for pearl culture in Western Australia. Annual catches are normally limited to 572,000 oysters and are administered as "quota units," each having a par value of 1,000 oysters. The number of quota units is indicated on each pearling license and each licensee is entitled to at least 15 such units, the minimum considered necessary to ensure economic viability.
2. *The right to seed hatchery-produced pearl oysters.* The development of hatchery technology has resulted in

"hatchery rights." These rights enable producers to use hatchery oysters for pearl production, but the number is controlled (currently a total of 350,000 annually in Western Australia). The hatchery rights help ensure that pearling licensees acquire experience in hatchery technology, while they discourage overproduction to maintain market value.

3. *The right to occupy an area of coastal waters to conduct pearl farming or hatchery activities.* Pearl-farm leases are issued to holders of pearling or hatchery licenses for periods of 21 years.

The 16 industry licensees in Western Australia currently have the rights described above, but to varying levels according to biological sustainability and economic considerations. MT

Oasis or mirage: The farming of black pearl in the northern Cook Islands. C. Macpherson, *Pacific Studies*, Vol. 23, No. 3–4, 2000, pp. 33–55.

Many Pacific Island governments have been looking for new forms of productive activity that address various environmental, economic, and social issues. Atolls, in particular, have special concerns because of their limited size, resources (e.g., energy and fresh water), and fragile ecosystems. This article considers the opportunities and risks of culturing black pearls in the northern Cook Islands as a development strategy for atoll states.

Black-pearl farming was attempted by nonlocals in the lagoon of the Manihiki atoll in the 1950s and 1970s, but both ventures failed, in part due to a lack of local support. Interest by the government and local people revived the industry in the 1980s. Despite differences in opinion on how to develop pearl farming, by 1987 eight family operations farmed a total of 10,000 seeded oysters. By 1996 there were 150 farming operations and 225,000 seeded oysters in the general area. The islanders are now earning higher incomes and enjoy greater autonomy from the Cook Islands government.

However, there are risks to be considered. These include environmental (e.g., overstocking of a lagoon may lead to death of the stock), economic (e.g., oversupply of black cultured pearls could cause farming to become uneconomic), and social (e.g., new inequalities in the distribution of wealth). MT

Too many Tahitians? J. Heebner, *Jewelers' Circular Keystone*, Vol. 172, No. 10, October 2001, pp. 98–100, 102–104, 106.

In an effort to maintain the high-quality reputation of Tahitian cultured pearls and to halt price declines, the French Polynesian government has imposed steps to control the production of Tahitian cultured pearls and raise quality standards for the material released into the market. These steps include broadening the category for "rejects," increasing the minimums for growth period and

nacre thickness, partially compensating farmers for losses incurred as a result of new regulations and standards, and increasing export taxes to help the government cover the costs of implementing its new plan. Further, since August 1, 2001, the government has refused to authorize any new pearl farms; there are now nearly 1,100 farms in French Polynesia. The new measures should reduce the supply of Tahitian cultured pearls by about 15% and result in overall increases in quality and price. These measures should also help pearl farmers maintain healthy oyster beds and ensure that they earn enough money to avoid defaulting on business loans. *D. Darmour*

DIAMONDS

Abundance and composition of mineral inclusions in large diamonds from Yakutia. N. V. Sobolev, E. S. Efimova, A. M. Logvinova, O. V. Sukhodol'skaya, and Yu. P. Solodova, *Doklady Earth Sciences*, Vol. 376, No. 1, 2001, pp. 34–38.

Mineral inclusions in diamonds can reveal information about the geochemistry of the upper mantle. On the basis of these inclusions, most diamonds can be grouped into either the peridotitic (or ultramafic) assemblage or the less common eclogitic assemblage. The authors identified the inclusions in 2,334 large (>10 ct) diamonds from the Mir, Udachnaya, and Aikhal pipes in Yakutia, Russia; most previously published inclusion studies have been from small diamonds. The chemical composition of garnet and chromite inclusions, exposed on the surface of some samples, was measured by electron microprobe.

The high-Cr but Ca-depleted pyrope in these large diamonds was typical of pyrope inclusions in smaller diamonds, as was the composition of most of the chromite inclusions analyzed. However, two diamonds had chromite inclusions with chemical compositions typical of a lherzolite assemblage. A third chromite inclusion had an unusually low Mg content. Diamonds from the different pipes showed some variations in the abundance of certain inclusions. For example, sulfide inclusions are significantly more abundant in diamonds from the Mir pipe than in those from Udachnaya and Aikhal. An eclogitic origin was found to be relatively common among these large diamonds. *TB*

A change in diamond properties induced by natural radioactive irradiation. V. I. Koptil and N. N. Zinchuk, *Journal of Superhard Materials*, Vol. 22, No. 2, 2000, pp. 56–67.

Diamonds from the Siberian Platform in Russia show systematic differences in the visible indications of natural irradiation according to locality. In most kimberlite bodies of the Platform, diamonds with bluish green color and green pigmentation spots are rare (i.e., "a few per thousand"), and none with brown pigmentation spots have been reported. A relatively high proportion (2%–10%) of diamonds from alluvial deposits in the northeast region of

the Platform have green spots. Diamonds with bluish green color (1.1%), green spots (12.3%), and brown spots (8.1%) are found in the Nizhnyaya Tunguska River basin in the Irkutsk region. Diamonds with brown spots also come from kimberlites of Precambrian age that were subsequently metamorphosed at 500°–550°C. An understanding of these irradiation features may help in prospecting for diamond deposits. *TB*

The colour of diamond and how it may be changed. A. T. Collins, *Journal of Gemmology*, Vol. 27, No. 6, 2001, pp. 341–359.

This article reviews the physical, chemical, and spectroscopic characteristics of atomic-scale defects that cause color in both natural and laboratory-treated diamonds, updating the author's 1982 report (*Journal of Gemmology*, Vol. 18, No. 1, pp. 35–75) on this topic. Most defects in diamond are related to structural factors (e.g., vacancies or slip) or the incorporation of impurities, particularly nitrogen (N). Diamonds with detectable N are type I; those with very little or no N are type II. N impurities can occur as single atoms, or in aggregates of 2, 3, or 4 atoms. Sometimes a carbon atom is dislocated from the crystal lattice, and the resulting vacancy also affects color. Radiation can create vacancies in both diamond types. N-bearing defects can combine with vacancies to form new defects in diamond.

Boron (B)-containing diamonds (type IIb) are gray-to-blue. Slip along {111} planes is associated with brown or pink colors, but the actual cause of these colors is not understood. N and B incorporated in diamond lead to local charge imbalance, and subsequently to vacancy-bearing defects. Some of diamond's defects are optical centers that impart color by absorbing selected visible, infrared, and/or near-infrared wavelengths; some of these centers also luminesce.

A combination of absorption spectroscopy and luminescence spectroscopy reveals the changes that occur to the various defects in diamond during high pressure/high-temperature (HPHT) treatment. These changes first occur at the slip-planes where vacancies are released. In type IIa (containing neither N or B) and IIb diamond, these vacancies are filled with interstitial carbon atoms, removing the presumed cause of brown color. In type Ia diamonds, A-aggregates break up into single nitrogen atoms, and both defects trap vacancies. The resulting centers (H3, N-V, and H2) can impart substantial amounts of yellow and green colors to a diamond. Some type Ia diamonds have few vacancies to start with, and the observed color change from pale to saturated yellow is caused by alterations in N-bearing defects.

Spectroscopic evidence of various kinds of treatment to create green and/or yellow colors in diamond is summarized. The author suggests ways of using these spectral features, in combination with gemological observations, to determine the treated or natural origin of these colors in a faceted diamond. The article concludes with a review

of the absorption and luminescence features found in type IIa diamond, and a discussion of the difficulty of identifying HPHT treatment in such diamonds, which contain so few defects that it is not easy to record any changes. *Ilene Reinitz*

Diamonds are a guerrilla's best friend: The impact of illicit wealth on insurgency strategy. A. Malaquias, *Third World Quarterly*, Vol. 22, No. 3, 2001, pp. 311–325.

This article presents a history of Angola's 25-year-long civil war, fought primarily between the governing MPLA (Movimento Popular para Libertação de Angola) and the rebel organization UNITA (União Nacional para Independência Total de Angola). For the first 15 years, the warring groups were sustained by competing global superpowers: The Soviet Union backed MPLA, and the U.S. supported UNITA. After the collapse of the Soviet Union, Angola's civil war became largely irrelevant to the strategic interests of major international players, so UNITA had to fund its war by mining and selling rough diamonds. Between 1992 and 1997, UNITA sold over \$3.7 billion worth for that effort. Although UNITA has since been forced to withdraw from many of the most productive diamond-producing areas, it still managed to sell \$300 million worth in 1999.

UNITA has done badly in both the political and military arenas—despite this lucrative source of income—because diamonds offered such a dependable income stream that the organization never had to depend on the local population for support. The government has vanquished UNITA from most of its occupied areas; yet the war continues sporadically, and the rebel organization still operates in several parts of the country, particularly the countryside. Since the war has been about control of the country's natural resources, the only lasting solution is for Angolans to find appropriate institutional arrangements that will wrest control of those resources from both the MPLA and UNITA, so the proceeds can be used to improve the lives of the country's citizens. *RS*

Observation of etch channels in several natural diamonds. T. Lu, J. E. Shigley, J. I. Koivula, and I. M. Reinitz, *Diamond and Related Materials*, Vol. 10, No. 1, 2001, pp. 68–75.

The authors studied seven gem-quality diamonds with dissolution etch channels (open tubes) that ranged from parallel lines to irregular ribbon shapes. The formation of the channels is thought to be related to linear lattice defects, because the openings of the etch channels display rhombic outlines and the direction of the channels is mainly linear. Rhombic outlines, solid inclusions found at the terminus of some channels, and the presence of many channels running perpendicular to octahedral faces all suggest that dislocation bundles are the most likely cause of etch channel formation. The shape of the etch feature depends on the interaction between the channel and adjacent defects dur-

ing the dissolution process. Tiny, easily etchable inclusions also contribute to the enlargement and morphology of the etch channels. Although etch channels are uncommon features, they occur in both type I and type II diamonds from various localities worldwide. *TB*

Post-eruptive processes in kimberlites—Implications for diamond exploration. K. Leahy, *Transactions of the Institution of Mining and Metallurgy, Applied Earth Science, Section B*, Vol. 110, 2001, pp. B1–B4.

The search for primary diamond deposits is mainly a search for kimberlites, which is difficult because of their scarcity even in highly prospective terrains. This article focuses on the eruptive and post-eruptive geologic factors that affect the formation of kimberlites, with particular emphasis on the sizes and shapes of their craters.

During the eruptive phase, three main types of diatremes or craters are recognized: "carrot-shaped," maar, and "champagne-glass." Each forms by a different process. The "carrot-shaped" diatreme is the most commonly described kimberlite (i.e., the South African pipe model) and is associated with degassing explosions at 2–4 km depth. Groundwater interaction is not essential, and craters may or may not be formed. The maar crater is shallow, contains a high proportion of country rock, and is surrounded by tuff rings. Groundwater plays an essential role in the explosive phase (i.e., diatreme formation) of this feature. The "champagne-glass" crater is very large and flat-bottomed (up to 2 km wide and typically <300 m thick) with little or no diatreme development; it has variable tuff ring buildup. This type of crater results from a relatively high-level phreatomagmatic explosion (caused by interaction of rising magma with groundwater) in poorly lithified country rocks saturated with groundwater, and subsequent lava fountaining within the crater.

Post-eruptive processes within crater-facies rocks include serpentinization of olivine by basinal fluids or meteoric water soon after eruption. Crater lakes may become filled with pyroclastic material. Post-eruptive processes beyond the crater are mainly erosional. To illustrate post-eruptive processes, the author presents a case study of the Fort à la Corne kimberlite field in the Canadian province of Saskatchewan, where the kimberlites and craters are the "champagne-glass" type. Last, the application and integration of these various processes into an exploration program is explained. *Adam Derrickson*

GEM LOCALITIES

Characteristics of opals from Simav, Turkey. F. Esenli, I. Kumbasar, R. H. Eren, and B. Uz, *Neues Jahrbuch für Mineralogie, Monatshefte*, No. 3, 2001, pp. 97–113.

Different colors of opal (white/colorless, yellow, orange, red, none of which shows play-of-color) have been mined intermittently from cavities and fissures in rhyolitic rocks near

Simav, about 240 km (150 miles) south of Istanbul, since ancient times. The authors determined their mineralogical properties and water contents by various techniques such as X-ray diffraction, scanning electron microscopy, and differential thermal and thermogravimetric analyses. On the basis of these studies, they identified four different types of opal from this locality: (1) massive opal-CT (C = cristobalite and T = tridymite) found as nodules, (2) opal-CT with prismatic tridymite in geodes, (3) fibrous opal-C as spherulites, and (4) opal containing microcrystalline quartz in the fractures and matrix of the rhyolites.

Massive opal-CT, the main subject of this study, has a high water content related to its fractured texture and disordered structure; the color variations are explained by these features, with increasing structural disorder from white to red. The red and orange opals, known as "Simav fire opal," have especially high contents of absorbed water (up to 15.5%), as well as high densities. These opals were precipitated from silica-saturated solutions at low temperature. RT

Colour-change garnets from Madagascar: Comparison of colorimetric with chemical data. M. S. Krzemnicki, H. A. Hänni, and E. Reusser, *Journal of Gemmology*, Vol. 27, No. 7, 2001, pp. 395–408.

Twenty-four color-change Madagascar garnets (all pyrope-spessartine) were studied to obtain data relating color-change behavior to chemical composition. The garnets were separated into five groups based on variations in the intensity of their color change, which is generally bluish green in daylight and purple in incandescent light. Colorimetric calculations were used to support the visual observations and are presented in CIELab color space.

The correlation of color and color-change behavior with chemical composition is complex. Although V (and Cr to a lesser extent) is responsible for the color-change effect in pyrope-spessartine garnets, the relationship is not simple and direct; samples with low V may exhibit a large color change, whereas those with high V may show only a slight change. The most satisfactory relationship was obtained by plotting the contents of MnO vs. V_2O_3 , where qualitative and gradational color-change behavior fields are evident. Garnets without V (and/or Cr) display no color change. In general, garnets with <0.5 wt.% V_2O_3 display a slight to moderate color change, whereas those with >0.5% V_2O_3 have the strongest color change. However, specimens with too much vanadium (i.e., >1.60 wt.% V_2O_3) show little or no color change. The potential for color change also is reduced with increasing Mn content (i.e., spessartine component), regardless of the amount of vanadium. WMM

The gemstone occurrences of Madagascar. U. Henn and C. Milisenda, *Australian Gemmologist*, Vol. 21, No. 2, 2001, pp. 76–82.

The authors report that more than 50 gem varieties are mined in Madagascar. Beryls (particularly emerald and

aquamarine), tourmaline, quartz (different varieties), garnets, and feldspars historically have been commercially important. In recent years, production of both pink and blue sapphires has increased dramatically. Following a brief review of the geology of Madagascar, information is provided on 49 gem localities, with their locations shown on an accompanying map. RAH

New gemstone occurrences in the south-west of Madagascar. C. Milisenda, U. Henn, and J. Henn, *Journal of Gemmology*, Vol. 27, No. 7, 2001, pp. 385–394.

In late 1998, many new alluvial gem deposits were discovered in southwestern Madagascar. Most significant are those that produce large quantities of blue and pink sapphire, as well as lesser amounts of fancy-color sapphire, spinel, chrysoberyl, garnet, tourmaline, and aquamarine.

The three main mining areas in southwestern Madagascar are (1) the area between Ranohira and Sakaraha (including Ilakaka), (2) the region south of Ankazoabo, and (3) the Murarano area. These secondary deposits are hosted by sediments of the Morandava basin of East Africa; before the breakup of Gondwana (~165 million years ago), Sri Lanka was related geologically as well. This explains the similarities of these gems with those found in Sri Lanka and the Uмба Valley and Tunduru/Songea areas of Tanzania. WMM

Rubies from the Vatomandry area, eastern Madagascar. D. Schwarz and K. Schmetzer, *Journal of Gemmology*, Vol. 27, No. 7, 2001, pp. 409–416.

Since early 2001, large amounts of rubies from the Vatomandry area of eastern Madagascar have appeared on the international gem markets. The deposits are mostly eluvial, but the nature of the actual ruby host rocks is unknown. Large variations exist in both quality and color of the rubies, with the best rivaling those from Myanmar (Burma). This article emphasizes the gemological and mineralogical criteria for separating Vatomandry rubies from those of Thailand and Myanmar.

Relatively high iron contents (0.1–0.7 wt.% Fe_2O_3) distinguish Vatomandry rubies from those of Myanmar, but overlap with those from Thailand. The three most characteristic inclusion features of Vatomandry rubies are (1) the lack of growth structures, (2) the presence of short oriented rutile needles, and (3) clusters of innumerable small colorless, transparent, or white birefringent zircon crystals. WMM

JEWELRY RETAILING

After Sept. 11, security should be top priority. V. Gomelsky, *National Jeweler*, Vol. 45, No. 23, December 1, 2001, p. 4.

Law enforcement agencies, including the FBI, have diverted many of their resources to fighting terrorism in the wake of the September 11 terrorist attacks on the U.S.

John J. Kennedy, president of the Jewelers Security Alliance, predicts that this will lead to an increase in crimes against the jewelry industry, as thieves attempt to take advantage of the situation. He reported that the Southeast, from Texas to the Carolinas, is now the "hot region" for jewelry crimes, taking over from Los Angeles. He called on all jewelry businesses and road salespersons to adopt stricter security practices. RS

The dark side. R. B. Drucker, *Jewelers' Circular Keystone*, Vol. 172, No. 9, September 2001, pp. 120, 122, 124, 126.

This article discusses three of the most common ways that unscrupulous dealers bilk unsuspecting jewelry consumers: gems as investments, gemstone scams, and non-disclosure of treatments.

Gems as investments: Many consumers ask jewelers and appraisers whether or not their diamond or gemstone is a good investment. While diamonds and gemstones may maintain much of their value over the years, they are not investments in the traditional sense—in which consumers buy in expectation of future profit. Accordingly, gems should not be sold as such. Tanzanite offers a clear illustration of the pitfalls of promoting gems as an investment: A consumer who purchased one in 1991 would have found its value halved within two years.

Gemstone scams: Modern gemstone scams have been around since the late 1970s, though their numbers have declined in recent years. Some scam artists set up companies in Canada and marketed gems to American consumers with promises of great returns every year. In reality, the prices of these gems were greatly inflated despite official-looking documents, appraisals, and reports from major laboratories including GIA (which only identifies the gem and states whether it is natural). It often took several years before buyers discovered that their purchases were worth only a fraction of the original price. The Canadian government arrested many of the scam artists, but little of the money was recovered.

In the early 1980s, rough "opals for real estate" deals, and variations thereof, in which the opals or other rough stones were offered as collateral for tangible assets, became a popular scam because rough gems are often difficult to evaluate and low-quality material is abundant.

Non-disclosure of treatments: Although the Federal Trade Commission has increased requirements for disclosure of gem treatments, many sellers still fail to disclose, some with the intent of deceiving buyers. The author cites the case of a New York jeweler who offered buyers from Chicago "the best diamond at the best price." When the buyers returned home, they discovered a certificate explaining that the diamond had been clarity enhanced "to bring out its beauty."

The article concludes that "working from the dark side will reap only temporary profits at the risk of losing much more." RS

Death and taxes. W. G. Shuster, *Jewelers' Circular Keystone*, Vol. 172, No. 7, July 2001, pp. 94, 95, 97, 98, 100.

The U.S. Congress has passed legislation eliminating the federal estate tax. The catch is that the law phases out the tax over 10 years rather than eliminating it immediately. The phase-out raises the tax-exempt amount of an individual's assets from \$675,000 in 2001 to \$1 million in 2002, \$1.5 million in 2004, \$2 million in 2006, and \$3.5 million in 2009, after which the tax will be eliminated totally. Further, the law immediately reduces the top tax rate for nonexempt assets from 55% to 50%, then to 45% in 2007. Estate tax receipts accounted for less than 1.5% of the federal budget last year.

Nearly 90% of retail jewelers in *JCK's* survey wanted the tax repealed immediately. Half of those surveyed said that federal estate taxes could jeopardize the successful transfer of a family business, because an heir must sell all or part of the business to pay them. Others claim that federal estate taxes are double taxation, since they have already paid business and income taxes on the assets. Many said that repeal would make independent jewelers more competitive and encourage succession. RS

How to get the most out of your chamber of commerce.

P. M. Perry, *National Jeweler*, Vol. 45, No. 5, March 1, 2001, pp. 48–49.

Membership in the local chamber of commerce means more than a wallet card and a wall plaque. Active participation, including reaching out and forging relationships with other chamber members during various chamber events (weekly breakfasts, monthly committee meetings, and the like) may be very beneficial to your business. Such an approach will enable you to network and gather new ideas and resources. Business roundtables are also helpful in providing guidance, since they often include lawyers, insurance representatives, accountants, retailers, and others with different skills and experiences. Appropriately mentioning the names of attendees at such events who are business contacts can create a powerful third-party endorsement.

Keeping the chamber updated with your business brochures can increase clientele, since chambers of commerce are often asked for recommendations. It is essential that your chamber be aware of new and important aspects of your business, especially what is unique. Readers are encouraged to join chambers of commerce in each community where business is conducted. MT

When everyone quits. B. Spector, *Jewelers' Circular Keystone*, Vol. 172, No. 6, June 2001, pp. 258, 260, 262, 264, 266.

This article recounts how an independent retail jeweler, R. F. Moeller of St. Paul, Minnesota, rebuilt its operations after the mass exodus of all four non-family sales staff in 1989. The reason for this exodus was a revision in the

store's sales associate compensation policy from straight salary (\$16,000 to \$25,000) with an annual bonus, to a greatly reduced salary (\$12,000) plus a commission (20% of the gross profit on each piece of jewelry they sold). Moeller anticipated the departures, but believed the new system would help increase sales and margins by giving associates a stake in the rewards of harder work.

Within a year, the store was again fully staffed and soon Moeller instituted a new requirement—that associates undergo company-paid sales training and product education (gemological and appraisal courses). Within five years, sales and margins had improved to the point that Moeller was able to buy another jewelry business in Edina, Minnesota. By 1998, the system was working so well that the store almost eliminated the small base salary and went to essentially all-commission. The base was cut to \$2,400 a year (the minimum required to ensure that the employer/employee relationship was preserved), plus 20% commission on the gross profit of sales, and 10% of the repair and service business. New hires received a guaranteed \$40,000 a year draw against commissions for the first year, but were not retained if they failed to achieve the necessary level of sales.

The results have been dramatic. Moeller's sales have increased tenfold: from about \$750,000 in 1989 to \$8.2 million in 2000, with a gross margin of about 51%. Four of the 14 sales associates have six-figure incomes. There are some downsides: Associates often have very slow periods with little or no income, and the burnout rate has been high. RS

SYNTHETICS AND SIMULANTS

Beware: Synthetic amethyst. P. Totty, *Modern Jeweler*, Vol. 100, No. 4, April 2001, pp. 12, 14.

During the period from January 1999 to July 2000, the American Gem Trade Association (AGTA) tested 2,791 amethysts and found that roughly one out of every six stones was synthetic. In the past, the industry has tended to ignore synthetics of relatively low-cost gem materials such as amethyst and citrine because testing methods have been both time-consuming and expensive. AGTA

vice president Eric Braunwart warns that failure to address this problem will be detrimental to consumer confidence. D. Darmour

Synthetic gem quality diamonds: Historical overview and newest developments. F. De Weerd, *Antwerp Facets*, No. 37, March 2001, pp. 6-14.

This article reviews three techniques for creating synthetic diamonds: high pressure/high temperature (HPHT) growth, chemical vapor deposition (CVD), and shock-wave synthesis. Only the first technique has yielded significant gem-quality synthetic diamonds: Graphite is dissolved in a metallic solvent-catalyst, and diamond crystallization proceeds under HPHT conditions. The main types of HPHT presses (i.e., BELT and BARS) are explained, as are the identifying characteristics of the synthetic diamonds produced (e.g., morphology, color zoning, fluorescence, inclusions, and infrared spectra).

CVD techniques employ a carbon-rich vapor to form thin layers of diamond on a substrate (which can be a diamond). Shock-wave synthesis uses explosives, rather than mechanical anvils, to produce the HPHT conditions needed for diamond formation. JS

TREATMENTS

Implantation of Fe ions in crystal structure of natural beryl. O. N. Lopatin, R. I. Khaibullin, F. G. Vagizov, V. V. Bazarov, A. I. Bakhtin, and I. B. Khaibullin, *Proceedings of the Russian Mineralogical Society*, Vol. 130, No. 4, 2001, pp. 122–127 [in Russian with English abstract].

After colorless natural beryls were treated with high-dose implantation of Fe ions (accelerated up to 40 keV) and then annealed in oxygen, the beryls became orange-yellow. A study by Mössbauer and optical absorption spectroscopy revealed optically active $\text{Fe}_{[6]}^{2+}$, $\text{Fe}_{[6]}^{3+}$, and $\text{Fe}_{[4]}^{2+}$ centers in the treated beryls, and it is suggested that the implanted ions are in octahedral and tetrahedral sites of the crystal structure. Further study of the ion implantation techniques followed by heat treatment may be useful for gem enhancement. RAH

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