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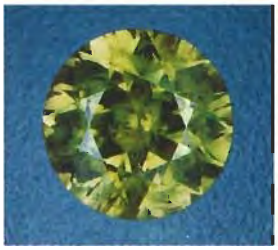
TABLE OF CONTENTS

FEATURE ARTICLES

NOTES AND NEW TECHNIQUES

REGULAR FEATURES


pg. 81


pg.107


pg. 115

pg. 129


ABOUT THE COVER: Perhaps no gem material in modern times carries the mystique of the demantoid garnet. Found in commercial quantities only in Russia's Ural Mountains, demantoids were esteemed by scientists and royals alike when first discovered in the mid-19th century. When Czarist Russia gave way to Communist Russia, however, demantoids—like other gems—fell out of favor. With virtually no mining for three-quarters of a century, few of these bright green garnets entered the marketplace except as part of historical pieces of jewelry like the fanciful Edwardian "dragonfly" shown here. Today, some efforts are being made to revive the historical localities and explore for new ones. The second article in this issue looks at the history of demantoid mining in Russia and reports on the current situation at the two main demantoid districts, north and south of Ekaterinburg. The dragonfly pin, platinum over gold with diamonds and rubies, contains 17 demantoids; the largest are 5.2 mm and 4.7 mm in diameter. The loose demantoid weighs 8.95 ct. The pin and the stone are courtesy of Michael M. Scott, Sunnyvale, California.

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Editor
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1660 Stewart St.
Santa Monica, CA 90404
(310) 829-2991 x251
e-mail: akeller@gia.org

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Jin Lim • Cristina Chavira
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MADAGASCAR: MAKING ITS MARK

Richard T. Liddicoat, Editor-in-Chief

The lead article in this issue of *Gems & Gemology* describes a new find of gem blue sapphires on the island of Madagascar. Over the years, we have come to think of Sri Lanka as the gem island, but Madagascar certainly vies with it in the variety of fine-quality gem materials that have been found there. It is interesting to compare the two islands historically as gem sources. Looking back to 1958, and the 13th edition of G. F. Herbert Smith's famous textbook *Gem Stones*, we see that the index to this volume refers to Sri Lanka 28 times and to Madagascar, 24 times. Both islands are underlain by ancient Precambrian rocks, with an abundance of later pegmatite dikes. Yet Madagascar is nine times the area of Sri Lanka, and it has not been prospected as extensively as the smaller island. The potential is enormous.

Over the years, the main gem materials to enter the international market from Madagascar were magnificent aquamarines and large morganites, plus topaz and tourmaline. (I must confess that Madagascar is my personal favorite source for the last of these gem materials, because it is the type locality for liddicoatite, the calcium end-member of the tourmaline group.) Within the last two decades, important quantities of fine emeralds have been found as well, primarily in the vicinity of Mananjary, on the island's east coast.

Both ruby and sapphire were among the stones Professor Smith listed for Madagascar in 1958, but the discoveries up to that date were not of any great significance. Today, however, major amounts of fine sapphires are coming from the Andranondambo region (including the newer Antsiermene area). From all reports in the literature and within the trade, this new find is important to the colored stone market, especially in light of decreasing production of blue sapphires at major localities such as Kanchanaburi (Thailand) and elsewhere. Even more recently, as we report in a Gem News item this issue, commercial quantities of gem rubies are also now coming from Madagascar.

Politically, Madagascar was a French territory from 1896 to 1958, when it became a republic of the French community, under the name Malagasy Republic. It gained independence in 1960. Since 1975, it has been the Democratic Republic of Madagascar. There was a time during the heady early days of independence from France when those operating mining ventures were summarily removed from their properties. In recent years, however, the island's government has been friendlier to mining activities and has even made some efforts to attract former operators back to the island.

As in many third-world countries, Madagascar's burgeoning population has resulted in the destruction of much of the forest cover. While ecologists worry, with good cause, about the future of the fauna and flora of this unique island, the encroachment into the wilderness area has led to the discovery of new gem deposits and has improved the economic outlook for Madagascar as an important source of gem minerals. As long as the political situation is encouraging to would-be prospectors and miners, Madagascar's growing role as a world power in the gem community seems assured. ❑

SAPPHIRES FROM THE ANDRANONDAMBO REGION, MADAGASCAR

By Dietmar Schwarz, Eckehard J. Petsch, and Jan Kanis

Since 1993, large amounts of gem-quality sapphires from the Andranondambo region of southern Madagascar have entered the international gem market. These sapphires, which are found in metamorphic skarn-type deposits, show a broad range of gemological and chemical properties, many of which are similar to those of sapphires from Sri Lanka, Myanmar (Burma), and even Kashmir. Most of the Andranondambo sapphires are heat treated in Bangkok; these can be separated from their non-heat-treated counterparts on the basis of inclusion features and absorption spectra. Key factors in the separation of Andranondambo sapphires from synthetic sapphires of different manufacturers are chemistry (especially the Ga content of the natural material) and internal features.

ABOUT THE AUTHORS

Dr. Schwarz is head of research at the Gübelin Gemmological Laboratory, Lucerne, Switzerland. Mr. Petsch is president of the firm Julius Petsch Jr., Idar-Oberstein, Germany. Dr. Kanis is a consulting geologist/gemologist specializing in gemstone occurrences; he resides in Veitsrodt near Idar-Oberstein.

Please see Acknowledgments at the end of the article.

Gems & Gemology, Vol. 32, No. 2, pp. 80–99

Madagascar has been a major gem-producing country for many years. In the past, the most important gems have been various pegmatite minerals such as beryls and tourmalines (see, for example, Chikayama, 1989) and emeralds from schist-type deposits (Schwarz, 1994). Most recently, however, fine sapphires have emerged onto the international gem market (figure 1).

Corundum occurrences in Madagascar have been reported occasionally in the literature (for geographic locations, see figure 2). Schmetzer (1986) mentions rubies from Vatomandry and Gogogogo in the southern region. Chikayama (1989) cites Gogogogo and Ejeda on the southwestern part of the island (rubies); Amboasary in the southeast, near Tolanaro (sapphires); and Antanifotsy in the central region, about 100 km south of Antananarivo (rubies and sapphires). Koivula et al. (1992) describe an unusual type of multi-colored sapphire from a locality called Iankaroka, southwest of Betroka, in Toliara Province. Non-gem-quality rubies examined in the Gübelin Laboratory in 1994 reportedly originated from Ihosy, about 120 km north of Betroka (L. Gentile, pers. comm., 1994). Whereas none of these localities has had much commercial importance, however, the Andranondambo (also called Andranondamtso) deposit in southern Madagascar has turned out to be a significant new source for fine blue sapphires. This has been of special interest for the gem trade, because Bangkok dealers report that some of the classic sources for high-quality blue sapphires in Kashmir, Myanmar (Burma), and Sri Lanka are declining in production.

The much-talked-about Andranondambo sapphire deposit is not a recent discovery, although fine-quality sapphires from here first appeared on the world market only a few years ago (Eliezri and Kremkow, 1994; Kammerling et al., 1995a). As early as 1952/53, French geologist Paul

Figure 1. In only the last few years, Madagascar has produced numerous fine sapphires. Although most of the crystals are small, some excellent large stones have also been recovered. The fine sapphires in this suite are all reportedly from the Madagascar deposits. The 16 graduated pear-shaped sapphires in the yellow-gold necklace weigh a total of 149.87 ct, the sapphires in the earrings weigh a total of 45.68 ct, and the ring is set with a 54 ct pear-shaped sapphire. Courtesy of Mouawad Jewelers.

Hibon reported the occurrence of small (up to 10 mm) eluvial sapphire crystals that came from an area 1 km northeast and 2 km south of Andranondambo village; the sapphires were found together with a previously unknown mineral that was subsequently named hibonite (Noizet and Delbos, 1955; Curien et al., 1956).

About four years ago, in 1992, local miners and Malagasy traders first offered on the Antananarivo market parcels of sapphires in various tones of blue, including a milky blue type (geuda), of which 90% were very small crystals. When one of the authors (EJP) visited Andranondambo in March 1995 with one of the claim owners, Chabany, he learned that rumors first circulated in Fort Dauphin, now called Tolanaro, that a new sapphire deposit had been found near the city of Bekily, in the central portion of southern Madagascar. It was subsequently shown, though, that the stones were from farther southeast, near Andranondambo. Thai merchants soon discovered that the pale milky blue sapphires reacted very well to heat treatment, changing to an attractive blue that in some cases was comparable to that of Kashmir sapphires. From then on, Thai, Indian, and other traders rushed to Madagascar to purchase rough material.

As news of the rich sapphire deposit spread quickly in Madagascar, thousands of gem miners traveled to the Andranondambo area, leaving behind their aquamarine and tourmaline mines in other regions of the island. As a result, production of these latter gem minerals dropped dramatically. Even in the Mananjary region, a decline in emerald production was noted. It is estimated that as many as 10,000 miners were aggressively working the new area at different times, leading to numerous fights and even some murders. According to various Bangkok dealers, since the end of 1994 approximately 100 kg of rough Andranondambo sapphires have been shipped to Bangkok monthly, with as much as 80% of the material ultimately usable for jewelry purposes (usually after heat treatment). Although most of the crystals are small, about 10%–15% are 2–7 ct and crystals as large as 50–60 grams—although not entirely gem quality—have appeared in the marketplace. The largest Madagascar sapphire

Figure 2. The Andranondambo sapphire deposit is located in southern Madagascar, east of the village of Andranondambo, approximately 150 km by gravel road from Amboasary.

reported to date is a 17.9 kg piece of rough that was recently described by Gary DuToit, of the Asian Institute of Gemological Sciences (AIGS) laboratory, as "definitely gem-grade sapphire, a fine gem blue color" ("The find of a lifetime," 1996).

During the March 1995 visit to the sapphire deposit, Mr. Petsch's reconnaissance flight in a small twin-engine plane over the Andranondambo mining area (figure 3) was followed by a Landcruiser safari to the sapphire deposit to collect first-hand information and samples. The present study is based on information gathered during this visit, and on the examination and analysis of samples obtained from the deposit at that time as well as from marketing channels in Bangkok and Switzerland.

LOCATION AND ACCESS

Situated in the Indian Ocean, Madagascar is the world's fourth largest island, 1,580 km long and 580 km at its widest point. The Andranondambo deposit is located at 24°26′ E and 46°37′ S. Travel from Tolanaro to Amboasary, about 70 km, is on a good paved road that follows the southern coastline (again, see figure 2). From Amboasary, however, the journey continues on a gravel road north through Behara and Tranomaro to the village of Andranondambo. The conditions of this latter road are so poor, however, that it takes five to six hours to cover the approximately 150 km from Amboasary to the mining area, through sparsely populated territory. This trip is possible only with a well-equipped four-wheel-drive vehicle. The road to Tranomaro crosses arid land covered by huge forests of cactus-like succulents that are so dense they are virtually impenetrable. There is very little rainfall in this

Figure 3. Seen from the air, looking north, the Andranondambo sapphire deposit looks like Swiss cheese, with hundreds of small shafts made by local miners over a distance of about 3 km. The buildings in the far north, near the river, belong to an overseas mining company. Photo by E. J. Petsch.

Figure 4. This geologic map of the Andranondambo region (adapted from Besairie, 1970) shows the location of the Fort Dauphin and Tranamaro groups of the Androyen system, in which the sapphires have been found. Also shown are the Cretaceous volcanics, younger granites, and Precambrian Anosyen granites.

region, and the climate is extremely hot. After Tranomaro, the succulent forests become less dense and the higher, semi-desert plateau presents a more pleasant, hilly landscape. There are no major rivers or lakes in this plateau region, which has an average altitude of 500 m above sea level, with several hills rising up to 1,200 m. The dry climate makes it possible to reach the mining area year round.

Andranondambo is a very small village, but the shanty town that has sprung up near the deposit is extensive; as noted earlier, at times it has housed as many as 10,000 people, under the most primitive hygiene conditions. By March 1995, only about 3,000 miners were still searching for sapphires in Andranondambo proper. One reason for this is that the local miners have only primitive equipment, which makes it impossible to sink extremely deep shafts. Therefore, only a limited number of miners can work effectively at any one shaft (see "Mining" below). Another, perhaps more important, reason is the discovery of sapphires nearby, about 10–12 km north of Andranondambo, at Antsiermene. According to Thomas Banker, of GemEssence Ltd. in Bangkok (pers. comm., June 1996), there is a new shanty town of 3,000–4,000 diggers in that area, which is also responsible for many of the fine southern Madagascar sapphires that are entering the market.

GEOLOGY AND OCCURRENCE

Serious geologic studies of Madagascar began only after its annexation by France in 1896. The first geologic map of the entire island was published in 1900, on the occasion of the International Geological Congress. The classic three-volume work on the mineralogy and petrology of Madagascar was published by Lacroix (1923).

The southern three-quarters of Madagascar is occupied by the Precambrian basement complex, of which the oldest system (> 3 billion years old) is the Androyen. The Androyen system is subdivided into three groups, two of which are found in the Andranondambo area (figure 4): the Fort Dauphin group, which is composed mainly of hornfels with cordierite; and the Tranomaro group, which consists mainly of a varied series of originally sedimentary rocks that were subsequently subjected to high-grade (granulite) metamorphism (Rakotondrazafy et al., 1996).

The sapphire deposits in the Andranondambo region occur in the high-grade granulite facies, metamorphic rocks of the Tranomaro group; in this area, the granulite facies consist of crystalline limestone (marble, figure 5) containing some diopside, anorthite-rich plagioclase, and wollastonite, as well as gneisses and pyroxenites. The granulite belt in the Andranondambo region is approximately 30 km wide and is sandwiched between two younger

Figure 5. Miners dig through the crystalline limestones along the eastern contact of the Andranondambo deposit. In the background is the Precambrian Anosyen granite massif. Photo by E. J. Petsch.

Figure 6. At the Andranondambo mining area, it is dangerous to walk between the deep shafts, which are sometimes not more than 50 cm apart. Note in the shafts the profile of the cataclastic structure of the calcareous sapphire-bearing rock. Photo by E. J. Petsch.

formations: the extensive Cretaceous volcanic massif (mountainous mass) that outcrops in the vicinity of Vohitsimbe in the west (again, see figure 4), and the Precambrian Anosyen granite massif in the east (figure 5). The area also has experienced episodes of intrusion by younger granites and the formation of skarns (Rakotondrazafy et al., 1996). Clearly, the rocks of the Androyen system have been repeatedly subjected to various types of geologic processes (e.g., metamorphism, igneous activity) throughout their long history. The profile exposed in the various shafts (see, e.g., figure 6) shows a cataclastic structure (i.e., a rock texture resulting from tectonic forces), which indicates that intense mechanical forces have crushed the rocks.

The sapphires actually occur in thin veins in the metamorphic rock. These have been described as fine strings, meandering through the rock, that seem to start and stop without any real geologic definition. An American mining engineer working in the area describes the occurrence as a "pea soup" mixture of minerals (T. Banker, pers. comm., 1996). H. Hänni suggested that the sapphires formed locally in nests and pockets in the reaction zones between pegmatite dikes and pyroxenite (as reported in Kammerling et al., 1995b).

Numerous explanations for the origin of sapphires and other varieties of gem corundum in calcareous metamorphic rocks are found in the literature. The explanation applicable to each deposit depends on the extent of metamorphism in the region, the nature and abundance of mineral impurities (e.g., clay minerals) in the original rock, whether or not additional elements have been added during the metamorphic event (e.g., metasomatism), as well as other factors, the discussion of which is beyond the scope of this article.

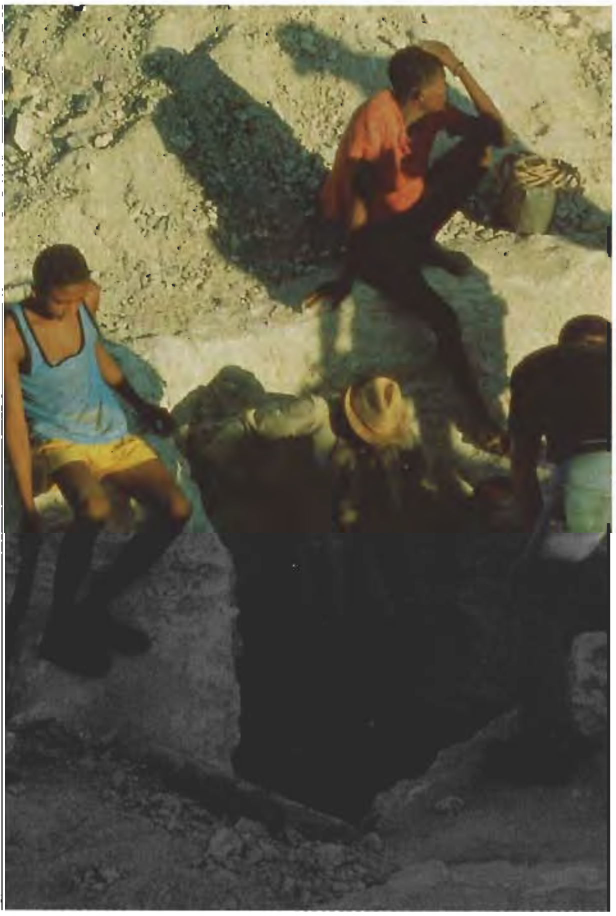
MINING

The irregularly shaped Andranondambo sapphire deposit covers an area that is at least 3 km long and varies in width between 500 and 1,000 m (again, see figure 3). From the air, one can easily observe the location and extent of the exposed mining area. The northern extremity, crossed by a small river and visible on figure 3, is the only section of the deposit where mechanical mining was being done, by an overseas company, in March of 1995. Today, there are a number of Thai groups, a Swiss group, a French group, and more than one Israeli concern working in the area, usually in partnership contracts with local residents. Mining concessions have been granted to some of these groups, with each concession 2.5 km × 2.5 km. However, local miners often do not observe the boundaries of the concessions. They regularly mine on the land illegally but with the approval of the local chiefs, who make their own often-powerful claims on the basis of ancestral rights (T. Banker, pers. comm., June 1996).

The local miners work independently in small groups by sinking narrow (2 to 2.5 m in diameter) shafts as much as 20 to 30 m deep (figures 6 and 7), which is as far as they can safely dig using manual mining methods. Fortunately, the area is very dry, so there is no rain or groundwater to cause the collapse of these shafts, which would further endanger the lives of the miners. The workers excavate the calcareous rock with 2-m-long crowbars and shovels to open their shafts. The material is hoisted in buckets to the surface with a rope, and after dry sorting the waste is carried to huge dumps. Every group of miners has its own small claim area where shafts are sometimes no more than half a meter apart, making it very dangerous to walk over some parts of the deposit (again, see figure 6).

At the time of Mr. Petsch's visit, the deposit was being worked very inefficiently, with some of the waste material being dumped on unexploited sections of the mining area (again, see figure 5). To date, however, no serious effort has been made to bring in heavy machinery to mine the deposit by open pit and set up a sophisticated processing plant. This is largely due to the nature of the veins, which, as noted above, are relatively thin, discontinuous, and do not appear to follow any set pattern (T. Banker, pers. comm., 1996). Consequently, the occurrence of sapphire crystals is erratic.

Figure 7. Small groups of miners work at each shaft, descending by ropes, tree trunks, or crude wooden ladders as deep as 20–30 m to reach the gem-bearing veins. Photo by E. J. Petsch.



PRODUCTION AND DISTRIBUTION

During his visit, Mr. Petsch saw no more than a few hundred grams of small gem-quality sapphires, most of which varied between 0.2 and 0.5 grams each. This left the impression that production at the time was very limited, considering the vast number of miners that had been working the area. Although larger crystals (2+ grams) have been reported, not a single crystal of more than 1 gram was seen during the visit (which consisted of two days at the mine and several days in the general area). There are always traders in the mining village, buying most of the miners' production at the end of each day. In fact, some Thai dealers were living permanently in the shanty town. Amornpongchai (1995, p. 6) reported that "around 100 Thai traders are in the country buying rough at the moment" (that is, at the beginning of 1995).

Most of the Andranondambo sapphire production is sent directly to Bangkok for heat treatment and cutting. K. Siu of Tai Hang Gems in Bangkok (pers. comm., 1996) estimates that about 90% of the gem-quality rough material is submitted to heat treatment before cutting. Part of the material is also cut in Israel. The finished goods are marketed mainly through channels in Thailand and Switzerland.

As noted earlier, dealers in Bangkok report that on average 100 kg of rough enters that city monthly from the Andranondambo region, 80 kg of which is gem quality. Most of the crystals are small, cutting stones less than 4 mm. Nevertheless, as much as 15% of the gem-quality crystals yield cut stones over 2 ct. Very large crystals—50–60 grams—have been recovered, but these usually must be cut before heat treatment to remove the potentially damaging negative crystals. However, a number of 15–20 ct cut stones have been reported in the trade and seen at the Gübelin Laboratory. The largest of the Madagascar sapphires shown in figure 1 is 54 ct, and (again as noted above) a 17.9 kg rough blue sapphire from Madagascar recently appeared in Bangkok.

MATERIALS AND METHODS

The test sample consisted of more than 800 non-heat-treated crystals of varying (including gem) quality that ranged from about 0.2 to 4 ct (see, e.g., figure 8). All were purchased by Mr. Petsch during his March 1995 visit to the mining site. From this collection, we selected a number of pieces for gemological research. One or two windows were polished on 200 non-heat-treated crystals to facilitate testing. Sixty additional crystals were subjected to heat treatment, half of these by T. Häger at the University of Mainz, Germany, and the other half by K. Siu of Tai Hang Gems Ltd., Bangkok. Windows were also polished on these heat-treated samples for examination. In addition, several parcels of faceted Andranondambo sapphires (about 60 total, ranging from 1 to 6 ct) were obtained through marketing channels in Bangkok and Switzerland for examination and chemical analysis. These stones had been heat treated in Bangkok (the treatment conditions are not known).

Figure 8. As these crystals from the test sample show, Andranondambo sapphires have a broad range of variability in their morphology. The most common type is the dipyramid, shown here at the top right and center right. Note also the dissolution features on the surface of the crystal on the bottom right in particular. The crystals range from 0.46 ct (bottom left) to 0.98 ct (center left). Photo © GIA and Tino Hammid.

Refractive indices, birefringence, optic character, and pleochroism were recorded for each of 50 non-heat-treated and 50 heat-treated samples. Specific gravity was determined hydrostatically on 60 faceted stones and 40 crystals. The fluorescence behavior was checked for the entire test sample, more than 800 crystals and faceted stones. Color and fluorescence of 60 of these samples were checked before and after heat treatment.

One hundred non-heat-treated sapphires, out of the 200 polished (windowed) samples, and 100 heat-treated sapphires (40 windowed and 60 faceted stones) were subjected to spectroscopic examination. Polarized ultraviolet-visible-near infrared spectra (280 to 880 nm) were run on a Perkin Elmer Lambda 9 spectrophotometer. We recorded a total of 100 spectra (both *o* [ordinary ray] and *e* [extraordinary ray]; 50 from samples that had not been heat treated, and 50 from heat-treated stones). Twenty samples were measured before and after heat treatment. Infrared analyses were performed on about 20 of the stones with a Pye-Unicam FTIR 9624 spectrometer. A total of about 80 polished samples and faceted stones were analyzed by means of energy-dispersive X-ray fluorescence (EDXRF) spectroscopy. These analyses were performed on a Tracor Northern Spectrace 5000 system, using a program specially developed by Prof. W. B. Stern, of the Institute of Mineralogy and Petrography, University of Basel.

The internal features (growth characteristics) were studied in all 320 windowed or faceted samples. To identify the mineral inclusions, we had selected samples polished down until the inclusions to be analyzed were exposed at the surface. Analyses of about 40 mineral inclusions were carried out with a scanning electron microscope equipped with an energy-dispersive spectrometer (SEM-EDS) at the SUVA laboratory, Lucerne. The mineral inclusions of about 20 polished samples were examined by Raman spectroscopy at the AIGS laboratory, in Bangkok.

As mentioned above, some stones in our test sample were heat treated in Bangkok and some were treated at the University of Mainz. Mr. Siu explained that the details of his heat-treatment process for the Andranondambo sapphires depend on the color of the original material. Pale blue sapphires are heated in a charcoal oven in a reducing atmosphere. For darker crystals, the material is first heated in an oxidizing environment. The sapphires are then heated in a gas oven at high temperatures (1200°–1700°C), for varying lengths of time, depending on the nature of the starting material. The oxidation/reduction can be controlled by changing the O_2/H_2 gas ratio. Mr. Häger used a slightly oxidizing atmosphere and temperatures of about 1850°C for approximately five hours. He heat-treats the stones in alumina crucibles without adding Al_2O_3 powder.

CHARACTERIZATION OF THE ANDRANONDAMBO SAPPHIRES

Visual Appearance. A large number of the Andranondambo sapphires showed more or less well-developed crystal habits (again, see figure 8). These can be classified into four main types: (a) dipyramidal (with or without a basal face), (b) prismatic (always with a basal face), (c) transition or combination type—prismatic + dipyramidal, and (d) distorted plate-like or distorted dipyramidal crystals. By far, the most common type is the dipyramid. Most of the Andranondambo sapphires showed at least a few crystal faces; rarely were they entirely irregular or fragments. Some of the crystals displayed interesting dissolution features on their surfaces (again, see figure 8). Before any treatment, the samples were typically weak to saturated light blue to dark blue; almost all of the crystals showed distinct color zoning.

Once faceted, the heat-treated samples are typically blue with tones that range from medium dark to very dark (figure 9); rarely, they appear almost black in daylight. Eye-visible color zoning is often present, but eye-visible internal features such as minerals or fissures are relatively rare. Cut stones of less than 1 ct can be quite clean, even when examined with a gem microscope at moderate (20×–30×) magnification.

Gemological Properties. The standard gemological properties for the Andranondambo sapphires (see table 1) were found to be consistent with corundum in general.

Figure 9. Heat-treated sapphires from southern Madagascar (like these 0.28–0.57 ct stones) typically range from medium dark to dark blue. Courtesy of heat treaters Kenneth Kin Ming Siu and Joao Jose Ip Iau Tchun; Photo © GIA and Tino Hammid.

Pleochroism. All heat-treated samples exhibited distinct to strong dichroism. In paler non-heat-treated crystals, the pleochroism was sometimes less distinct. Normally, the colors seen in the dichroscope are blue (parallel to the c-axis) and greenish blue (perpendicular to the c-axis).

Fluorescence. Most of the Andranondambo sapphires (heat treated and non-heat-treated) were inert to both long- and short-wave UV radiation. Rarely, we observed a bluish white fluorescence in non-heat-treated crystals exposed to long-wave UV. Some heat-treated stones showed a chalky blue or

Table 1. Gemological characteristics of sapphires from Andranondambo, Madagascar.

Property	No. samples (natural/ heat treated)[a]	Natural (non-heat-treated)	Heat treated
Color[a]	800/120	Weak to saturated colors ranging from light to dark blue. Almost all crystals show distinct color zoning.	Medium to highly saturated blue with medium to very dark tones. The color zoning, in general, is less distinct.
Clarity	800/60	Very clean to heavily included. Most faceted material slightly included to clean.	Same as non-heat-treated.
Refractive indices	50/50	n_e = 1.760–1.762 n_o = 1.768–1.770	Same as non-heat-treated.
Birefringence	50/50	0.008–0.009	Same as non-heat-treated.
Optic character	50/50	Uniaxial negative	Same as non-heat-treated.
Specific gravity[b]	60 faceted 40 crystals[b]	3.99–4.01 3.89–3.99	Same as non-heat-treated.
Pleochroism	50/50	Light greenish blue (perpendicular to c-axis). Saturated blue; rarely, violetish blue (parallel to c-axis). Sometimes less intense in paler crystals.	Light greenish blue (perpendicular to c-axis). Satured blue; rarely, violetish blue (parallel to c-axis). Distinct to strong.
Fluorescence[a] (reaction to UV radiation)	800/120	Usually inert to long- and short-wave; sometimes faint bluish white to long-wave; very rarely, a faint red fluorescence to long-wave UV is seen.	By far, most samples are inert to long- and short-wave UV; rarely, chalky blue or green to long- and short-wave; a weak red fluorescence to long-wave UV is extremely rare.
Optical absorption spectrum (UV/Vis)	50/50	• Most pronounced absorption minimum, in general, around 490 nm (*e*-spectrum). • Absorption edge, in most cases, at relatively high values (compared to sapphires from Myanmar and Sri Lanka): o ~ 320–335 nm, *e* ~ 320–340 nm. • Very rarely, absorption shoulder around 320 nm.	• Almost always, the absorption minimum shifts to 360 or 420 nm (*o*- and *e*-spectrum). • Absorption shoulder (around 320–330 nm) becomes more pronounced and more frequent than in non-heat-treated sapphire.
Chemistry (trace and minor elements)	60/20	Fe_2O_3 = 0.12–0.61 TiO_2 = 0.01–0.10 Ga_2O_3 = 0.01–0.04 Cr_2O_3 < 0.01 V_2O_5 < 0.01 MnO < 0.01	Same as non-heat-treated.
Internal features[c] (growth characteristics)	200/120	• Strong color zoning, mainly parallel to the basal face *c;* sometimes very dark blue or brownish bands. • Prominent growth structures (parallel to the basal pinacoid *c*, to various dipyramids [normally *n,z*], to the 2nd order prism *a*, and to the rhombohedron *r*). • Healing fissures with varying textures; often "frosty" appearance. • Negative crystals showing a large variation in sizes and shapes. • Stringers of pinpoints. • Fine hollow tubes. • Mineral inclusions: calcite, apatite, feldspar (plagioclase, K-feldspar), phlogopite, Mg-hornblende, pyroxene ("hedenbergite"), rutile (grains and needles), Fe-mineral (exact nature not yet determined, probably hematite), Ca- and K-silicates (exact nature not yet determined). • Tentatively identified (based on visual appearance): "sulfide," "spinel," thorianite/uraninite.	Changes after heat treatment: • Mineral inclusions become "turbid"-translucent or even opaque; superficially, they appear glass- or mirror-like, some porcelain-like. • Stress fissures are formed around crystal inclusions and negative crystals; these show a mirror effect (mostly, they have a frosted appearance). In other healing fissures, the original fluid inclusions become rounded and look like highly reflective spheres. Rarely, textures are similar to those observed in some synthetic flux corundums. • Most striking are fine-, medium- or, sometimes, coarse-grained bands that are grayish white; these bands may have a bluish gleam. • Color zoning (mostly weak to moderate with light to medium blue tones), parallel to the basal pinacoid *c*, to different dipyramids, to the 2nd order prism *a*, and to the rhombohedron *r*.

[a] *For "color" and "fluorescence," 60 of the 800 non-heat-treated samples were also tested after heat treatment.*

[b] *Some of the crystals contained many mineral inclusions.*

[c] *Most of the minerals were identified by SEM-EDS; calcite, apatite, phlogopite, and rutile were also found by RAMAN spectroscopy.*

green fluorescence in short- or long-wave UV; this was probably induced by heat treatment, as we did not observe it in any of the 800 non-heat-treated stones we examined (see also Themelis, 1992). Very rarely, we observed a faint red fluorescence to long-wave UV in both heat-treated and non-heat-treated samples.

Internal Features/Growth Characteristics. *Growth Structures.* The dominant crystal forms are the

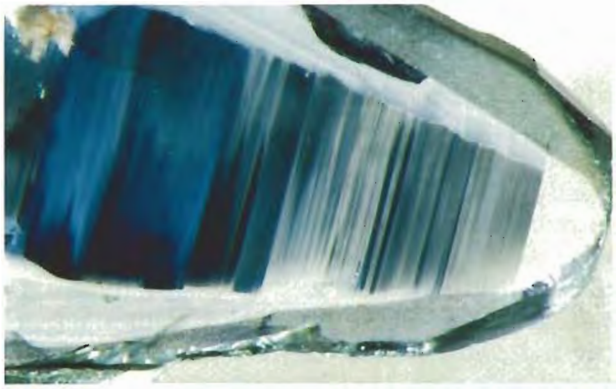


Figure 10. These growth structures and color zoning were common in the Andranondambo sapphires examined (view perpendicular to the c-axis): narrow growth planes parallel to the basal face c *and repetitive sequences of the dipyramids* n *and* z*. Color bands that show different shades of blue are confined to these well-defined domains. Magnified 40×.*

Figure 11. Also seen were growth structures and color zoning that consisted of sequences parallel to the dipyramid n *and the rhombohedron* r*. Immersion; magnified 60×.*

dipyramids *n* $\{22\bar{4}3\}$ and *z* $\{22\bar{4}1\}$ and the basal pinacoid *c* $\{0001\}$; the second order prism *a* $\{11\bar{2}0\}$ and the rhombohedron *r* $\{10\bar{1}1\}$ may also be of importance. Under the gem microscope, with an immersion liquid, most of the Andranondambo sapphires showed prominent growth characteristics that reflected most of the morphological properties that have been observed macroscopically. These consisted mainly of straight and angular sequences of growth planes/bands ("zones") parallel to the basal pinacoid *c*, the dipyramids *n* and *z* (often in repetitive sequences), the prism *a*, and the rhombohedron *r* (see figures 10 and 11).

Color Zoning. In most of the non-heat-treated crystals, color zoning was very pronounced, with dark, intense areas. After heat treatment, color zoning usually was less distinct, and for the most part the color bands were light to medium blue. The color bands were, in general, very narrow (figure 12) and tended to be concentrated in certain areas of the crystal. Even without magnification, the color zoning in the non-heat-treated crystals was often seen as strong, well-defined domains of a dark blue (almost black) or dark brownish blue that were typically delineated by faces parallel to the basal pinacoid *c*, the dipyramids *n* and *z* (normally, in repetitive sequences; again, see figure 10) and, rarely, the prism *a*. We commonly saw darker central zones (tube-, cone-, columnar-, or pipe-like in appearance; see, e.g., figure 13) with more-or-less well-defined outlines, similar to those observed in Mong Hsu rubies (Smith and Surdez, 1994; Peretti et al., 1995). In some cases, the central zones were also accompanied and delineated by growth structures parallel to the basal *c* plane and to the dipyramidal faces.

A few crystals showed a dark blue border zone (rim) along the dipyramidal faces. These zones varied in thickness on the different faces but, in general, were less than 1 mm. The opposite case—that is, a large, intensely colored blue central zone (core) and a narrow near-colorless outer zone—also was observed. Here, the color zoning was parallel to the faces of the second-order prism *a* (figure 14). When looking parallel to the c-axis of the Andranondambo sapphires, we often saw different types of color zoning. Most frequent were very compact central zones of intense blue color and hexagonal

Figure 12. The color bands in Andranondambo sapphires, here shown parallel to the basal pinacoid, were typically very narrow. Magnified 80×.

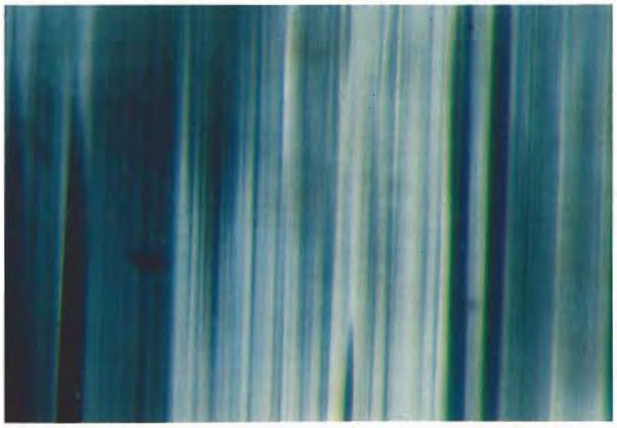


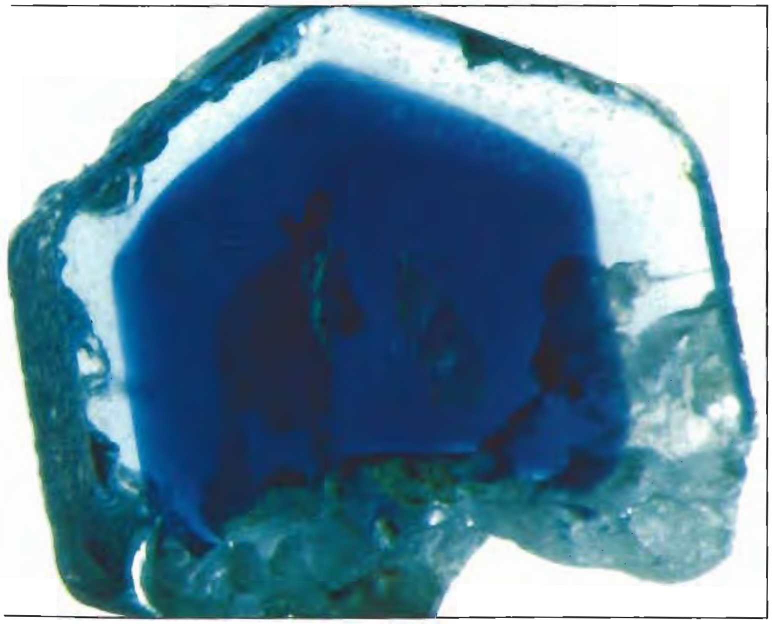
Figure 13. Commonly seen in the Andranondambo sapphire crystals was a central zone with a cone- (as here) or pipe-like appearance. Such central zones are delineated by planes parallel to the basal c face and by repetitive dipyramidal (n,z) faces. These central zones are similar in appearance to those observed in Mong Hsu (Myanmar) rubies. Magnified 60×.

outline, as well as hexagonal "growth rings" that varied in color intensity and thickness.

Twinning. Pronounced twinning is rare. In most cases, the presence of twin planes and intersection lines was only suggested.

Mineral Inclusions. The minerals we observed in Andranondambo sapphires were randomly distributed. The most common mineral appeared to be calcite (chemical analyses showed an almost pure Ca-carbonate). The calcite crystals varied greatly in size (up to 1 mm) and shape. Some were rounded and some were elongated (figure 15), whereas still others were plate-like. Frequently, the calcite inclusions were well-developed, presenting various morphologies. Although usually transparent and colorless, the calcite crystals themselves sometimes contained numerous small (usually fluid) inclusions, which gave them a turbid white appearance.

Figure 14. In a few samples, a large, intensely colored blue core was surrounded by a narrow (< 1 mm) near-colorless "rim." Magnified 20×.



Other colorless and transparent crystal inclusions were identified as apatite. They occurred most often as irregularly rounded prisms (figure 16), or as elongated hexagonal prismatic crystals. They also appeared as plate-like crystals with many faces. Two types of feldspar were identified. Plagioclase most commonly occurred as colorless, transparent grains of varying size (normally less than 0.5 mm) and irregular morphology, but it was sometimes seen as whitish crystals or as "filling material" in fissures. Typically, the plagioclase was of anorthite composition. The K-feldspar crystals appeared as transparent, often slightly yellow grains and as small, irregularly shaped crystals. Colorless, transparent, needle-like to long-prismatic or stalk-like crystals distributed without any orientation were identified as the amphibole Mg-hornblende.

The second-most-common included mineral was biotite/phlogopite (figure 17). As a rule, it formed isolated orangy brown transparent platelets or mineral aggregates. The chemical analyses actually distinguished two types of mica: In addition to the "normal" biotite/phlogopite composition, some of the analyzed crystals showed distinct Ti concentrations (a few weight percent TiO_2). Sometimes, the mica crystals were intergrown with other mineral inclusions (most often, with calcite and pyroxene). A Ca/Al-silicate that normally occurs in the form of greenish brown grains or irregularly shaped crystals belongs to the pyroxene group (hedenbergite). The chemical analyses proved some crystals to be Ca- and K-silicates, but we have not yet determined their exact nature. Some grayish to black grains with metallic luster showed only the element titanium in the chemical analyses. With Raman spectroscopy, we identified these as rutile. We also saw rutile in the form of oriented needle-like crystals of varying length and as plate-like inclusions.

Figure 15. Colorless calcite crystals were the most common mineral inclusions identified in the Andranondambo sapphires. They occurred rounded or elongated (as shown here) or even plate-like. Magnified 80×.

A few mineral inclusions could not be analyzed chemically because they were too small or were in faceted gems that could not be polished to bring the minerals to the surface. These inclusions were identified on the basis of their visual appearance under the gem microscope: (a) opaque, brownish yellow grains with metallic luster (sulfide); (b) opaque, black, cube-like crystals with metallic luster, sometimes accompanied by stress-fissures, which are probably uraninite or uran-thorianite (see also "Discussion" section); and (c) other opaque grains with a grayish black metallic luster and more-or-less rounded outlines, which probably belong to the spinel group.

In one non-heat-treated sample, we observed fine yellowish brown needles and pinpoints that, in reflected light, had a strong metallic luster; these were concentrated in some well-delineated areas of the host crystal (figure 18). Although we could not conclusively identify these needles, chemical analyses in areas of the host crystal where the needles reached the surface revealed high Fe concentrations. This indicates that the needles are an Fe mineral (possibly hematite, which has been identified—e.g., by Barot et al., 1989—in sapphires from Kenya). We also observed, but could not identify, long, fine needles that ran parallel to the basal face of the host crystal.

Negative Crystals and Fluid Inclusions. Relatively common in the Andranondambo sapphires were so-called negative crystals and their fluid fillings. These inclusions varied greatly, from minute particles and flat, disk-like cavities to elongated, irregularly shaped cavities and large forms delineated by many faces or showing bizarre shapes. Some of the larger, elongated negative crystals were accompanied by tails or "seams" of smaller negative crystals (figure 19). Small negative crystals were often arranged in rows, giving the appearance of strings of

Figure 16. Also identified in the sapphires from southern Madagascar were irregularly rounded prisms of apatite, like the sample shown here at the top center with some colorless to near-colorless calcite crystals and a few opaque black grains (probably rutile or spinel). Magnified 60×.

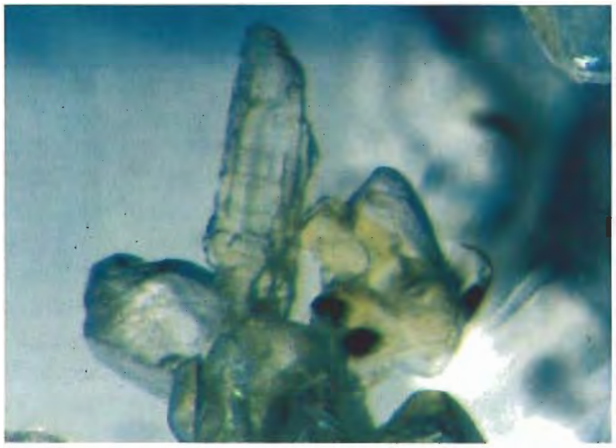
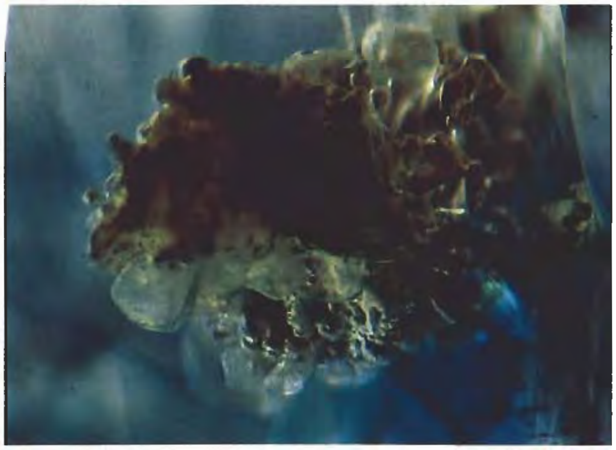


Figure 17. Biotite/phlogopite was the second most common mineral observed in the southern Madagascar sapphires, often appearing as mineral aggregates. Photomicrograph by E. J. Gübelin; magnified 66×.



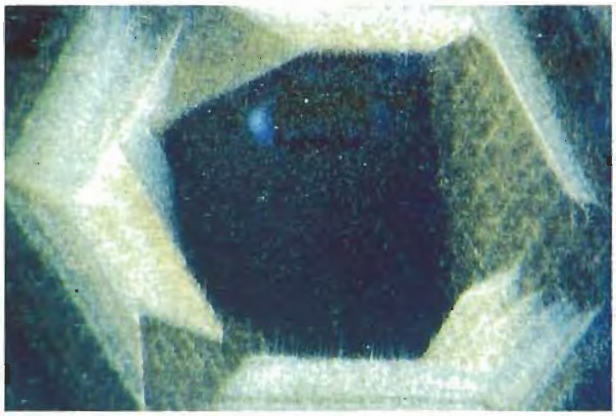
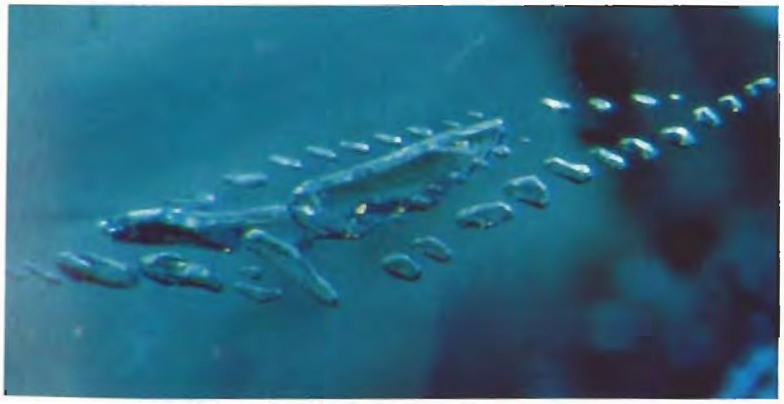


Figure 18. One crystal had concentrations (in well-defined areas) of fine needles and "pinpoints" of a yellowish brown color and a strong metallic luster in reflected light. Chemical analyses of the areas with high concentrations of these needles cutting the surface had distinctly higher Fe contents than the rest of the stone. Thus, the needles probably represent an Fe mineral (probably hematite). Magnified 60×.

pearls, or they were dispersed over former growth planes (figure 20). Sometimes, the negative crystals on the growth planes were accompanied by small crystals of different minerals. The faces of larger negative crystals (especially the flat ones) frequently showed a strong reflection (mirror effect) or striation of the cavity walls. All types of negative crystals may be accompanied by relatively flat healing fissures with random orientation.

Figure 19. Negative crystals were common in the Andranondambo sapphires. Here, large, elongated negative crystals are accompanied by a "seam" of smaller ones. Magnified 80×.



The nature of the material(s) filling the negative crystals is still not well known. Most of the negative crystals looked like single-phase fluid inclusions. However, they are probably two-phase inclusions in which one liquid phase occupies almost the entire cavity. One large three-phase negative crystal contained a colorless liquid, a brownish liquid, and a gas bubble. Rarely, we saw grayish black platelets with strong luster (graphite?) in the fluid inclusions; more common, however, were needle-like inclusions that we have not yet been able to identify.

The fact that the negative crystals in Andranondambo sapphires are often concentrated on growth planes can have significant consequences for heat treatment. As these inclusions commonly rupture at high temperatures, they may result in the breakage of the host crystal or cut stone.

Color Bands. The most striking internal feature in the heat-treated Andranondambo sapphires examined were the grayish white (rarely, grayish brown) fine-, medium-, or coarse-grained bands (figure 21). Because we did not see such bands in non-heat-treated Andranondambo stones, we believe that their formation is directly related to the heat-treatment process. In the Andranondambo sapphires, these HT-bands (the designation *HT* is given to emphasize that these structures formed during heat treatment) were observed in most of the samples examined; sometimes, especially in small stones, they were not easily seen. These bands were often accompanied by color zoning. Fine-grained HT-bands often appeared very compact, giving the impression of three-dimensional "block structures." Others were less compact and appeared fainter and more delicate. With the microscope, using oblique fiber-optic illumination, we frequently observed a bluish "gleam" to the HT-bands. Some very compact bands appeared brown in transmitted light.

Healing Fissures. Healing fissures were also quite common in the Andranondambo sapphires. They were typically flat, rarely wavy, with net-like, (rarely) grain-like, or tube-like "textures." They might consist of isolated rounded or elongated fluid inclusions, of larger negative crystals, or sometimes of "stringers" of small rounded or slightly elongated particles. Even in non-heat-treated stones, many healing fissures had a distinct frosty appearance. In the healing fissures of some heat-treated stones, the

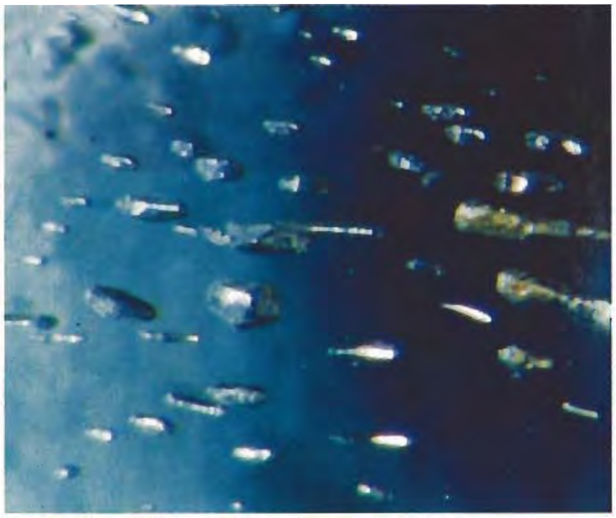


Figure 20. In some of the southern Madagascar sapphires, negative crystals were dispersed over a former growth plane. Magnified 60×.

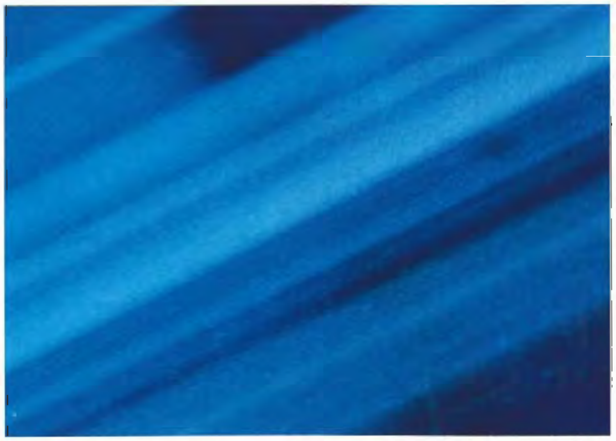
original fluid inclusions were rounded and looked like highly reflective spheres, or they had textures similar to those seen in some synthetic flux corundums (figure 22).

Other Internal Features. In the Andranondambo sapphires, we also observed: (a) stringers of pinpoint-like inclusions in different arrangements (rarely, a sheaf-like appearance), some of which were very delicate (almost cobweb-like); and (b) fine hollow tubes (sometimes needle-like), which have been reported to contain polycrystalline material (by H. Hänni in Kammerling et al., 1995b). Any of the inclusion minerals described in the preceding sections may be accompanied by (c) wing-like healing fissures, unhealed stress fissures, or long, thin, tube- or canal-like inclusions (figure 23). Sometimes, we also observed swarms of delicate, divergent tubes and stringers, which were almost identical to the "comet tails" seen in many Kashmir sapphires.

After heat treatment, many of the originally transparent crystal inclusions turned turbid or even opaque. In addition, the surface of a mineral inclusion sometimes changed dramatically: Many crystal faces developed a porcelain- or glass-like appearance, whereas others became so reflective as to display a mirror effect. Sometimes, a surface acquired a frosted or even crust-like appearance. In some mineral inclusions, we observed the formation of small tension fissures at the contact with the host crystal. Several of the heat-treated Andranondambo sapphires showed grayish white to white needle-like inclusions. Because the samples in which we observed these needles were seen only after heat treatment, we could not establish whether the needles were formed during treatment or were present before but changed their appearance during heating.

Absorption Spectra. *Non-Heat-Treated Sapphires.* A typical absorption spectrum for most of the non-heated Andranondambo sapphires is shown in figure 24a. The spectrum in figure 24b was seen in non-heat-treated material as well as in heat-treated samples. The broad absorption bands around 570 nm in the *o*-spectrum and around 700 nm in the *e*-spectrum are responsible for the blue color (see, e.g., Ferguson and Fielding, 1971 and 1972; Schmetzer and Bank, 1980; Fritsch and Rossman, 1987, 1988a and b; Moon and Phillips, 1994). The main difference between the two spectral types is the presence/absence of an absorption shoulder in the 320–330 nm range. The absorption minima for both spectral types lie around 360, 420, and 490 nm in both the *o*- and *e*-spectra. As a rule, in non-heat-treated Andranondambo sapphires the deepest absorption minimum for the *e*-spectrum was observed at 490 nm. In both heat-treated and non-heat-treated samples with the 320–330 nm absorption shoulder, the absorption minimum almost always shifted to 360 or 420 nm.

Figure 21. The most striking internal feature of the heat-treated Andranondambo sapphires examined were bands of fine-, medium-, or coarse-grained textures and grayish white (rarely grayish brown) color. The formation of these HT-bands is directly related to the heat-treatment process. Magnified 80×.



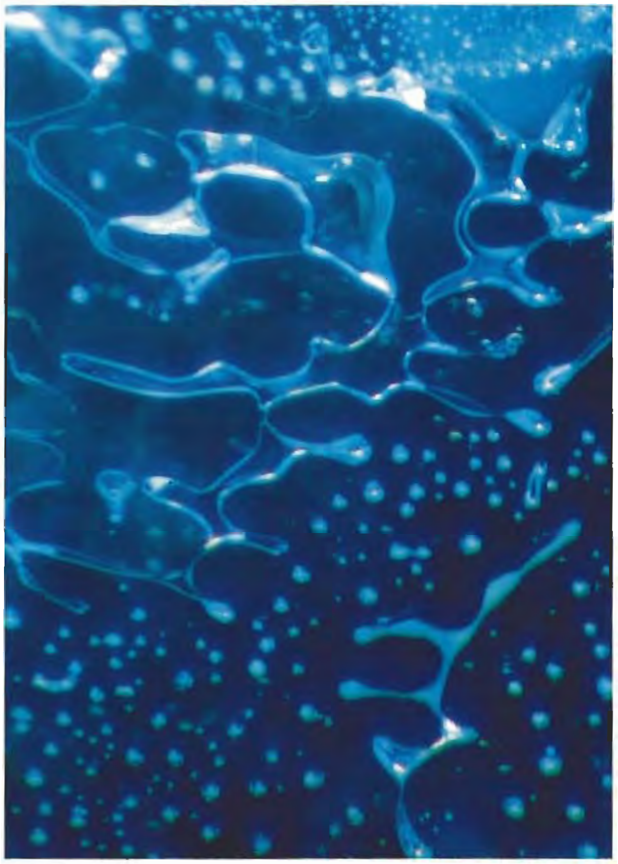


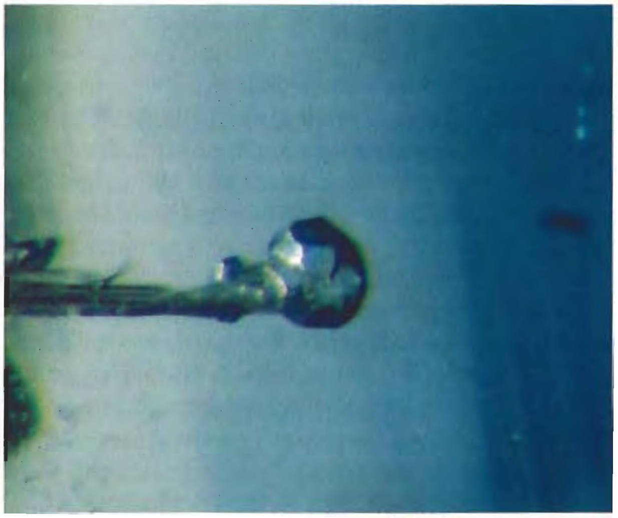
Figure 22. Healing fissures in some heat-treated Andranondambo sapphires were reminiscent of the textures observed in some flux-grown synthetic corundums. Magnified 60×.

Heat-Treated Sapphires. Most of the heat-treated samples had absorption spectra similar to that shown in figure 24b. The absorption shoulder around 320–330 nm is more or less pronounced, and in general the absorption edge lies between 290 and 300 nm. In non-heat-treated material, the absorption edge was usually located between 320 and 340 nm. It must be emphasized, however, that a strong 320–330 nm absorption shoulder was not always present in heat-treated Andranondambo sapphires. The shoulder may be very weak or even completely absent. As illustrated in figure 24 a and b, for the non-heat-treated and for most of the heat-treated Andranondambo sapphires, the absorption bands around 570 and 700 nm were dominant. These bands are ascribed to charge-transfer transitions between Fe^{2+} and Ti^{4+} (see, e.g., Krebs and Maisch, 1971; Ferguson and Fielding, 1971 and 1972; Schmetzer and Bank, 1980; Moon and Phillips, 1994). In rare cases, however, an additional absorption trend, beginning at about 700 nm and extending into the near-infrared region as a result of Fe^{2+} <—> Fe^{3+} charge transfers (Krebs and Maisch, 1971; Ferguson and Fielding, 1971 and 1972; Schmetzer and Bank, 1980), may become more intense (figures 24 c and d). Very strong Fe^{3+} absorption features at 375 and 387 nm, which are considered typical for sapphires associated with basaltic rocks (see figure 24e, the spectrum of a sapphire from Antanifotsy, in central Madagascar), were not observed in the Andranondambo sapphires. For comparison, the absorption spectra considered typical for sapphires from Kashmir, Burma (Myanmar), and Sri Lanka are presented in figure 25.

Chemical Analysis. Table 2 gives the (semi-quantitative) EDXRF results for trace and minor elements in 80 sapphires from the Andranondambo deposit and in four sapphires of basaltic origin from Antanifotsy, central Madagascar.

Compared to the sapphires from Kashmir, which are associated with pegmatite intrusions (Levinson and Cook, 1994), and those from Myanmar and Sri Lanka, which are of metamorphic origin, the Andranondambo "skarn sapphires" have similar $Fe_2O_3 + TiO_2$ and $V_2O_5 + Cr_2O_3 + MnO + Ga_2O_3$ contents (although the latter may have a slightly broader range of variability; these figures are based on preliminary data from an ongoing Gübelin laboratory research project). The main difference between

Figure 23. It was not uncommon in the Madagascar sapphires to see minerals like this calcite crystal accompanied by a tube-like inclusion. Magnified 40×.



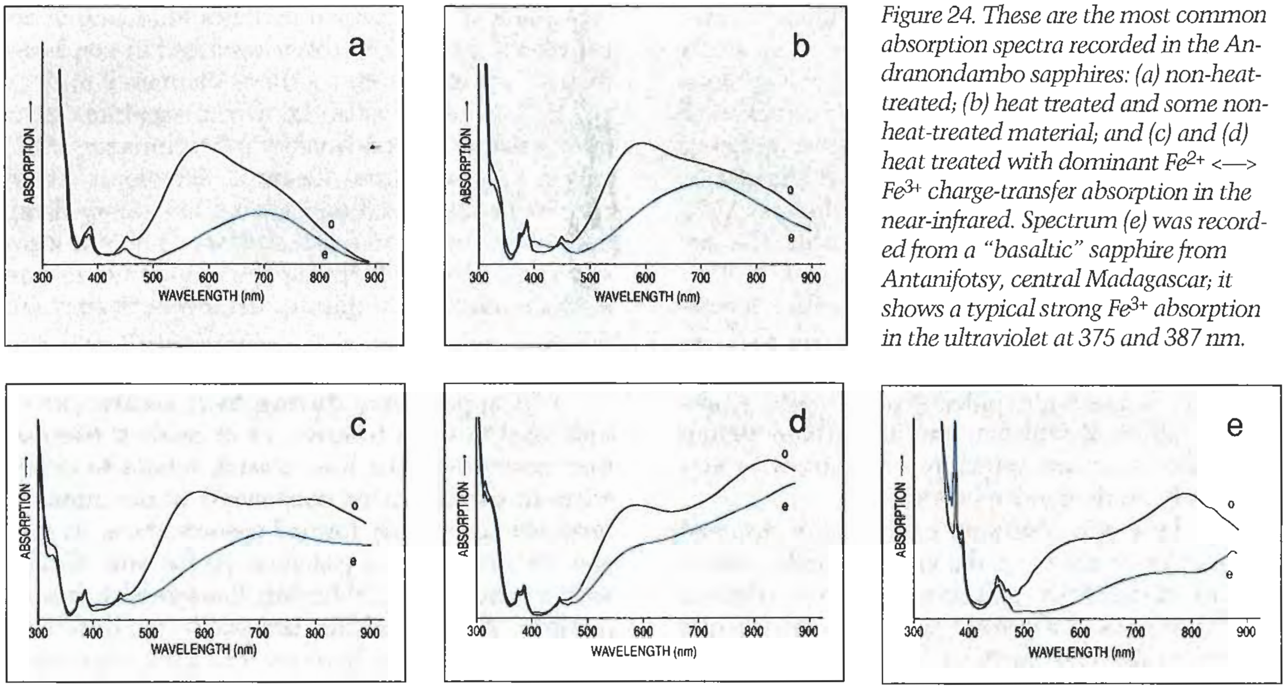


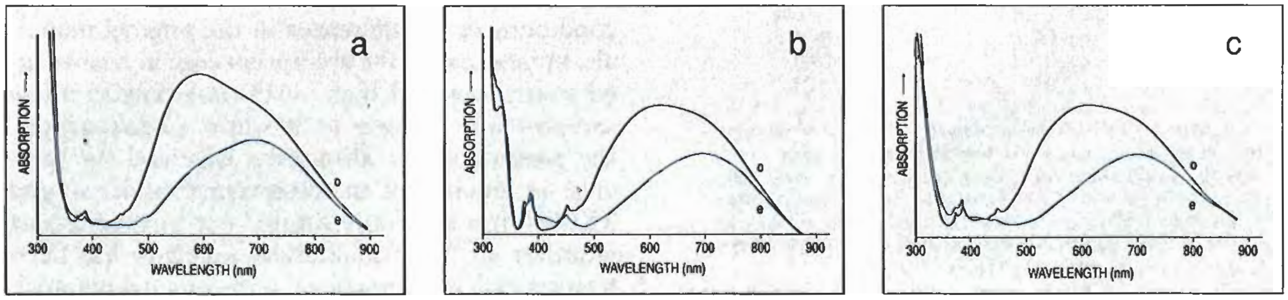
Figure 24. These are the most common absorption spectra recorded in the Andranondambo sapphires: (a) non-heat-treated; (b) heat treated and some non-heat-treated material; and (c) and (d) heat treated with dominant Fe^{2+} <—> Fe^{3+} charge-transfer absorption in the near-infrared. Spectrum (e) was recorded from a "basaltic" sapphire from Antanifotsy, central Madagascar; it shows a typical strong Fe^{3+} absorption in the ultraviolet at 375 and 387 nm.

these and the basalt-associated Antanifotsy sapphires lies in the iron concentration, which is higher for the sapphires found in basaltic deposits. We did not see any definite correlations (for example, higher Ti contents where Fe concentrations are higher) in the Andranondambo sapphires. Also, there was no evidence of a simple correlation between iron content and color intensity.

DISCUSSION

Geology and Occurrence. The Andranondambo deposit—like the occurrences in Kashmir, Myanmar, and probably Sri Lanka—results from metamorphic conditions. The sapphires of the Andranondambo mining region in southeast Madagascar were formed in U-Th skarns that belong to the Pan African granulitic formations. Rakotondrazafy et al. (1996) defined two main stages of crystallization in the skarns: The minerals aluminous diopside, CO_3-scapolite, titanite or spinel, and thorianite/uraninite—as well as corundum—are characteristic of stage 1; one of the main mineral reactions of stage 2 is the crystallization of hibonite at the expense of corundum and spinel. Many of the Andranondambo sapphires are well-developed crystals (figure 8), which often show interesting dissolution features at their surfaces. The dissolution phenomena are the result of changes in the mineralogic environment during stage 2 of skarn metasomatism.

Figure 25. The three spectra shown here are typical for (a) Kashmir, (b) Burma (Myanmar), and (c) Sri Lankan blue sapphires.



The mineral inclusions in the Andranondambo sapphires—predominantly Ca minerals, especially calcite—reflect the nature of the surrounding metamorphic carbonate and calc-silicate host rocks and the paragenesis of these sapphires. Other minerals found in sapphires from this deposit include: apatite, feldspar (plagioclase and K-feldspar), phlogopite, Mg-hornblende, pyroxene (hedenbergite), rutile, Ca- and K-silicates, spinel, thorianite/uraninite, and sulfide. The following minerals related to sapphire genesis were identified in sapphire-bearing rock samples obtained at Andranondambo for this study: calcite, anorthite, wollastonite, phlogopite, hibonite, scapolite, pyroxene, K-feldspar, and amphibole. Behier (1960) also described spinel as occurring with sapphire in the Andranondambo area.

The lack of a continuous increase or decrease in the color intensity of the growth bands evident in most of the Andranondambo sapphires (figures 10–12) means that there was no continuous increase or decrease in the coloring agents present in the nutrient fluid during crystal growth. Rather, the sequences of alternating color zones indicate a multi-stage growth with the several growth phases characterized by changes in the genetic environment (e.g., variations in the composition of the nutrient).

Comparison to Sapphires from Other Localities. Most of the Andranondambo sapphires that reach the gem market are heat treated. The fine-grained bands induced by heat treatment in the Andranondambo sapphires are not exclusive to this locality. Clouds of fine-grained particles following internal growth planes have been described in non-heat-treated sapphires from southern Vietnam (Smith et al., 1995). They are also known in sapphires from other basaltic sources (Kiefert and Schmetzer, 1987) and in sapphires from Kashmir (Schwieger, 1990) and Sri Lanka (based on Gübelin laboratory data). Because of their very small size, we could not identify the particles forming the HT-bands in the Andranondambo samples to determine if they are different from those seen in non-heat-treated sapphires from other deposits.

TABLE 2. EDXRF analyses of trace and minor elements in sapphires from the skarn-associated Andranondambo deposits and the basalt-associated Antanifotsy deposits.

	Content (wt.%)	
Oxide	Andranondambo[a]	Antanifotsy[b]
Fe_2O_3	0.12–0.61	1.80–2.09
TiO_2	0.01–0.10	0.04–0.08
Ga_2O_3[c]	0.01–0.04	0.01–0.02
V_2O_5	< 0.01	< 0.01
Cr_2O_3	< 0.01	< 0.01
MnO	< 0.01	< 0.01

[a] *Concentration ranges in 80 samples from the Andrandambo deposits.*

[b] *Concentration ranges in 4 samples from the Antanifotsy region.*

[c] *In 10 synthetic sapphires from Kyocera, examined by the senior author, the Ga concentration was < 0.01 wt.% (Ga_2O_3); in eight Seiko synthetic sapphires and in 36 Chatham flux-grown blue and orange synthetic sapphires, the Ga contents were below the detection limit of about 0.005 wt.% (Ga_2O_3) (see also Schrader and Henn, 1985).*

The appearance during heat treatment of unhealed tension fissures, or of healing fissures that extend into the host crystal, relates to differences in the expansion coefficients of the minerals involved. The newly formed fissures show, in general, two modes of appearance: (a) flat and circular with a "seam"; and (b) healing fissures with frosted textures. At the Gübelin laboratory, we have also seen both types in heat-treated sapphires from other sources. The absence of such fissures, as well as the presence of negative and/or mineral crystals that do not show evidence of rupture or other damage, provide good indication that a cut stone has not been subjected to heat treatment (figure 26).

Non-heat-treated samples, in general, show absorption spectra (figures 24 a and b, respectively) that are similar to those of Kashmir sapphires or, more rarely, to sapphires from Myanmar (figure 25). In the first case, the absorption edge is normally positioned at higher values (*o* ~ 320–335 nm; *e* ~ 320–340 nm), compared to sapphires from Myanmar or Sri Lanka (again, see figure 25).

The heat-treatment process influences the absorption behavior of Andranondambo sapphires. However, the appearance of the absorption shoulder at about 320–330 nm cannot automatically be related to heat treatment, both because the absorption shoulder was not seen after treatment in many samples and because the shoulder was observed in some unheated stones (figure 24b). This variable absorption behavior may be due to different heating conditions or to differences in the original materials. In most cases, the absorption edge in heat-treated stones was still high (>315 nm); only in a few samples was it lower (< 305 nm). Consequently, the position of the absorption edge and the presence (or absence) of an absorption shoulder around 320–330 nm is of only limited use in establishing whether an Andranondambo sapphire has been heat treated. In comparison to the original material, the broad absorption bands in the 500–800 nm range do increase as a result of heat treatment. Empirical experience at the Gübelin Laboratory indicates that, in general, the absorption spectra of heat-treated Andranondambo sapphires are more similar to those of most Sri Lankan sapphires (when no absorption shoulder is present; see figure 25) or of Burmese sapphires (when a pronounced shoulder is developed; see figure 25). Whereas the absorption spectra of some Andranondambo sapphires (figures 24c–d) in the 500–800 nm range resemble those of sapphires originating from basalt-associated deposits, the Fe^{3+} absorption in the ultraviolet, at 375 and 387 nm, is never as intense as in typical basaltic sapphires (figure 24e).

The concentrations of Fe, Ti, and Ga in the Andranondambo sapphires sometimes reach values higher than those that are considered typical of sapphires from the metamorphic deposits in Myanmar and Sri Lanka (up to 0.61 wt.% Fe_2O_3, 0.10 wt.% TiO_2, and 0.04 wt.% Ga_2O_3). The iron contents of the Andranondambo sapphires, however, are lower than those measured in the four (basaltic) Antanifotsy sapphires, but they may overlap those of sapphires from other basaltic deposits (compare, e.g., Guo et al., 1992; Smith et al., 1995). The chemical behavior of the Andranondambo sapphires is probably related to the special genetic conditions that exist during skarn metasomatism.

The range of mineralogical and gemological properties shown by Andranondambo sapphires is relatively broad, but within this range are specimens with spectral and chemical characteristics as well as internal features similar to those of sapphires from Sri Lanka, Myanmar, and even Kashmir.

Internal features of non-heat-treated Andranondambo sapphires that resemble those of Sri Lankan or Kashmir sapphires include prismatic amphibole crystals; black, cube-like grains; colorless, irregularly rounded crystals; and short rutile needles. However, in our sample, we did not see the long, fine rutile needles that are typical for Sri Lankan sapphires (compare Gübelin, 1973; Webster, 1983; Anderson, 1990), or the nests/bands of short, dull rutile needles that are more common in Burmese sapphires (Gübelin, 1973). Nor did we see those internal features that are most typical of Kashmir sapphires (the velvety appearance that is caused mainly by clouds, lines, strings, and flake-like arrangements of dust-like inclusions; or the association of zircon, tourmaline, pargasite, plagioclase, allanite, uraninite [compare Schwieger, 1990]).


Figure 26. This 0.24 ct sapphire from southern Madagascar shows no evidence of rupture of the fluid inclusion or stress cracking around the small solid inclusions. This suggests that the stone was not subjected to high-temperature heat treatment. Stone courtesy of I. Z. Eliezri; photomicrograph by John I. Koivula, magnified 30×.

After heat treatment, many Andranondambo sapphires lack specific inclusion features. Small stones (< 1 ct) may be quite clean, even when examined with the microscope. For such stones, growth characteristics are of little or no diagnostic value, and identification should be based on absorption spectra and chemical data. It appears that the reaction to UV radiation is a useful additional test to separate the Andranondambo sapphires from their Sri Lankan counterparts. Sri Lankan sapphires very often show quite strong red or orange-red fluorescence to long-wave UV-radiation.

The properties for the few samples from Antanifotsy appear to be consistent with sapphires from other basaltic deposits (see, e.g., Kiefert and Schmetzer, 1987). The distinction between these basaltic sapphires and the Andranondambo sapphires is relatively easy based on the inclusion features, absorption spectra (figures 24a–e), and chemical properties (table 2).

Separation from Synthetic Sapphires. Andranondambo sapphires can be fairly easily separated from synthetic blue sapphires grown by different methods. The synthetics (Verneuil, Chatham, Kyocera, Seiko) normally have very little or no Ga (see the footnote to table 2). In addition, most of the internal features seen thus far in Andranondambo sapphires are quite different from those observed in laboratory-grown sapphires (compare, e.g., Kane, 1982; Gübelin, 1983).

CONCLUSIONS

The appearance and properties of the sapphires from the Andranondambo deposit are related to the metamorphic geologic (skarn) environment in which these sapphires formed. Some Andranondambo sapphires, at least in some aspects, resemble sapphires from Sri Lanka, Myanmar, or Kashmir. On the one hand, non-heat-treated stones revealed some inclusions that are similar or almost identical to those seen in some Sri Lankan or Kashmir sapphires. On the other hand, many (heated and not-heated) Andranondambo sapphires showed "Burma-type" absorption spectra. In most cases, however, these Madagascar stones could be separated from sapphires of other localities by means of, in addition to inclusion features, absorption spectra in combination with chemical data.

The separation of heat-treated from non-heat-treated Andranondambo sapphires is easy when the so-called HT-bands are present. Additional features that indicate that the stone has been heat treated are changes observed in the appearance of many inclusions and, to some extent, the absorption spectra.

Although some internal features of Andranondambo sapphires may be similar to those observed in certain synthetic sapphires (especially the healing fissures in heat-treated Andranondambo stones and those seen in flux-grown synthetics), the overall inclusion scenes should make confusion unlikely. For sapphires that lack (typical) inclusions, a quite reliable separation is possible based on Ga content: The known synthetic sapphires have very little or no Ga, whereas the Madagascar stones can have quite high Ga values.

Precise production figures for the sapphire deposits of Andranondambo in southern Madagascar are not available; nevertheless, we believe that thousands of kilograms of these sapphires have reached the gem market since 1992/93. For the trade, this has been important because these sapphires could, at least in part, compensate for the inconsistency of production from the traditional localities. In addition, a certain percentage of the Andranondambo material represents an alternative to "Burma-type" sapphires, and some stones have even been compared to Kashmir sapphires. As the relatively recent discovery of sapphires at the Antsiermene perimeter, less than 12 km north of Andranondambo, indicates, the regional geologic conditions in this part of the island favor the occurrence of other skarn-associated sapphire deposits.

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RUSSIAN DEMANTOID, CZAR OF THE GARNET FAMILY

By Wm. Revell Phillips and Anatoly S.Talantsev

Demantoid, green andradite garnet, was discovered in the Central Ural Mountains of Russia in the mid-19th century. A favorite of the Czar's court, demantoid was another victim of the 1917 Bolshevik Revolution, when mining of this and other Russian gems was halted. Today, however, independent miners are recovering notable quantities of stream-worn demantoid pebbles from two major districts: Nizhniy Tagil, about 115 km north, and Sissertsk, about 75 km south, of Ekaterinburg. As a result, these distinctive bright "golden" green to dark green garnets are re-emerging in the gem market. Although cut stones continue to be small for the most part, a number of fine demantoids over 1 ct have been seen.

ABOUT THE AUTHORS

Dr. Phillips is emeritus professor of geology (Ph.D. mineralogy) at Brigham Young University, Provo, Utah, and director of Ural Gem, a division of NEFT Inc., Moscow, Russia. Dr. Talantsev is professor and chief specialist of the Ural Branch of the Russian Academy of Sciences, and president of the Ural Division of the Russian Mineralogical Society, Ekaterinburg, Russia.

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The popular garnet family is one of the most prolific mineral groups, with a family tree rooted primarily in five common end-member garnets and branching to a spectrum of colors and gem varieties. Historically, garnet was loved for its deep, rich red color, and the word *pyrope* is derived from the Greek word meaning "fire-like" (Dana, 1958).

The green garnets are of a younger generation and the "darlings" of the family. Demantoid emerged first, in the 19th century, when it entered the royal courts of Czarist Russia from the valleys of the Ural Mountains. Purged in the early 20th century by the Bolshevik revolution, demantoid all but disappeared from the international gem scene. In recent decades, it was largely replaced by its younger sibling, tsavorite, from the East African bush country. In a new Russia, however, the demantoid sites are again becoming active, with a trickle of green fire reentering the market (figure 1).

Demantoid ($Ca_3Fe_2[SiO_4]_3$) is the chromium-green gem variety of andradite, but it usually exhibits a yellow overtone due to intrinsic ferric iron. With a hardness slightly less than 7, demantoid is not a good ring stone. However, its high index of refraction (1.89) and dispersion (0.057; diamond is 0.044) make it a gem of great brilliance and fire for other jewelry purposes.

The following account looks at the early history of demantoid as a gem material and its present status with regard to localities, geology, production, and marketing, as demantoid reemerges from virtual obscurity into a promising future. Locality information is based largely on the authors' own experience and knowledge of the Urals region. A review of demantoid's place in the garnet family helps explain its distinctive properties, especially in contrast to tsavorite, with which it has been compared in the trade.

HISTORY

About 1853, children from the settlement of Elizavetinskoye (also spelled "Elezavetinskaya"), southwest of the larger village of Nizhniy Tagil (also known as Nazhniy-

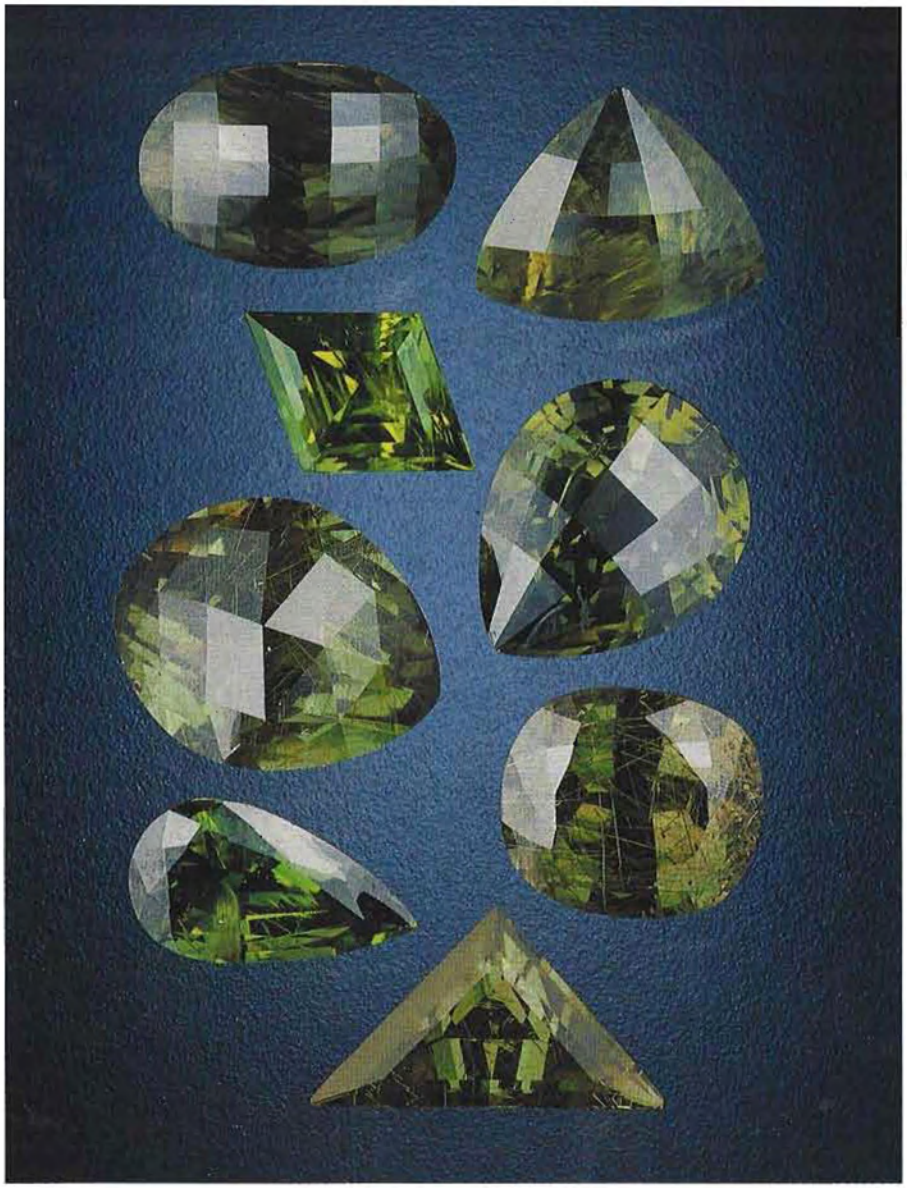


Figure 1. A number of fine demantoids from Russia have appeared in the gem market recently. These unusually large demantoids (1.64–5.40 ct) range from "golden" green to a deep "emerald" green. Stones courtesy of Gebr. Henn, Idar-Oberstein, Germany; photo © GIA and Tino Hammid.

Tagilsk) in the Central Urals (figure 2), found unusual "grass"-green pebbles (probably similar to those shown in figure 3) in the heavy spring runoff of the Bobrovka River (Eichmann, 1870; Samsonov and Turingue, 1985). Local jewelers identified the green gem as chrysolite (olivine, [$(Mg, Fe)_2SiO_4$]—generally known by gemologists as *peridot*). Mineral collecting was very stylish in late-19th-century Czarist Russia, especially among the nobility, and mineral collectors soon converged on Nizhniy Tagil in search of specimens of this gem. This "Ural chrysolite" (which also was called "Bobrovsk emerald," "Uralian emerald," and "Siberian chrysolite") soon appeared in the jewelry shops of Moscow and St. Petersburg, mostly as small, fiery calibrated stones framing enamel work or the larger gems of the Urals, such as pink topaz or beryl.

Nils von Nordensheld (also spelled "Nordenskiöld"), a Finnish mineralogist who first gained fame in the Urals with his identification of the new mineral phenakite (Be_2SiO_4), arrived at Nizhniy Tagil a year after the initial demantoid discovery. He remained for a year and a half studying copper deposits in the area. P.V. Eremeyer (also spelled "Eremeev"), his friend and biographer, suggests that von Nordensheld never visited the actual site where the green stones were found, but rather examined those in several collections. On the basis of these examinations, von Nordensheld declared the green gem a new mineral and certainly not chrysolite.

On February 20, 1864, von Nordensheld described the beautiful green gem before the St. Petersburg Mineralogical Society as green andradite garnet colored by a small chromium content (Eremeyer, 1871). The fact that andradite has the highest R.I. and dispersion of any of the garnets explained the unusual brilliance and fire, and he proposed the name *demantoid* (i.e., "diamond-like") for the little "green diamonds" (Clark, 1993,

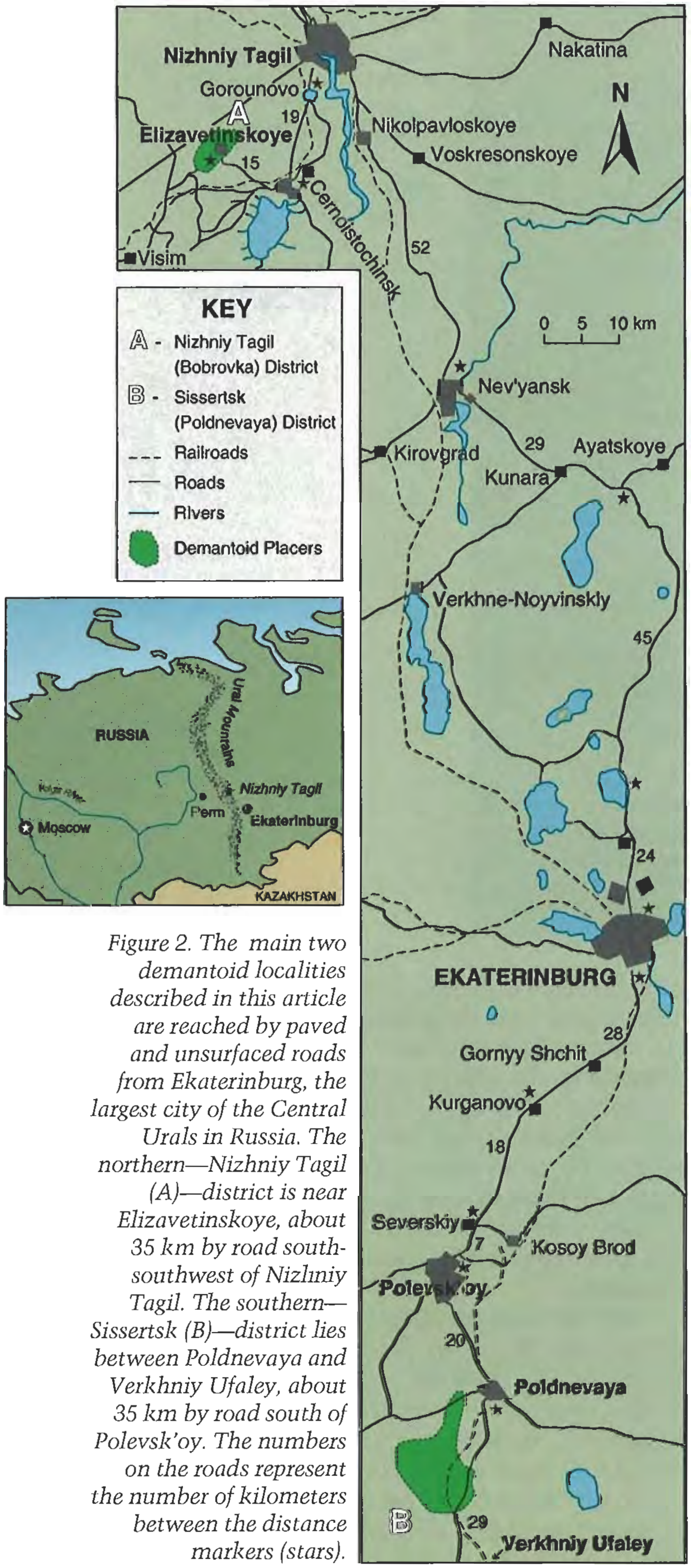


Figure 2. The main two demantoid localities described in this article are reached by paved and unsurfaced roads from Ekaterinburg, the largest city of the Central Urals in Russia. The northern—Nizhniy Tagil (A)—district is near Elizavetinskoye, about 35 km by road south-southwest of Nizlniy Tagil. The southern—Sissertsk (B)—district lies between Poldnevaya and Verkhniy Ufaley, about 35 km by road south of Polevsk'oy. The numbers on the roads represent the number of kilometers between the distance markers (stars).

p. 176, gives 1878 as the year the term was introduced and first published). The name was accepted subsequently by Russian mineralogists and jewelers, but it was initially rejected by the local people, who continued to call it "Ural chrysolite," as *demantoid* sounded too much like a word that was vulgar in the local dialect.

A second discovery was made about 75 km (90 km by road) south of Ekaterinburg in the Sissertsk (also spelled "Sysert" and "Syssert") District (also referred to as the Polevsk'oy District or Poldnevaya District) on the Chusovaya and Chrisolitka Rivers of the west slopes of the Ural Mountains. This area produced gems equal, or superior, in quality to those at the first locality (Church, 1879).

Demantoid was very popular in Russia from about 1875 to 1920 (figure 4). It was even incorporated into some of the fabulous creations of Peter Carl Fabergé and other court jewelers. Although most of these gems were used by the Russians, who preferred the brownish or yellow-green stones (R. Schafer, pers. comm., 1996), a few—including the less popular (and less brilliant) intense green gems—were exported to the European market at exorbitant prices. Edward VII of England favored green gems, and demantoid entered the "Belle Epoque" (see cover and figure 5).

Serious efforts have been made to find demantoid deposits in similar geologic environments elsewhere in Russia. In 1980, one was reported at a site in the Kamchatka Peninsula of eastern Siberia. The stones are usually small (2–3 mm) but of good quality. Several deposits of yellow andradite (sometimes referred to as "topazolite," although this term is in

Figure 3. These pebbles, in the form of abraded dodecahedra, are typical of the alluvial demantoids found in the Central Urals. The stone on the left clearly shows the spray of radiating "horsetail" fibers that is characteristic of demantoid garnets. From left to right, they weigh 6.63, 4.81, and 4.62 ct. Photo by David W. Hawkinson, BYU Museum of Art.

disfavor with modern gemologists) and uvarovite (the chrome analog of andradite) also came to light. Minor occurrences of demantoid also have been reported from Zaire, Korea, Sri Lanka (gem gravels), California (San Benito County; Payne, 1981), and south-central Mexico (Wilson, 1985). Even some stones from the Ala Valley of Italy are green enough to be considered demantoid. Nevertheless, demantoid has largely remained a gem of the Ural Mountains (Samsonov and Turinge, 1985). Crystals from all of these other localities are rare, seldom more than a few millimeters, usually very pale, with cut stones over one-quarter carat rare indeed.

With the onset of the Bolshevik Revolution in 1917, gems went out of vogue in Russia, along with other symbols of wealth and royalty, and Soviet resources turned to mineral production more in demand by industry. Localities of emerald and other beryls were mined for their beryllium, diamond was mined for industrial applications, and the tailings piles of chrysoberyl mines were hand-picked for molybdenite. In the early stages of World War II, Joseph Stalin moved the Soviet heavy industry to the Central Urals, away from immediate Nazi invasion. The Urals produced planes, tanks, and guns for a desperate nation; demantoid and other gems for personal adornment seemed unimportant.

Figure 4. Popular in Russian jewelry from 1875 to 1920, demantoids provide a field of green for this antique star brooch manufactured in Russia. Courtesy of À La Vielle Russie, New York City; photo by Nicholas DelRe.

Figure 5. Demantoids were particularly popular in late 19th- and early 20th-century Edwardian jewelry. This yellow-gold and silver 19th-century dragonfly pin is set with two relatively large demantoids—1.30 and 1.03 ct—in the main body, as well as assorted smaller demantoids (2.80 ct total weight) throughout the balance of the piece, together with diamonds and two rubies. Courtesy of the Susan Clark Gallery of Gem Art, Vancouver, BC, Canada.

LOCATION AND ACCESS

Two major districts in the Central Ural Mountains of Russia have historically yielded demantoid garnet: Nizhniy Tagil (along the Bobrovka River) and Sissertsk (near Polevsk'oy and Poldnevaya). These regions are alternating dense forest (spruce, pine, aspen and birch) and open meadows, with much of the area marshland (figure 6).

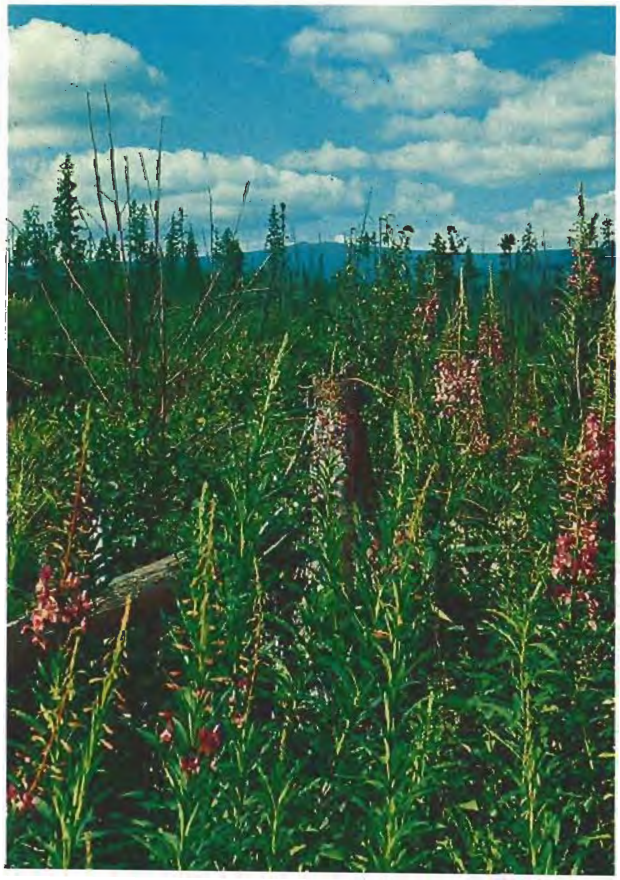
The Nizhniy Tagil district is near the tiny village of Elizavetinskoye, about 115 km north-northwest of Ekaterinburg (figure 7). It is best accessed from there via Nev'yansk and Nizhniy Tagil over paved roads. This district contains two deposits: (1) the placer on the Bobrovka River (Bobrovskaya Placer), which runs for about 2 km through Elizavetinskoye; and (2) a primary, *in situ*, deposit at the head of the Bobrovka River (Tochilny Kluch), which is the source of the alluvial demantoid.

The Sissertsk district lies between Poldnevaya and Verkhniy-Ufaley near the Korkodin railway station, which is about 75 km south-southwest of Ekaterinburg (figure 8). All but 4 km of the road from Ekaterinburg to the site (90 km), via Polevsk'oy, is paved. In this district there are two primary, *in situ*, deposits: at Kladovka (point I in figure 8) and at Korkodin (point II in figure 8). In addition, there are five river placers: Bobrovka (area 1, figure 8), Zyachiy Log ("Hare Creek," area 2), Ufaleyka (area 3), Chrisolitka (area 4), and Kamenuschka (area 5). (Note that the Bobrovka area in the Sissertsk district should not be confused with the larger Bobrovka River that is in the Nizhniy Tagil district.)

In 1985, a small demantoid deposit was discovered in the southern part of the Arctic Urals on the Hulga River. This new deposit contains both *in situ* demantoid and a small placer. Crystals are gem quality, relatively large (6–8 mm), and good green color. The site is difficult to reach and has not been studied.

In 1995, another demantoid deposit was reported in the Arctic Urals on the Hadata River. The primary deposit is on the Saum-Kev pyroxenite massif and is accompanied by a placer deposit about 1 km long. It is scheduled for exploration and study in the summer of 1996.

Figure 6. There is no formal mining site at Nizhniy Tagil. Rather, alluvial pebbles of demantoid are recovered from stream beds in a complex of low, mature hills covered by dense forest—largely birch, pine, aspen, and spruce—and, as shown here, open meadows.



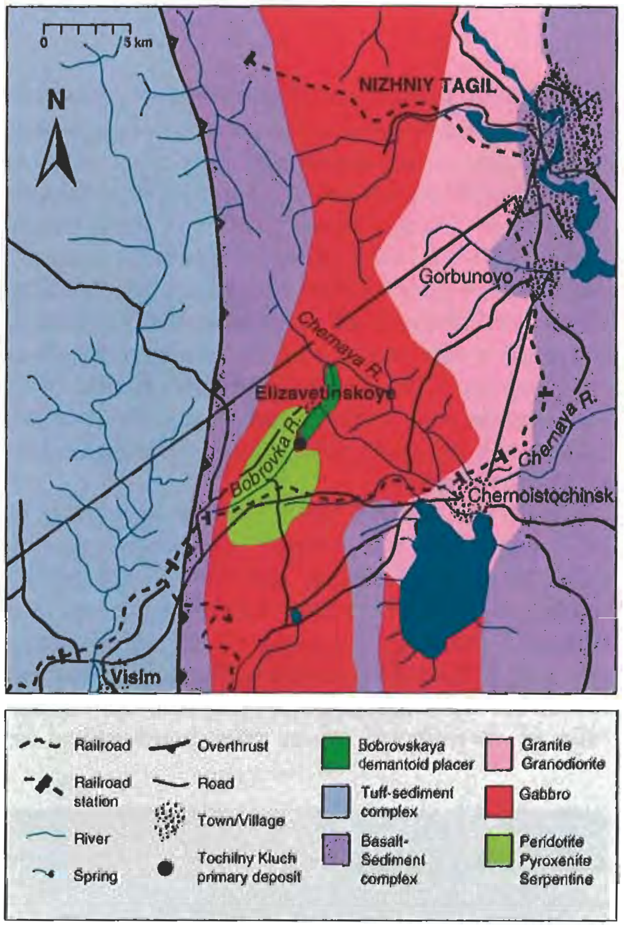


Figure 7. Demantoid was first discovered in gravels of the Bobrovka River near the small settlement of Elizavetinskoye, in what is now called the Nizhniy Tagil district. Primary crystals are also recovered from the peridotite intrusion south of the village, at Tochilny Kluch, where the demantoid forms in thin chrysotile veins in serpentinized pyroxenites.

GEOLOGY AND OCCURRENCE

In the Central Urals, primary deposits of demantoid crystals occur in both major districts, as shown in figures 7 and 8. At Nizhniy Tagil, serpentine lenses about 1.5 km long by 200–300 m wide occur within ultramafic (pyroxenite-peridotite) intrusions, and are cut by veins of coarse-grained olivine (chrysolite) and minor dolomite. At Tochilny Kluch (="Creek"), the demantoid crystals appear to form around tiny grains of chromite in the highly fractured contact zones between chrysolite veins and serpentine. Ultramafic rocks—such as peridotite, pyroxenite, and their alteration product, serpentine—usually contain high concentrations of chromium and are the source both of chromite ($FeCr_2O_4$) and of the chromium for a plethora of

Cr-bearing minerals, including emerald, alexandrite, and demantoid.

Because demantoid crystals are relatively soft and brittle, they will not withstand the rigors of extensive stream transportation. Alluvial pebbles of demantoid (again, see figure 3) are found largely in the sandy gravels of the shallow headwaters of small streams fed by large springs (Samsonov and Turinge, 1985). Demantoid in the Nizhniy Tagil district is recovered from Pleistocene river gravels cut by the active Bobrovka River; the principal deposit measures about 500 m along the river valley and is 20 to 100 m wide (again, see figure 7). The productive sandy, red gravels (sand-size to gravel-size grains and pebbles of the available rock types, stained red by iron oxides from the weathering of the iron-rich rocks) are as much as 2.5 m thick. They lie on an eroded surface of Paleozoic volcano-sediments, and are covered by several meters of detritus and soil. The best horizons are near the base of ancient terraces; these may contain 100 g of demantoid per cubic meter, 80% of which are pebbles of 4 mm or less. A second deposit on the Bobrovka (also within the placer area marked in figure 7) is even larger (2.5 km by 50–60 m); much of the Pleistocene sand and gravel lies below the present stream cut and may reach a total thickness of 6 m. Only the modern river bed has been exploited for demantoid crystals, which are poorly formed dodecahedra {110} and may reach 5–6 cm, although such large crystals are very rare.

The geology and deposits of the Sissertsk (Poldnevaya) district are similar to those of Nizhniy Tagil (again, see figure 8). At both primary deposits, demantoid occurs in thin (1.5–2 cm) chrysotile veins in serpentinized pyroxenites. Thus far, these primary sites have produced only mineral specimens. In all of the five placer deposits, demantoid is recovered from the lowest gravel bed (the basal bed), with minor amounts from sand bars.

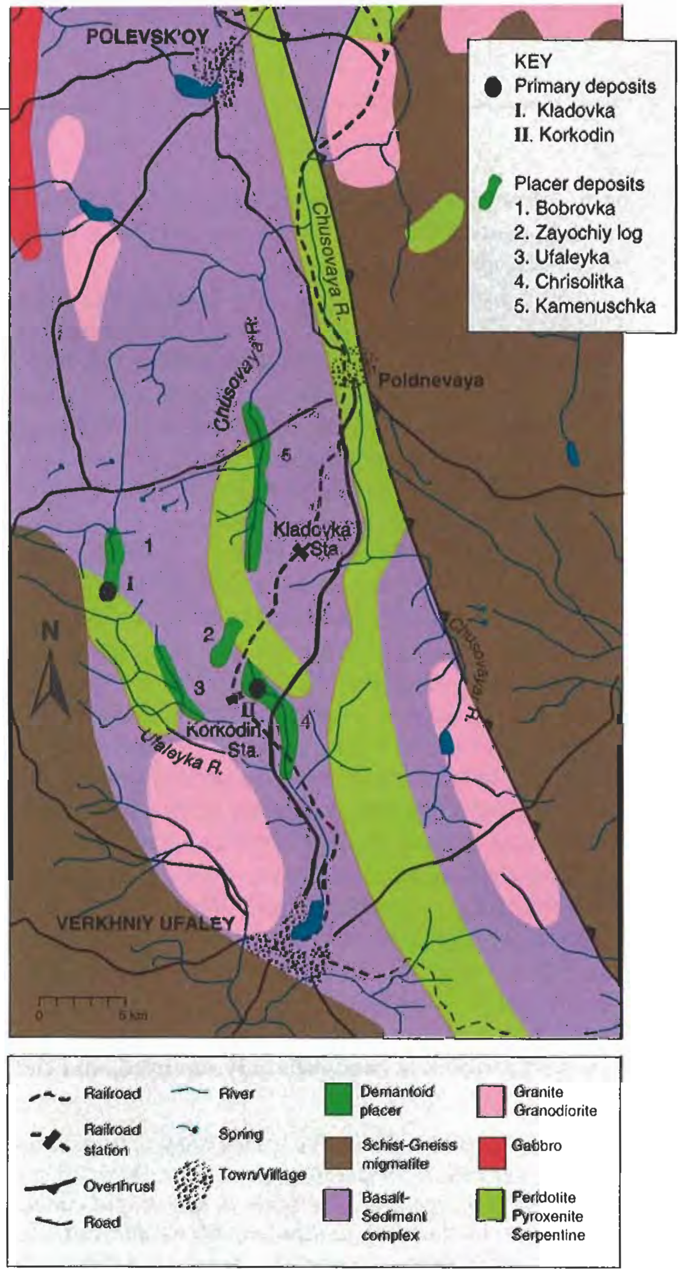


Figure 8. In the Sissertsk demantoid district, the garnets occur as primary crystals in serpentinite pods in ultramafic pyroxenites and as detrital pebbles in stream gravels a few kilometers west of the Kladovka railway station or north of the Korkodin station.

MINING AND PRODUCTION

Mining specifically for demantoid in Russia has been very erratic. Before 1915, the stones were usually obtained as a by-product of platinum mining of the placers at Elizavetinskoye and gold mining of the placers in the Sissertsk district. Since then, the demantoid deposits have been worked mostly by private miners (figure 9), operating illegally, who search river gravels or dig pits up to 5 m deep and then wash and screen the pit gravels. Only the contract companies have licenses to dig, and even those may be for exploration only. Illegal digging is a dangerous profession, as the authorities are always alert and local competition is keen. Miners have been subject to arrests, threats, and even shootings.

In the 1970s, government geologists studied the Nizhniy Tagil–Elizavetinskoye deposits for commercial development, and for three to five years thereafter, the AO Uralquartzsamotsvety ("Ural-quartz-colored stones" Company) attempted hydraulic mining. Recovery was poor (40%–60%), and much high-quality rough was lost in the tailings. However, most of the demantoid was ultimately recovered by the local people, who work over every dump and tailings pile.

A very crude estimate would suggest that, prior to 1990, a total of perhaps 200 kg of demantoid rough had been mined; the total remaining commercial reserve of the Elizavetinskoye placers has been estimated at 2,000–3,000 kg. In 1993, the deposit was licensed to a metallurgical company (AO NTMK [Nizhniy Tagil Metallurgical Kombinat]) for prospecting, but no commercial production has resulted. The license expires in 1997, and the company is desperately seeking foreign financing.

The Korkodin-Chrisolitka deposit was explored in the late 1980s, and a license was purchased by a private conglomerate (TOO "Grani") from the Chelyabinsk region. A production company was formed, and some small-scale organized mining began in 1994; however, no commercial production has yet been reported. Reserves at the Korkodin-Chrisolitka deposit are estimated at 5,000 kg.

The Kamenuschka deposit, about 5 km north of Korkodin, is unexploited, unlicensed, and remains available for development. Trenches cut by "bandit diggers" expose the bedrock and reveal demantoid in drusy cavities, which are valued both for jewelry and as mineral specimens. No commercial production has been officially reported, and the reserves at the Kamenuschka deposit are estimated at roughly 2,000–3,000 kg.

Figure 9. In the Urals, most of the demantoids are recovered by local villagers who illegally search the river gravels. Here, a Russian woman examines gravels from the Bobrovka River.

Figure 10. These five stones (0.24–0.35 ct) were selected from a collection of about 50 small cut stones to represent the range of demantoid colors. On the basis of qualitative EDXRF analysis, the bright green stone on the far left contains much more chromium than any of the others, and the near-colorless stone on the far right contains much less. The three center stones all have about the same chromium content, between that of the previous two samples. By comparison, a medium-green tsavorite garnet analyzed revealed more chromium than all but the brightest green demantoid here, but it also had 10 to 100 times more vanadium than chromium. Photo by David W. Hawkinson, BYU Museum of Art.

Unofficial estimates place total demantoid rough production for 1995 at about 8 kg (Elizavetinskoye—5 kg, Poldnevaya—3 kg). About 40% of this total, some 16,000 carats, is recovered as cut stones. Less than 10% of the latter group, about 1,600 carats, is represented by stones of one carat or more.

Little more can be said at this time about the present status or future development of demantoid garnet in the Ural Mountains of Russia, except that interest is growing, foreign investors are welcome, and proposals to develop the deposits are under consideration. However, all of the areas containing demantoid, except Korkodin, supply drinking water to local cities, so the serious development of any one of them could become an environmental concern.

MATERIALS AND METHODS

The senior author selected from his collection of about 50 Russian demantoids five small cut stones (0.24 to 0.35 ct.) that ranged from the deepest green to almost colorless (figure 10). In addition, for comparative spectral analysis he included one yellowish brown andradite from Coyote Front Range, Inyo, California; one medium green tsavorite from east Africa; and one colorless grossular from Wakefield, Canada.

Qualitative energy-dispersive X-ray fluorescence (EDXRF) analysis was performed on these samples at Brigham Young University, solely to determine the presence or absence of chromium in the five samples. The UV-visible spectra were obtained by the senior author with a Hewlett-Packard HP8452A diode array spectrophotometer, also at BYU, on one medium-green demantoid as well as on each of the tsavorite, andradite, and grossular samples described above. Details of analyses are available on request from the senior author.

DESCRIPTION OF THE DEMANTOIDS

Demantoid garnet is gem-quality green andradite ($Ca_3Fe_2[SiO_4]_3$), usually very near the ideal andradite composition, 97.02 wt.% to 99.67 wt.% andradite (Stockton and Manson, 1985), with minor chromium contributing the valued green color, and traces of aluminum, titanium, vanadium, and sometimes manganese. Demantoid ranges from yellowish or brownish green to "golden" green (figure 11), and—the rarest—"emerald" green (again, see figure 1). The gemological properties are consistent with those for other garnets (see table A-1 in Box A), with the exception of the unusually high R.I. (1.89) and dispersion (0.57). As noted earlier, for the most part demantoids are small, less than 1 ct. Although the authors have heard of at least one faceted stone over 21 ct (S. Fesenko, pers. comm., 1996), this is extraordinarily rare.

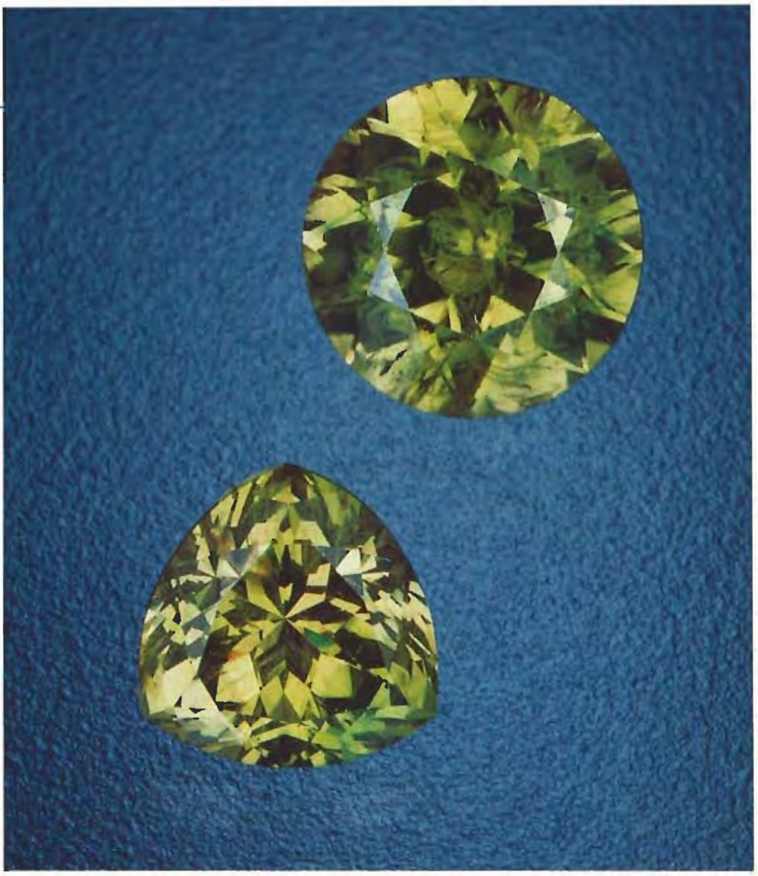


Figure 11. One of the most distinctive demantoid colors is this bright yellowish or "golden" green color. These two Russian demantoids, 1.36 ct (round brilliant) and 1.08 ct, are courtesy of Mayer & Watt, Maysville, Kentucky. Photo © GIA and Tino Hammid.

Cause of Color. Cr^{3+} substitution for Fe^{3+} in octahedral Y sites (again, see Box A) is responsible for the rich "grass" green of demantoid, which is superimposed over the yellow overtone contributed by the intrinsic ferric iron of andradite (figure 12). Cr-bearing demantoid shows red through the

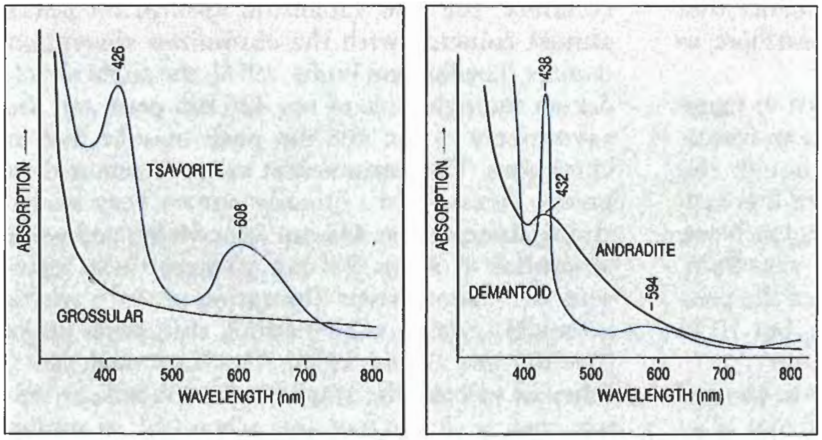


Figure 12. These UV-Visible spectra for a medium green tsavorite garnet from East Africa and a medium yellowish green demantoid garnet from the Central Urals clearly separate the two green garnets and also illustrate the greater influence of chromium in the demantoid. The spectra shown for samples of andradite and grossular that lack significant chromium and vanadium, illustrate the effects of these chromogens on these garnet types. The andradite is a brownish yellow sample from Coyote Front Range, Inyo, California, and the colorless grossular is from Wakefield, Canada.

BOX A: Demantoid's Place in the Garnet Group

The general formula for the garnet group is $X_3Y_2(SiO_4)_3$: where X = divalent ions with eightfold coordination, primarily Ca^{2+}, Mg^{2+}, Fe^{2+}, and Mn^{2+}; and Y = trivalent ions with sixfold coordination, primarily Al^{3+}, Fe^{3+}, V^{3+}, and Cr^{3+}. Nature combines X and Y elements to form real garnets depending on the availability of elements and the pressure and temperature of formation; it seldom, if ever, forms a pure, end-member garnet (i.e., one in which only one ion occupies the X site and one the Y site). Within the garnet group, the six most important end members, grouped by series, are: (1) uvarovite $[Ca_3Cr_2(SiO_4)_3]$, grossular $[Ca_3Al_2 (SiO_4)_3]$, and andradite $[Ca_3Fe^{3+}{}_2(SiO_4)_3]$ (the calcium series); and (2) pyrope $[Mg_3Al_2(SiO_4)_3]$, almandine $[Fe^{2+}{}_3Al_2(SiO_4)_3]$, and spessartine $[Mn_3Al_2(SiO_4)_3]$. Recently, a seventh garnet species in the Ca series, *goldmanite* $[Ca_3V_2(SiO_4)_3]$, has gained significance for gemologists, as it forms solid solution with grossular to produce tsavorite.

Demantoid is an andradite garnet. Complete solid solution is possible between grossular and andradite, and individual members of this series (notably, demantoid) may contain minor Cr_2O_3 in partial solid solution with uvarovite, their chromium analog.

The green gem varieties tsavorite and demantoid both lie near the ideal end-member compositions, respectively, of grossular and andradite (Stockton and Manson, 1985). However, intermediate (yellow, not Cr-containing) grossular-andradite gems recently have been noted (Hurwit et al., 1994; Johnson et al., 1995). Selected optical and physical properties of garnets in the Ca series are presented in table A-1. The individual species, and their relationship to demantoid, are discussed below.

Andradite forms a complete solid solution with grossular, and intermediate compositions are common (Stockton and Manson, 1983; Griffen, 1992); however, gem-quality specimens of both andradite and grossular occur, in nature, usually with compositions near their ideal end-members. Andradite is intrinsically colored as a consequence of ferric iron (Fe^{3+}) in sixfold coordination (Y site), which produces yellow (Loeffler and Burns, 1976). Yellow or yellow-green andradite gems (once referred to as "topazolite," a term now in disfavor) are attractive but rare (Gill, 1978; Webster, 1983). Demantoid results when Cr^{3+} from solid solution with uvarovite substitutes for Fe^{3+} in the Y sites and superimposes a green color over the intrinsic yellow.

Schorlomite $[Ca_3(Fe,Ti)_2(Si,Fe)_3O_{12}]$ is a black garnet colored by Ti^{4+} and Mn^{2+} in combination with intrinsic ferric iron (Phillips and Griffen, 1981) that occurs in solid solution with andradite to yield "melanite," a Ti-rich black andradite. These black garnets have little gem application except in mourning jewelry, which was popular with the late Victorians, as an alternative to jet or black onyx.

Uvarovite is a beautiful green garnet in small sizes, with larger specimens so dark as to appear almost

Chelsea filter in proportion to the amount of chromium present. It typically shows no color zoning; however, the color is patchy (i.e., not homogeneous), and the senior author has observed intense green surrounding tiny chromite grains that appear to act as nucleation points for the demantoid crystals (figure 13). This is also graphic evidence that dissolution of chromite frees Cr to contribute to the green color of the demantoid.

EDXRF analysis of the stones shown in figure 10 confirmed that the intense color was an indication of high chromium content, although the stones of the medium color range showed less variability in chromium than in apparent color. None of these five stones showed measurable vanadium. The single East African tsavorite revealed the presence of both chromium and vanadium, but 10 to 100 times more of the latter than the former.

Both the demantoid and the tsavorite showed two major absorption peaks (again, see figure 12)—one in the blue and violet wavelengths, with lesser absorption in the orange and yellow range—and transmit green and red wavelengths. Also evident in figure 12, the tsavorite showed strong absorption peaks at 426 and 608 nm, which are attributed largely to V^{3+} modified by lesser Cr^{3+}. Unfortunately, the two vanadium absorption peaks almost coincide with the chromium absorption doublet (Loeffler and Burns, 1976); the slight shoulder on the right side of the 426 nm peak and the asymmetry of the 608 nm peak may be due to chromium. The transmission valley is centered on green. Demantoid typically shows very sharp, strong absorption at 438 nm (blue-violet) and weak absorption at about 594 nm (orange); these represent the characteristic absorption of Cr^{3+}, which normally consists of two strong absorption peaks (Loeffler and Burns, 1976). The ferric iron (Fe^{3+}) inherent to andradite amplifies the 438 nm chromium peak in demantoid and, when Cr^{3+} is minor,

Table A-1. Selected properties of garnets in the ugrandite (uvarovite-grossular-andradite) series.

Garnet species/ gem variety	R.I.	S.G.	Hardness	Dispersion
Andradite[a,b,c]	1.880–1.886	3.77–3.88	6½	0.057
Demantoid[a]	1.880–1.889	3.80–3.88	6½	0.057
Uvarovite[a,b]	1.798–1.868	3.71–3.81	7½	
Grossular[a,b]	1.731–1.760	3.40–3.78	7	0.028
Tsavorite[a]	1.739–1.744	3.57–3.65	7	0.028
Goldmanite[d]	1.821	3.75		
Intermediate (Mali)[e]	1.752–1.782	3.63–3.70		

[a] *From Rouse (1986).*
[b] *Calculated value from McConnell (1964).*
[c] *From Stockton and Manson (1985).*
[d] *From Moench and Meyrowitz (1964).*
[e] *From Johnson et al. (1995).*

black. It occurs mostly as drusy layers of tiny dodecahedral crystals in fractures in chromite. It is sometimes used for jewelry, showing tiny, bright green scintillation points. Uvarovite is typically associated directly with chromite spinel ($FeCr_2O_4$).

Grossular is colorless when pure; the addition of transition-element impurities (Fe^{3+}, Mn^{3+}, Cr^{3+}, V^{3+}) produces a wide variety of colors. For example, the hessonite variety (colored by Fe^{3+}) ranges from brownish yellow to orange-red, and manganese varieties are pink.

Tsavorite (also "tsavolite") is gem-quality transparent green grossular in partial solid solution with goldmanite, which contributes vanadium as the primary source of color. It is a recent addition to the garnet family, having been discovered in the 1960s in Kenya and introduced to the gem community in 1974 (Bridges, 1974). As much as 3 wt.% V_2O_3 has been recorded in some stones (Muije et al., 1971). Some specimens are colored solely by vanadium, but others contain a subordinate contribution from chromium and may even appear red through the Chelsea filter. Tsavorite ranges from intense "emerald" green (the most valuable) through yellow-green to almost colorless. Good-color gem tsavorites over 3 ct are very rare (Rouse, 1986, p. 100).

Goldmanite is a dark green to brownish green garnet that is much rarer (and much less attractive) than any of the other Ca garnets. It was first described in 1964 (Moench and Meyrowitz) from specimens found in Laguna, New Mexico, where it derives from the contact metamorphism of a uranium-vanadium ore deposit in a sandstone-limestone host rock.

demantoid transmits essentially all colors except violet. This yields strong yellow (red and green add to form yellow) with lesser blue, so the stone is green with a strong yellow overtone. As the Cr^{3+} content increases, the absorption peak at 594 nm becomes both higher and broader, absorbing orange and most of the yellow and red wavelengths. A similarly enlarged peak at 438 nm may absorb more short wavelengths, so that only green wavelengths are transmitted. Thus, Cr-rich demantoid may be "emerald" green without any modifying hue. A third high-energy Cr^{3+} absorption in the ultraviolet may be responsible for the red fluorescence of most Cr-colored gems.

Internal Features. The most distinctive internal feature of demantoid is its characteristic "horsetail" inclusion (again, see figure 13) which was present, whole or in part, in most of the Russian demantoids examined by the authors and which is found in no other green gem. In the gemological literature, the "horsetail" generally is referred to as hair-like byssolite (an obsolete name for asbestiform amphibole, usually of actinolite-tremolite composition) fibers that diverge from a focal point, usually a tiny opaque crystal of a spinel-group mineral, probably chromite or magnesiochromite. Recently, however, the horsetail fibers emanating from the chromite grains have been identified as serpentine (chrysotile) by Dr. A Peretti (pers. comm., 1996). Sometimes the fibers form a dense, eye-visible bundle (figure 14) or cone stained orange or brown by ferric oxide. Each demantoid crystal appears to nucleate on the tiny chromite crystal that also serves as a nucleation point for the serpentine "horsetail," so the demantoid and serpentine fibers must grow simultaneously. As the crystals are small, seldom large enough to cut more than one gem, each cut gem is likely to contain one horsetail, or the part thereof not removed by cut-

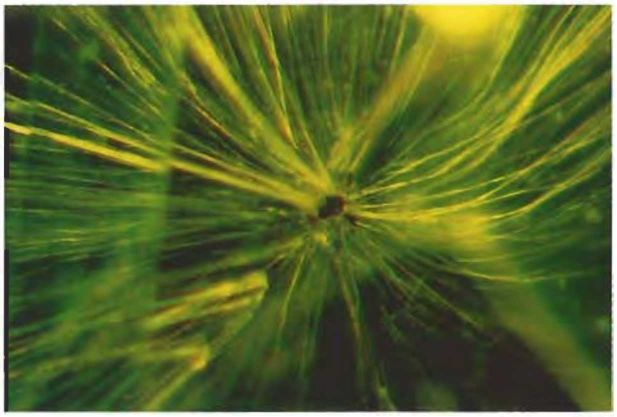


Figure 13. The most distinctive internal feature of demantoids is the "horsetail" of fibrous serpentine (chrysotile) that is present, in whole or in part, in most pebbles or cut gems. Note the tiny crystal (probably chromite) from which all the fibers radiate. Photomicrograph by John I. Koivula; magnified 20×.

ting. In the authors' experience, cut specimens lacking all traces of a horsetail are exceedingly scarce. Rarely, the fibers are uniform and parallel, and the gem may be cut to show chatoyancy ("Cat's-eye demantoid," 1960). Some of the demantoids that have emerged most recently on the international gem market contain randomly oriented acicular inclusions that do not appear to be related to a "horsetail" (figure 15).

MARKETING AND DISTRIBUTION

Because of its extreme rarity, the small size of the crystals, and its relatively low hardness, demantoid has not enjoyed widespread recognition outside Russia. It was popular in the Western world for a brief period during the Edwardian age at the turn of the century, but it slipped back into relative obscurity after World War I, when little emerged from the young Soviet Union. Many of the demantoids seen in the market today are set in estate jewelry from the Edwardian period. Typically, demantoids appeared in Edwardian jewelry as a field of green melee or as an encircling band of melee or calibrated stones highlighting a much larger central stone. They also appeared in whimsical jewelry of the era, as bright green frogs, lizards, snakes, dragonflies (again, see figure 5), and the like (Misiorowski and Hays, 1993, p. 164).

Much of the modern production represents the secret caches of villagers and the work of "bandit diggers." Each team of "thieves" has its own lapidaries, who cut all the rough in some corner of a small apartment in Ekaterinburg. Many stones are poorly cut, although some fine ones are produced. Unfortunately, many are slightly scratched or chipped in handling. Essentially no rough demantoid appeared in the Russian "gem fairs" in 1995, and very little rough reaches the outside market. Although many cut stones (about 15%–20%) are sold in Russia, where there is historic appreciation, the bulk of present production goes "unofficially" abroad, most of it to Germany with lesser amounts finding their way to Israel, the United States, the United Arab Emirates, Spain, Italy, and Canada. The authors' experience is that German dealers, like most Russians, tend to prefer the pale "golden green" stones that best display demantoid's inher-

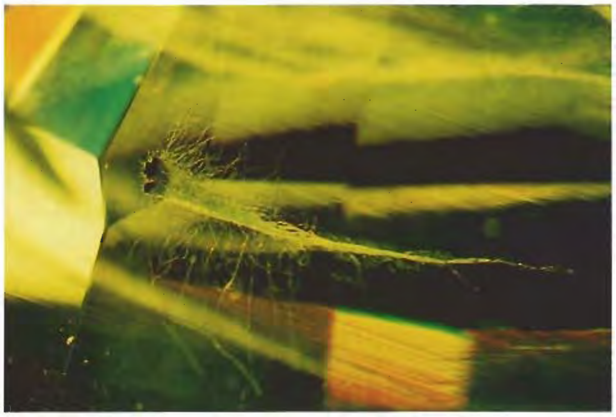
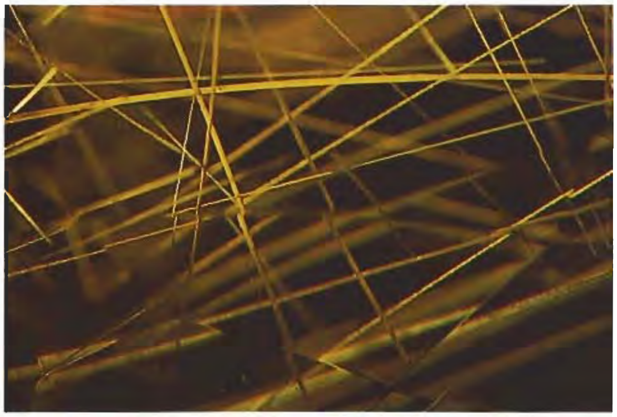


Figure 14. In some demantoids, like this recently mined stone, the "horsetail" takes the form of a cone-like bundle of fibers. Photomicrograph by Shane F. McClure; magnified 20×.

Figure 15. In some of the newer demantoids to emerge from Russia (see, for example, figure 1), large quantities of randomly oriented acicular inclusions are found throughout the cut stones, with no evidence of a nucleating crystal. Photomicrograph by Shane F. McClure; magnified 20×.



ent brilliance and fire. American dealers usually seek out the much rarer "emerald"-green stones, in which the darkness of the color largely masks the fire (again, see figure 1). The best prices are found in Ekaterinburg at the Urals Exhibition of Colored Stones, held each year in the fall.

CONCLUSION

Demantoid is a beautiful green to yellow-green gem variety of andradite garnet, colored by minor chromium and intrinsic iron. It has great brilliance and "fire" (dispersion), but it is slightly lower in hardness than tsavorite.

Historically, demantoid has been found almost exclusively in Russia's Central Urals. Discovered in the mid-19th century, this bright green gem soon became popular among the nobility of Czarist Russia and even enjoyed brief exposure in Western Europe at the turn of the century. With the onset of the Bolshevik Revolution in 1917, however, exportation of this rare gem came to a halt, and little new material emerged until the economic restructuring (*perestroika*) of the late 1980s.

Two important demantoid districts are known in the Central Urals, one about 115 km north-northwest and one about 75 km south-southwest of Ekaterinburg; each of these districts has two or more alluvial or *in situ* deposits. All of the localities appear to have significant reserves, as to date there has been no systematic or sustained mining of this gem material. Although two deposits are presently leased to Russian companies by the Russian government, neither provides a significant, continuous, or dependable supply of demantoid rough. Neither company has the finances to develop the properties they hold, and thus they are eagerly seeking foreign investment. The Kamenuschka deposit is of special interest, as it yields stones of the most desirable color and presently is not licensed. Unauthorized recovery from river gravels by illegal miners provides most of the present production; unfortunately, there are no reliable statistics for demantoid production—historic or recent—from this area.

In the next few years, the Russian government is likely to assume control of the production, cutting, and distribution of demantoid, as it has recently done with emerald and alexandrite. Demantoid may also be declared a gem of the "first group," which would put it in the company of diamond, emerald, ruby, sapphire, and alexandrite and thus result in more stringent purchase and export regulations.

Political and economic stability in Russia may bring about the development of these world-class deposits. Until then, demantoid will remain a rare and costly gemstone, sought primarily by wealthy collectors and those with a taste for the exotic.

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OPAL FROM SHEWA PROVINCE, ETHIOPIA

By Mary L. Johnson, Robert C. Kammerling, Dino G. DeGhionno, and John I. Koivula

Opal occurs as nodules in volcanic rocks at a new gem opal locality in the Menz Gishe district of Shewa Province, Ethiopia. The opal field, still in the early stages of exploration, extends over several square kilometers. Opals from Shewa Province have near-colorless to white, yellow, orange, gray, or brown body colors; some show face-up play-of-color, and many have contra luz play-of-color. The gemological properties are consistent with those of other natural opals, and small particles are common inclusions. Preliminary stability tests indicate that much of the material absorbs water, and some crazes when exposed to light and heat.

Gem-quality opals, for the most part, come from two types of deposits: volcanic and sedimentary (Frondel, 1962). Although the most significant deposits of gem opal—those in Australia—are sedimentary in nature (see, for instance, Wise, 1993), other important opal deposits are related to siliceous volcanic rocks. These volcanic occurrences include, among others, Querétaro, Mexico (see, e.g., Koivula et al., 1983; Gübelin, 1986; and Spencer et al., 1992), and Opal Butte, Oregon (Smith, 1988), with the latter's related deposits in Idaho (Broughton, 1972) and British Columbia (Downing, 1993).

Recently, opals were discovered at Yita Ridge in the Menz Gishe district of Shewa Province, Ethiopia. The opal-bearing rock is a nodular rhyolite (similar to that at Opal Butte). Material examined from the Ethiopian deposit included stones resembling "contra luz" (that is, play-of-color only visible with transmitted light) and "crystal" opal, as well as a fire agate–like opal that shows play-of-color on a dark brown body color (figure 1). As the deposit is still in the preliminary evaluation stage (T. Yohannes, pers. comm., 1996), its full production potential is unknown. However, early sampling results indicate that the opal-bearing rocks extend over several square kilometers.

BACKGROUND

To the best of our knowledge, the first report on gem opals from Ethiopia appeared in the February 1994 *ICA Gazette* (Barot, 1994). According to that report, Ethiopian opals were first seen in the Nairobi gem market in mid-1993. Some of these opals (obtained in Nairobi as being of Ethiopian origin, but with the precise locality unconfirmed) were subsequently examined and reported in the Spring 1994 Gem News section (Koivula et al.,

ABOUT THE AUTHORS

Dr. Johnson is a research scientist, the late Mr. Kammerling was vice president for research and development, Mr. DeGhionno is senior staff gemologist, and Mr. Koivula is chief research gemologist at the GIA Gem Trade Laboratory, Santa Monica, California.

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1994a). The Summer 1995 Gem News section contained a short entry specifically describing opals from the Yita Ridge area of Shewa Province (Kammerling et al., 1995).

LOCATION AND ACCESS

Yita Ridge, in the Menz Gishe District of Shewa Province, is about 240 km (150 miles) northeast of Ethiopia's capital, Addis Ababa (Kammerling et al., 1995; figure 2). The opal field lies approximately 15–20 km north of Mezezo, about 8 km off the road between Mezezo and Hirute, which branches off the main road between Addis Ababa and Dese. The road between Yita Ridge and the Mezezo-Hirute road has been washed out for about 10 years, however, so the opal area is currently accessible only by mule trail or helicopter (T. Yohannes, pers. comm., December 1995).

The opal-bearing rocks outcrop along the north flank of Yita Ridge, at about 2,450 m elevation. The surrounding area is predominantly agricultural (figure 3).

GEOLOGY AND OCCURRENCE

The opal-bearing area lies in a large volcanic field just west of the northern Great Rift Valley of Ethiopia (the valley of the Awash River, in this area), according to Mr. Telahun Yohannes, of the Ethio-American Resource Development Corporation, a joint Ethiopia-U.S. firm that is mining the area. The opal nodules (figure 4) occur in a continuous layer of welded tuff (approaching obsidian in character), about 3 m thick, that lies between more weathered (decomposing) rhyolite layers. The beds have been uplifted and tilted slightly since deposition, but they are still more-or-less horizontal. The entire sequence of volcanic rocks, about 300–400 m thick, is probably part of the Amba Alaji rhyolites, which are Miocene in age (8 to 27 million years old; Merla et al., 1979). The opal nodules average about 10 cm (4 inches) in diameter.

PROSPECTING AND MINING

Only a small amount of material (about 200 kg) has been produced so far, all from surface and near-surface occurrences. Although the opal-bearing layer is primarily horizontal, the steep, gulch-like nature of the topography means that this layer outcrops in many places. The decision to begin commercial production is pending completion of surveys of the area to determine the economic feasibility of the deposit. It is expected that these surveys—tracking the opal-bearing outcrops, and assessing the quality and quantity of opal present—will be completed before the end of 1996. The few (less than 20) miners now working in the area use hand tools only, as the opal is too fragile for blasting (figure 5). In the future, however, road-grading equipment may be used to remove the decomposed rhyolite above the opal-bearing layer.

As of December 1995, on the basis of these outcrops of opal-containing rock, the gem field had been estimated visually to extend over an area of at least 7 × 7 km. It has also been estimated, from opal nodules randomly gathered from 12 area sites, that about 15% of the opal recovered is gem quality. About 1% of this gem opal shows distinct play-of-color.

Figure 1. Gem-quality opal was recently discovered in Shewa Province, Ethiopia. These four opals demonstrate the range in body color and play-of-color in stones from that locality. Clockwise from top, 7.52 ct cabochon, 2.15 ct round brilliant, 4.04 ct cabochon, and 2.31 ct triangle modified brilliant. Photo © GIA and Tino Hammid.

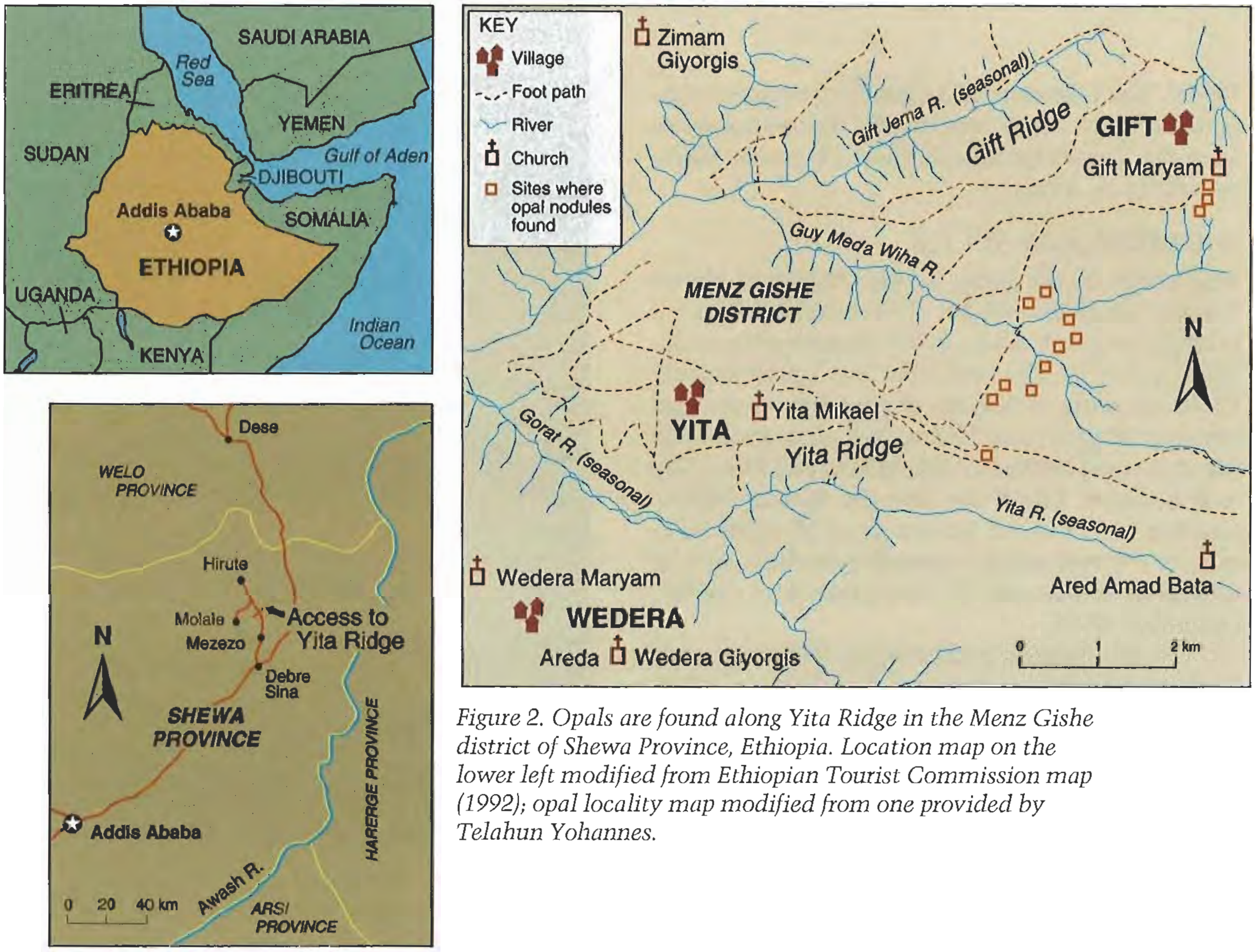


Figure 2. Opals are found along Yita Ridge in the Menz Gishe district of Shewa Province, Ethiopia. Location map on the lower left modified from Ethiopian Tourist Commission map (1992); opal locality map modified from one provided by Telahun Yohannes.

MATERIALS AND METHODS

We examined 19 fashioned stones—six faceted (0.55–4.80 ct) and 13 cabochons (0.83–19.71 ct)—and over 250 grams of rough, including sections of several different nodules. We viewed the face up colors using both fluorescent and incandescent illumination. We observed play-of-color with the stone against a dark background and spot illumination placed above and then perpendicular to the viewing direction (the latter to observe any contra luz effect). Refractive indices were measured with a Duplex II refractometer and a near-monochromatic, Na-equivalent light source. Specific gravity was determined by hydrostatic weighing; in those several cases where the stone absorbed water, we reported only the first result, which should be regarded as a minimum S.G. for that stone. Ultraviolet fluorescence was observed in a darkened room using a controlled viewing environment and a short-wave/long-wave UV lamp. Polarization behavior was noted using a GIA GEM Illuminator polariscope, and absorption spectra (for the body color of the stones) were observed using a Beck prism-type spectroscope. The Chelsea color filter reaction was determined with illumination from a spectroscope base. Internal features were observed with a standard gemological microscope and brightfield, darkfield, and oblique fiber-optic illumination, as well as polarizing filters.

Trace-element chemistry was determined qualitatively by energy-dispersive X-ray fluorescence (EDXRF) spectrometry, using a Tracor X-ray Spectrace 5000 unit with a rhodium-target X-ray tube. Mid-infrared FTIR absorption spectra were taken with a Nicolet Magna-IR Model 550 spectrometer, with data collected in the range between 6000 and 4000 cm^{-1}. We employed X-ray powder diffraction analysis to identify some included materials, using a Debye-Scherrer camera mounted on a Siemens Kristalloflex X-ray generator.

Eight partially polished pieces were tested for durability. We exposed four samples to light and heat by placing them on a black surface, 8 cm from a 100-watt, high-intensity incandescent light, for

Figure 3. The area in which the opal nodules are found is very rural, consisting primarily of numerous small farms and villages. Photo courtesy of Telahun Yohannes.

24-hour periods up to a total of 192 hours (the temperature of the black surface reached 155°F—about 68°C) to simulate shop-window conditions. Another four pieces were immersed in water for a few hours and dried in air to a constant weight (about 24 hours), for two cycles, to test the effects of drastic humidity changes.

APPEARANCE AND GEMOLOGICAL PROPERTIES

Color. The fashioned stones were near-colorless, milky white, and yellow through orange to brown (again, see figure 1); one cabochon was pinkish brown. The two darkest stones had brown and black body colors; however, the darkest stone was a doublet that had been backed with black obsidian, which affected the apparent body color. Most of the material was suitable for jewelry (figure 6).

Play-of-Color. Two dark brown opals showed good play-of-color face-up, and the lighter stones had good (one example), moderate (four examples), weak (one example), or no play-of color when viewed face-up. Nine stones showed contra luz play-of-color. (The play-of-color is designated "contra luz" if it is seen with transmitted light—as described by Koivula and Kammerling [1988] and Smith [1988] for the Opal Butte material. For our nine contra luz samples, we saw play-of-color when we viewed the stones face up while they were illuminated from the side or rear; figure 7.) The black opal doublet had good play-of-color face up.

Diaphaneity. The fashioned samples were transparent to opaque. The darker they were, the less transparent they became.

Refractive Index. Refractive indices ranged between 1.40 and 1.45. In six cases, a second R.I. could be seen, usually at 1.45; this effect resembled the anomalous R.I. seen in some tourmaline (illustrated in Koivula et al., 1994b).

Figure 4. Opal nodules (the split one on the dark rock is about 10 cm in diameter) are abundant in the rhyolitic welded tuff, a rock that approaches obsidian in character. Photo courtesy of Telahun Yohannes.

Figure 5. Workers remove opal nodules from a sample pit in this outcrop of the opal-bearing welded tuff zone. Photo courtesy of Telahun Yohannes.

Polariscope Reaction. Twelve pale-colored stones showed weak-to-moderate anomalous double refraction (ADR) when viewed between crossed polarizing filters. Two darker stones showed no ADR.

Optical Absorption Spectrum. No spectrum was seen in the 14 lightest-color stones with the hand spectroscope. Three stones showed lower cutoff edges at 510 (yellow stone), 530 (yellowish orange), and 600 nm (brown). One mottled brown stone showed a band between 550 and 590 nm, a lower cutoff at 520 nm, and an upper cutoff at 670 nm.

Color filter. Two brown stones appeared red when viewed through the Chelsea color filter.

Fluorescence to UV Radiation. We observed the following reactions to long-wave UV radiation: faint-to-weak, even yellow-green (with weak phosphorescence); slightly chalky faint blue (moderate whitish blue); inert; faint uneven blue and yellow; and faint even orange. When the stones were exposed to short-wave UV, we saw: faint-to-strong, even yellow-green (with no phosphorescence); slightly chalky faint (even) to weak (uneven) yellow-green; slightly chalky faint-to-weak blue; inert; faint even blue-white; faint uneven blue and yellow; and faint even orange. The doublet was inert to long-wave UV radiation, but it fluoresced a weak even yellowish green to short-wave UV.

Specific Gravity. The hydrostatic measurements ranged between 1.35 and 2.03; samples that did not soak up water were in the 1.87–2.03 range. Most of the near-colorless opals had specific gravities of 2.0 or higher. Seven stones changed their weights noticeably by soaking up water during the S.G. measurements: two near-colorless opals, two milky white opals, and one each orangy brown, light pinkish brown, and mottled yellow.

Microscopy/Inclusions. Solid inclusions were relatively common in the fashioned Ethiopian opals.

Figure 6. As these three pendants indicate, the Ethiopian opals (2.31–7.52 ct) make attractive jewelry stones. Jewelry courtesy of the Gold Rush, Northridge, California; photo by Shane F. McClure.

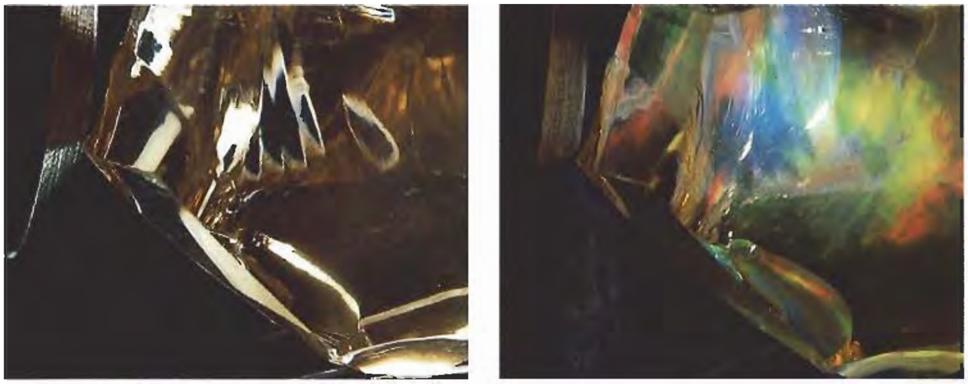


Figure 7. This piece of rough Ethiopian opal illustrates the contra luz effect: With darkfield illumination (left) no play-of-color is seen; with fiber-optic illumination from the side (right), strong play-of-color is visible. Photomicrograph by John I. Koivula; magnified 4×.

Most of the transparent-to-translucent gems contained tiny crystals of unknown composition. Perhaps the most distinct inclusions (because of their color) were randomly scattered red-brown grains (figure 8).

Intermixed with the red-brown grains were numerous small, opaque, black grains (figure 9). Some of these appeared a dark, brassy yellow when they were examined from above with a strong pinpoint fiber-optic light. Although most of the mineral grains were extremely small, a few of the largest were surrounded by small tension cracks (figure 10), which were probably caused by a difference in volumetric expansion between the inclusions and the enclosing opal.

Many of the red-brown and black inclusions appeared to have a square cross section or outline, indicating that they might be isometric. Even the largest of these inclusions was too small for X-ray diffraction analysis, however, so their identity is still unknown. Although there is no direct proof, we speculate that the black grains might be pyrite (on the basis of their brassy metallic luster and square outline). Similarly, the red-brown grains might be pyrite altered to hematite.

Also present, although much less common, were tiny white to near-colorless grains that revealed no distinct form (visible in figures 8, 9, and 10; see also figure 11). Like the black and red-brown inclusions, these particles were too small to be identified by the methods available to us.

The most distinctive inclusion type—and the rarest—was observed in only one stone. These inclusions had the appearance of elongated, rough-sided "voids" or "tube systems" (figure 11). All reached the surface of their host and were partially packed with what apparently was a light brown-to-white, semi-translucent epigenetic matter. At the interface with the surrounding opal, the surfaces of these "tubes" were randomly spotted with tiny red-brown and black grains, similar to those previously described. In comparable inclusions seen in opals from Mexico (Koivula et al., 1983), the voids once contained hornblende crystals that had dissolved away and been replaced by, or partially filled with,

Figure 8. Tiny red-brown grains were visible with magnification in most of the Ethiopian opals. In some stones, small near-colorless crystals were also seen. Photomicrograph by John I. Koivula; magnified 50×.

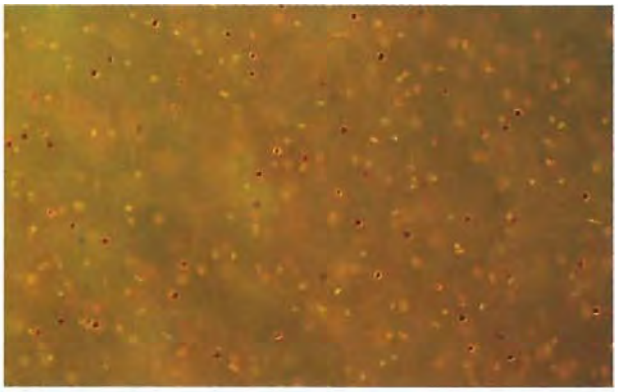
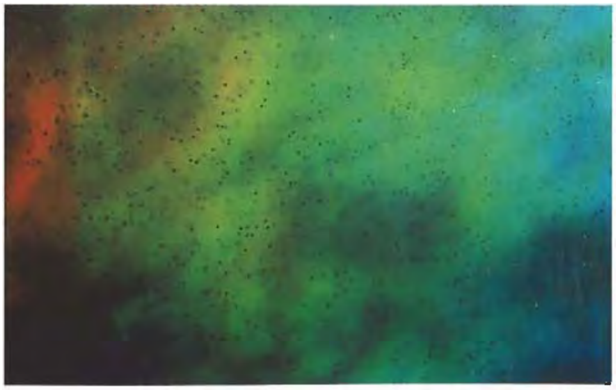


Figure 9. These small opaque grains (in a 4.77 ct Ethiopian opal) may be pyrite crystals. Photomicrograph by John I. Koivula; magnified 20×.



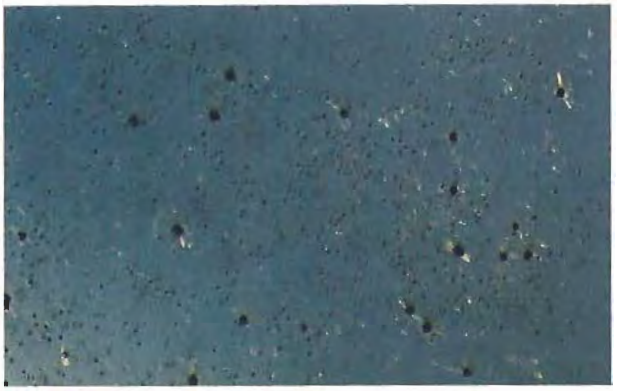


Figure 10. Some of the largest black mineral grains were surrounded by tension cracks. Photomicrograph by John I. Koivula; magnified 40×.

Figure 11. Rough-sided epigenetically filled "tubes," similar to those seen in some opals from Querétaro, Mexico, were observed in this 3.57 ct Ethiopian opal cabochon. Photomicrograph by John I. Koivula; magnified 15×.

limonite and a white kaolinitic clay. Because we could not perform destructive tests on the sample loaned to us for this study, however, we could not determine the identity of the filling material in this Ethiopian opal.

When opal nodules are freed from the rhyolite matrix, a black crust is sometimes visible on both the surfaces of the rough opals and on the rhyolite itself (figure 12); it may also be present in the cracks in some gem opals. An X-ray powder diffraction pattern, obtained from a scraping taken from one of these black crusts, matched that of the black manganese oxide ramsdellite.

Only the two opaque dark brown oval cabochons showed any obvious flow structure. This resulted from varying degrees of iron pigmentation, and it was manifested in the form of light brown veins and fingers extending into and through a much darker brown opal groundmass (figure 13). In one of these stones, a cell-like structure had formed where the light brown areas surrounded the darker areas. This was particularly obvious in oblique reflected light, in which the dark brown "cells" showed strong play-of-color (figure 14).

SPECTRAL AND CHEMICAL ANALYSES

Infrared Spectrum. All the stones showed a typical opal spectrum in the range between 6000 and 4000 cm^{-1} (see Fritsch and Stockton, 1987, for comparison).

Chemistry. Qualitative EDXRF analyses were performed on all 19 fashioned stones and on two pieces of matrix-free rough. For each stone, the only major element seen was silicon. Every stone also contained detectable trace amounts of calcium, iron, strontium, and zirconium; most stones contained trace amounts of potassium (20 stones), rubidium (17 stones), or niobium (15 stones); and some stones also contained trace amounts of copper (10 stones), yttrium (8 stones), zinc (7 stones), lead (6 stones), titanium (5 stones), manganese (3 stones), chromium (2 stones), barium (2 stones), or gallium (1 stone).

STABILITY AND DURABILITY TESTING

Very little has been published about testing opals for durability. Pearson (1985) tested opals for crazing by refluxing them in flammable organic liquids; however, we did not try to duplicate this test because the materials involved are hazardous. A

Figure 12. Black flakes of ramsdellite were sometimes visible at the interface between the opal and its matrix and may occur in the cracks in some rough and fashioned Ethiopian opal. Photomicrograph by John I. Koivula; magnified 5×.

Figure 13. Flow structure is clearly visible in this 2.36 ct Ethiopian opal. Photomicrograph by John I. Koivula; magnified 25×.

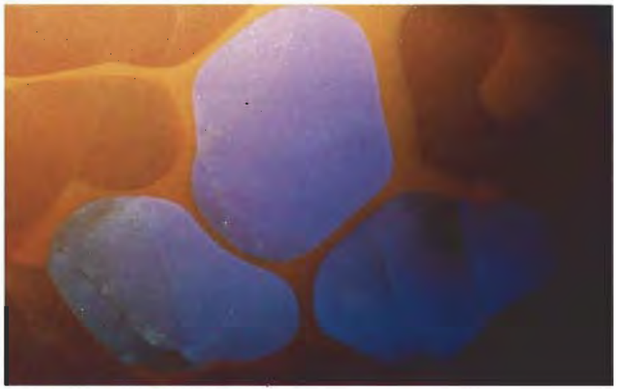


Figure 14. Play-of-color in this 4.04 ct dark brown Ethiopian opal is confined to distinct "cells," separated by lighter-colored brown opal, as seen here in oblique reflected light. Photomicrograph by John I. Koivula; magnified 15×.

practical "field test" for opal stability consists of exposing the material in a sunlit location for a few months, then recovering the undamaged remnants, according to Smith (1988), who also recommended a slow-drying technique to stabilize Oregon opal. He estimated that about 20% of the "fire opal" from Opal Butte, Oregon, was stable.

The lack of consensus in the literature led us to develop a few simple tests based on the assumption that gradual or sudden dehydration/rehydration was the process most likely to affect opals. Although we could not subject the fashioned stones we had borrowed to destructive testing, Mr. Yohannes kindly allowed us to do durability testing on some of the rough material. We had a flat surface polished on each of eight pieces of rough—two each of semi-transparent yellow contra luz, semi-transparent gray, semi-translucent yellow, and semi-translucent gray opal. We then divided the stones into two groups for testing, one for gradual dehydration and the other for sudden changes in water-vapor pressure. Because of the limited amount of material tested, we regard our results as informative but not definitive.

Gradual dehydration was simulated under "shop window" conditions: a bright light source and a black background (see "Materials and Methods"). Under these conditions, the contra luz and the semi-translucent gray opals did not change. The two other stones had developed cracks when first examined after 24 hours (figure 15); these cracks increased in size with subsequent exposure, but no new ones formed. It is interesting to note that during the first 24-hour test period, the semi-transparent gray stone developed a transparent outer layer (figure 16) that did not extend further into the stone on subsequent exposure, although cracks formed during the same period did grow. No additional changes were noted in any stone after 96 hours' exposure, which suggests that an exposure test such as this one may be sufficient to separate durable from easily crazed Ethiopian opals.

Sudden changes in water-vapor pressure were accomplished by repeated hydrostatic specific-gravity determinations. Between each test, we allowed the stones to dry completely (until the weight did not change). The contra luz and semi-transparent gray opals showed weight fluctuations of about 0.5–0.6 wt.% between wet and dry conditions, with significant cracking after the second humidity-change test. The two semi-translucent opals (yellow

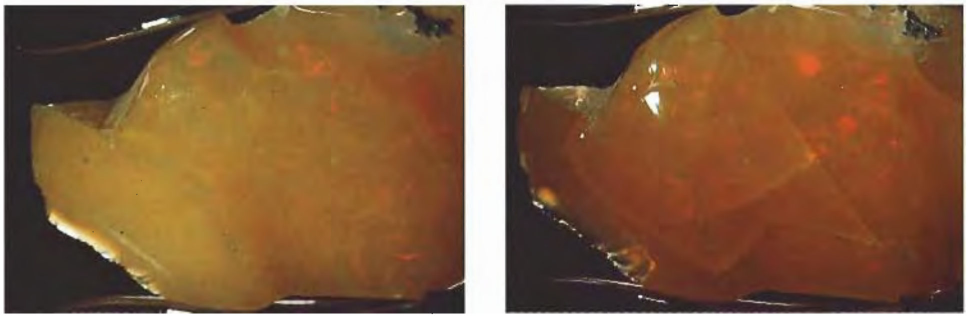


Figure 15. This 7.74 ct piece of rough yellow Ethiopian opal (left) cracked during 24 hours' exposure to light and heat (right). Photos by John I. Koivula.

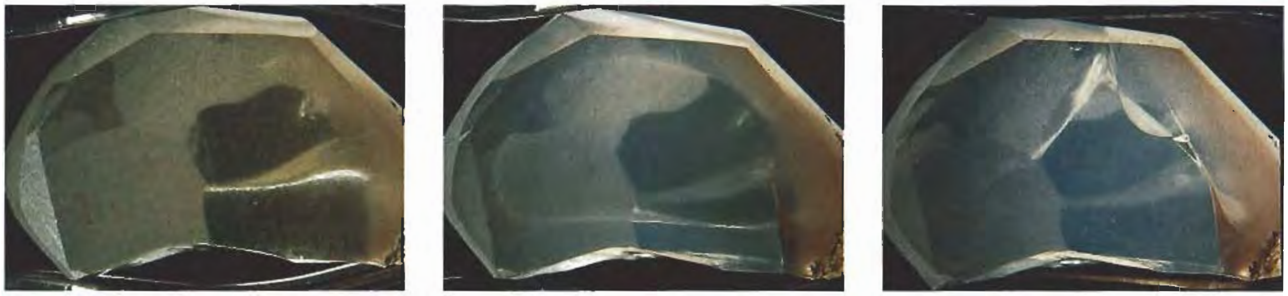


Figure 16. A 9.59 ct piece of semi-transparent gray Ethiopian opal (left, before testing) showed "clarification" of the less transparent areas and a few incipient cracks after 24 hours' exposure to "shop window" conditions (center); by 48 hours (right), the cracks had extended through the stone. Photos by John I. Koivula.

and gray) developed less-pronounced cracking after two cycles, despite far greater weight fluctuations of about 11 and 18 wt.%, respectively. The weight gains (with soaking) and losses (as the stones dried) did not vary much with repeated soaking and drying, indicating no permanent gain or loss of water. Note, however, that we consider this test inherently destructive and do not recommend any "real world" equivalent—such as wearing an opal ring while washing dishes—for any opal.

In addition, the fashioned stones were exposed to variable temperature and humidity in open plastic bags for six months in our laboratory. During this time, external (relative) humidity fluctuated between about 10% and 70%. One stone—the black opal doublet—crazed, but none of the other stones was affected.

CONCLUSION

A new source for precious opal is being evaluated at Yita Ridge, in the Menz Gishe district of Shewa Province, Ethiopia. The nodules occur in a broad range of body colors and play-of-color, including excellent contra luz material. Tiny red and black particles are pervasive throughout even the most transparent opals; among the other inclusions noted were hollow tubes and black platy manganese oxides. As with opals from other regions (including the similar volcanic environments of Querétaro, Mexico, and Opal Butte, Oregon), durability is a potential cause for concern. Only time will tell if full-scale mining at Yita Ridge will prove to be economically feasible. However, current indications are that some material will continue to reach the world market even if only small-scale mining continues.

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GIA GEM TRADE LAB NOTES

DIAMOND
Some Unusual Cuts

Most modern diamond cuts are symmetrical in shape and in facet arrangement, with proportions chosen to take maximum advantage of diamond's optical properties. By contrast, diamonds cut before the turn of the century were more likely to be characterized by "lumpy" shapes and an irregular placement of facets. Although modern-cut diamonds are generally more pleasing to the eye than the older styles, these earlier styles—such as the Mogul, table, rose, old mine, and old European cuts—often have considerable historic and aesthetic appeal.

A few months ago, the East Coast lab had the opportunity to examine some of these older cuts. One client submitted two Mogul-cut stones (figure 1). The Mogul cut is characterized by a broad, often asymmetrical base; a crown with either a table or four shallow facets in place of a table; and two or more rows of facets between the table and the girdle. (The 115.60 ct Taj-i-Mah [Crown of the Moon] diamond in the Iranian crown jewels is a famous example of a Mogul cut.) The client mentioned that these Mogul-cut diamonds might be several centuries old and may have come from the Golconda region of India, which gained broad fame as a source of spectacular diamonds after French gem merchant Jean-Baptiste Tavernier chronicled his 17th-century travels there.

Figure 1. These Mogul-cut diamonds (9.27 ct, left, and 9.54 ct) may be from India's Golconda region, possibly fashioned several centuries ago.

A third example was a drilled diamond (figure 2) that our client said was old and came from India. It was cut and polished to follow and retain the external crystal shape, in contrast to modern cutting techniques which typically leave no evidence of the original external morphology. The hole, which ran along the longest dimension, had been drilled at an angle from each end to meet in the middle of one side of the stone. In the early days of diamond cutting, drilling holes in diamond was very time consuming. The worker could either use a diamond "sharp"—a small, sharp-edged crystal fragment—or continually load diamond dust onto the steel point of a bow drill. We suspect that the latter method was used for this stone because the hole was so deep. In outline, this stone resembles the Shah Jahan Table Cut diamond, which also was pierced. However, those holes were much shallower, and they probably were drilled with a "sharp," perpendicular to the longest dimension (see, e.g., E. A. Jobbins et al., "A Brief Description of a Spectacular 56.71 carat tabular diamond," *Journal of Gemmology,* Vol. 19, No. 1, 1984, pp. 1–7).

Figure 2. This diamond, which measures 11.65 × 9.75 × 5.60 mm and weighs about 6.5 ct, was cut along the original crystal shape and drilled at an angle from each end for mounting.

Figure 3 shows a 12-sided tablet cut, a variety of the table cut. This stone (16.24 × 15.73 × 3.63 mm thick) was probably cut recently, as indicated by its symmetrical facet arrangement and the lack of abrasions. The tablet cut resembles a rondelle (a thin, flat round bead) that has not been drilled. Historically, such tablet cuts, if used to cover watch faces or miniature portraits set in rings, were called portrait diamonds.

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

Gems & Gemology, *Vol. 32, No. 2, pp. 122–127*

Figure 3. Despite the antique cutting style of this 10.74 ct tablet-cut diamond, the facet symmetry and good polish indicate that it was probably fashioned within the last several years.

The last example was a thin, irregular but roughly oval-shaped tablet-cut diamond on which an inscription had been engraved (figure 4). The stone was probably cut from a cleavage piece. Our client informed us that this was an old cut, and we determined that the inscription was in Arabic. Because of diamond's extreme hardness, pre-modern examples of inscriptions are relatively rare. Perhaps the largest known inscribed stone is the Darya-i-Nur, also in the Iranian crown jewels, which has been variously reported to weigh between 175 and 195 ct.

Nicholas DelRe

Figure 4. Historic engraved diamonds, such as this 2.65 ct example, are relatively rare because of diamond's hardness. The inscription, in Arabic, reads "Ya Allah" and is an invocation of God.

Figure 5. These natural-color jadeite cabochons appeared red when examined with a Chelsea color filter, which could lead a gemologist to falsely suspect that they were dyed.

JADEITE JADE

Natural Color

Recently seen in the East Coast lab were two slightly dark, but otherwise very attractive, jadeite cabochons (figure 5). Routine gemological testing established that the stones were jadeite; and chrome lines in the red end of the spectrum proved that the color was natural.

However, when we examined the stones with a Chelsea color filter, they appeared red. Usually, a red color under the Chelsea filter indicates that the stone has been dyed. However, we have seen that jadeite that is very rich in chromium (especially so-called "Yunnan jade"), may appear red under this filter, as well as show strong absorption in the red end of the spectrum. This should serve to remind readers that under some circumstances, the Chelsea color filter test is not reliable, and other means should be used to determine whether a stone has been dyed. *GRC and TM*

Figure 6. The green stone in this closed-back ring proved to be a jadeite imitation.

Imitation Jade

A stone in a closed-back ring (figure 6), seen in the East Coast lab, reinforced the fact that bleached, polymer-impregnated jadeite (so-called "B" jade)—although an ever-growing concern worldwide—is not the only challenge in the identification of translucent green gems. We must remain aware of the earlier attempts to imitate fine jadeite and be on the lookout for these as well.

Normally, a spectroscope will quickly prove the identity of natural-color jadeite. However, because of the closed-back mounting, we could not use transmitted light. Instead, we reflected light off and into the surface of the stone. Since we saw no jadeite spectrum, this test was inconclusive (sometimes reflected light will not reveal a spectrum that might have been seen easily with transmitted light).

The 1.63 spot refractive index was too low for jadeite, which is usually about 1.66. Close examination with magnification quickly revealed the piece's true identity—an imitation. A fern-like pattern (figure 7) distinctive of partially devitrified glass was present. This type of glass is known in the trade as "meta-jade" or "Iimori stone." *GRC and TM*

A PEARL Mystery

What started off as a routine investigation into whether a pearl was natural or cultured turned into a challeng-

Figure 7. Microscopic examination of the jade imitation in figure 6 revealed the fern-like pattern that results from the devitrification (partial crystallization) of glass. Magnified 20×.

Figure 8. This 14-mm-long drop-shaped pearl, here set as the pendant on a Retro-style necklace, was proved to be natural only after it was removed from its mounting.

ing task for our East Coast lab. The very light gray, fairly symmetrical drop shape measured about 10.5 mm in diameter by 14 mm long (figure 8). The yellow-metal Retro-style necklace from which it was suspended had a scroll motif that was popular in the 1940s and '50s. The necklace was also embellished with diamonds, blue sapphires, and smaller pearls.

The drop-shaped pearl did not fluoresce to X-rays, which indicated a saltwater origin but not whether it was natural or cultured. Usually an X-radiograph readily reveals a pearl's mode of growth and, hence, its origin. However, this one was peculiar: Except for the thin outside nacreous surface layer, the interior appeared completely and uniformly black (figure 9). This indicates that either there was no material in this area or the substance present was transparent to X-radiation.

Figure 9. The X-radiograph of the drop-shaped pearl in figure 8 shows that the center is either hollow or contains a substance that is transparent to X-radiation.

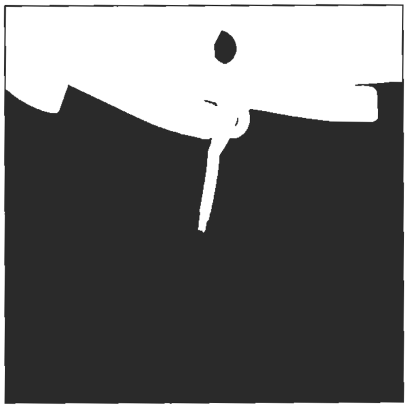
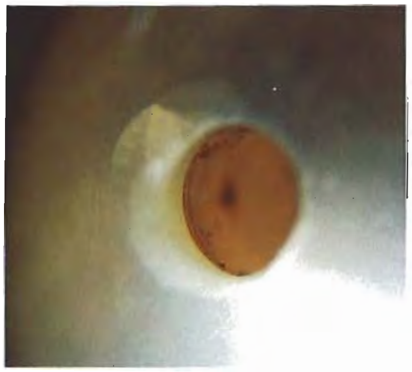


Figure 10. When we examined the pearl in figure 8 inside the drill hole, we found that it contained a natural organic substance.



In the past, pearls with similar X-radiographs have turned out to be hollow (see, e.g., Spring 1984 and Spring 1994 Lab Notes, pp. 48–49 and 45, respectively). However, most of those pearls were irregular in shape.

Since our findings were still inconclusive, the client removed the pearl from the mounting so we could examine inside the drill hole. Although the hole was narrow (1.1 mm), which made examination difficult, a combination of strong overhead and oblique illumination revealed that the pearl was filled with a substance (figure 10). A minute amount of this material, which appeared to be conchiolin, was removed and tested with a thermal reaction tester (hot point). It gave off an odor of burnt hair, proving that it was organic and the pearl was natural.

KH

PYROPE GARNET

Late last year, a 3.14 ct oval mixed cut arrived in the East Coast lab for identification. The stone's overall color was a pale brownish pink (figure 11). This 9.53 × 7.29 × 5.79 mm stone (reportedly from one of the new deposits in Tunduru, Tanzania) had the following gemological properties: diaphaneity—transparent; R.I.—1.735; optic character—singly refractive; S.G.—3.69; and fluorescence—faint red to long-wave ultraviolet radiation (inert to short-wave UV). A faint Fe^{2+} spectrum, with features

Figure 11. This 3.14 ct pale brownish pink garnet was identified as pyrope.

similar to those seen (in a much more pronounced fashion) in rhodolite and almandine, was visible in the handheld spectroscope: absorption below 430 nm, and lines at 505, 527, and about 576 nm. With magnification, we saw some intersecting coarse needles and interrupted needles. From these gemological properties, we readily identified the stone as a garnet. But which species? The spectrum was not consistent with the R.I. and S.G.

The most common pale pink garnets are grossular and hydrogrossular. However, pale pink pyropes are also known (see C. M. Stockton's "Pastel Pyropes," *Gems & Gemology*, Summer 1988, pp. 104–106). To obtain conclusive evidence, the stone was sent to the West Coast laboratory for X-ray diffraction analysis. The resulting pattern confirmed that the material had a garnet structure, with a unit-cell spacing of less than 11.49 Å. (Unit-cell spacing, the distance across one structural unit of a mineral, is measured by X-ray diffraction.) End-member pyrope has a unit-cell spacing of 11.459 Å, while grossular and hydrogrossular have quite different unit-cell spacings of 11.851 Å and 11.85–12.16 Å, respectively (W. A. Deer et al., *An Introduction to the Rock Forming Minerals*, 1974, Longman Group, London, pp. 21–31). To further confirm that this was pyrope, we also performed qualitative energy-dispersive X-ray fluorescence (EDXRF) analysis on the stone, which revealed major Mg, Al, and Si (consistent with pyrope garnet); minor Mn, Fe, Ca, and Zn; and trace amounts of Cr, Ti, V, K, Ga, Ge, Y, and Zr. (The chromium was probably responsible for the faint red long-wave UV fluorescence, rarely seen in garnets, and the iron was probably responsible for the spectral features). Note that although R.I and S.G. do not distinguish grossular or hydrogrossular from pale pyropes, Stockton's (1988) criterion—the spectrum seen with the handheld spectroscope—still can separate them. *MLJ and TM*

Figure 12. Note the uniformity of color in these cabochons (1–4 ct), all of which proved to be quench-crackled synthetic rubies.

SYNTHETIC RUBY, Quench Crackled

Occasionally over the years, we have tested synthetic stones that have been quench crackled to produce natural-appearing fractures. In some instances, the stones had been quenched in dye or (we have been told) in tincture of iodine. The coloring agent penetrated the induced fractures and crystallized to form very realistic "fingerprints."

We have seen numerous other stones that have been quench crackled in various dyes. Quartz that has been quench crackled and dyed green to imitate emerald is the most common. We also have encountered quartz dyed purple to imitate amethyst and quartz dyed red to imitate ruby. Some years ago, we were shown a necklace of quench-crackled red stones that had been purchased, incredibly, as "Swiss Jade" in Europe.

More recently, the East Coast lab was asked to identify a group of red cabochons that the client thought were suspiciously uniform in color (figure 12). Routine gemological tests proved that the stones were ruby. However, although they appeared highly flawed, as cabochon rubies usually are, these flaws seemed too uniform. In fact, on the surfaces of some of the cabs, the fractures formed a distinctive honeycomb appearance (figure 13). Some of the fractures resembled fingerprint inclusions (figure 14), and some seemed to contain a substance which gave them a more believable appearance than a fracture alone would have had. Fortunately, subtle curved striae—crossing the fractures—were visible when the cabochons were examined in the microscope with darkfield illumination. This proved that these rubies were actually synthetic.

GRC and TM

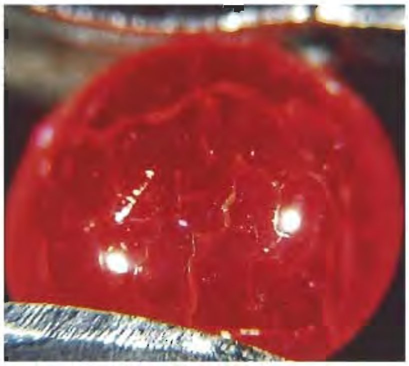


Figure 13. A distinctive honeycomb-like pattern was evident where the fractures reached the surface of the synthetic ruby cabochons shown in figure 12. Magnified 13×.

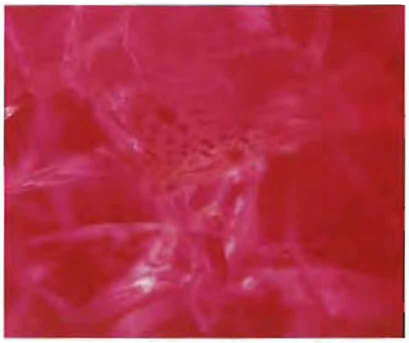


Figure 14. Some of the fractures induced in the synthetic ruby cabochons shown in figure 12 had the appearance of natural fingerprint inclusions. Magnified 40×.

SAPPHIRE

A Natural Stone Mistaken for a Doublet

Shortly after issuing a laboratory report on a ring-mounted natural sapphire (figure 15), staff members at the East Coast lab received a call from the client, who insisted that an error had been made on the report. In fact, he was so certain of our error that he had already sent the ring back to us for reexamination. Eventually, we were able to convince him of the accuracy of our conclusion.

His confusion was due to a distinct separation of colors in the girdle plane that made the sapphire appear as if it had been assembled, with a blue crown and a colorless pavilion. We explained to him that this separation was caused by well-defined blue and colorless zoning, not by the boundary between two pieces of an assemblage. Our original observations revealed fluid-filled "fingerprints" that were perpendicular to the girdle plane and extended across it into *both* the crown and the pavilion. Furthermore, when the ring was immersed in methylene iodide, a routine procedure for all corundum that we examine, the side view (figure 16) showed both color zoning and the lack of a cement plane, the latter an unavoidable feature of any sapphire-sapphire doublet.

Because of the nature of sapphire crystals, we more commonly see color-zoned stones in which the color is confined to the pavilion (see, e.g., figure 17). Although such stones appear evenly colored face up, they are much less likely to be mistaken for an assembled stone than this stone, in which the apparent color zone separation was straight and lay in the girdle plane.

GRC and TM

With an Unusual Star

As heat-treated rubies and sapphires becoming increasingly common, it is a pleasure to see inclusions that prove that a natural sapphire has not been treated. The gemologist gets an added bonus when the arrangement of these diagnostic inclusions also creates a beautiful internal scene. Such was the case when a 2.22 ct cushion-shaped, modified brilliant-cut sapphire was submitted to the West Coast Gem Trade Laboratory for identification.

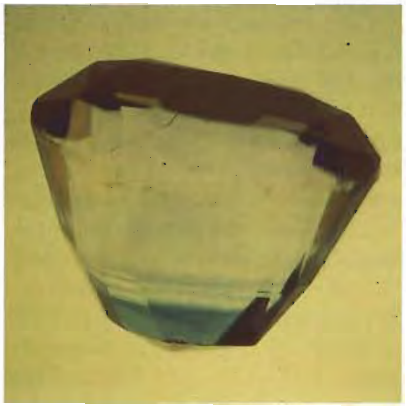
Figure 15. Our client mistakenly thought that this 8.2 × 6.6 mm natural sapphire was an assemblage.

The transparent blue gem contained both fluid inclusions, which proved that the stone had not been heated to the temperature needed to alter its color, and a bold display of rutile needles that painted an obvious picture. The specific arrangement of the rutile needles and their orientation to the table facet made this stone unique.

Figure 16. A side view of the stone in figure 15 shows that the color is confined to the crown, but there is no cement plane.

As can be seen with darkfield illumination (figure 18), the rutile formed a six-spoked stellate pattern of thin, white-appearing needles that are oriented in a planar arrangement perpendicular to the optic axis. There is little or no rutile between the spokes. The six wedge- or V-shaped areas that are devoid of rutile needles extend outward from the center of the

Figure 17. Unlike the stone in figures 15 and 16, color-zoned sapphires more typically reveal color confined to the pavilion, toward the culet, as illustrated by the stone shown here (immersed in methylene iodide). Such stones usually appear evenly colored when viewed face up.



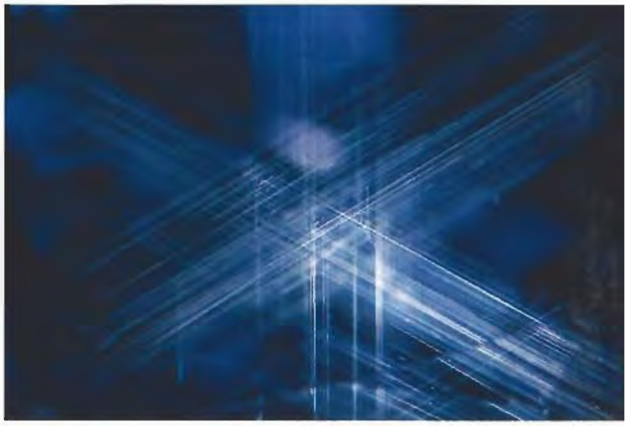


Figure 18. The spoked arrangement of the rutile needles in this natural sapphire creates a pleasing star pattern, but not true phenomenal asterism. Magnified 10×.

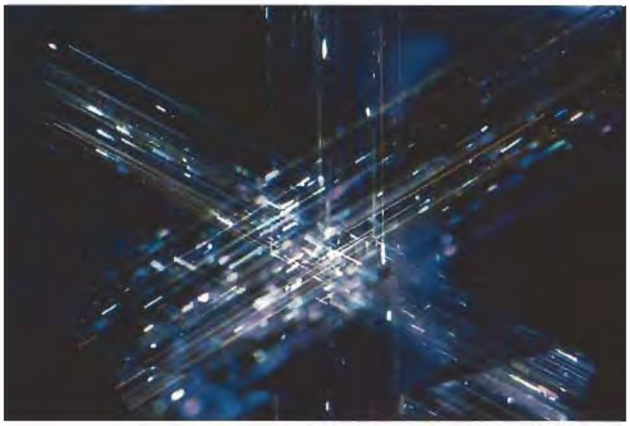


Figure 19. The star pattern becomes iridescent when illuminated by a strong fiber-optic light directed through the table facet from above. Magnified 10×.

"star" formation, which results in the isolated rutile star seen in this stone.

Another interesting feature of this stone was visible because the plane of the table facet was cut just off-parallel to the plane of the rutile star. This orientation results in a beautiful iridescent display by the rutile needles when they are illuminated through the table from above by intense fiber-optic lighting (figure 19).

Although iridescent needles have been observed many times in the past, the combination in this stone of the vibrant iridescence and the unusual spoked star pattern make this a most pleasing inclusion display.

John I. Koivula

PHOTO CREDITS

Nicholas DelRe supplied the pictures used in figures 1–10 and 12–16. Figure 11 was taken by Maha DeMaggio. Figure 17 is courtesy of the GIA slide library, photographer unknown. The photomicrographs in figures 18 and 19 were taken by John I. Koivula.

GEM N·E·W·S

Editors • Mary L. Johnson and John I. Koivula

Contributing Editors

Dino DeGhionno, Robert C. Kammerling, Shane F. McClure,
GIA GTL, Santa Monica, California

Henry A. Hänni, SSEF, Basel, Switzerland

Karl Schmetzer, Petershausen, Germany

DIAMONDS

Diamond with a fluorescent phantom crystal. Bob Lynn, of Lynn's Jewelry, Ventura, California, found an unusual faceted diamond in his stock and loaned it to the editors for examination. The 1.00 ct near-colorless round brilliant looked normal under standard fluorescent and incandescent illumination; however, when the stone was illuminated by (long- or short-wave) ultraviolet radiation (figure 1), a fluorescent internal octahedral crystal was easily seen. Higher magnification revealed that the fluorescence in the phantom crystal was zoned (figure 1, right).

In other respects, the diamond was not notable. With the standard fluorescent lighting used for grading purposes, the included crystal was visible only as transparent graining and did not set the clarity grade of the stone. In polarized light, the inclusion appeared as a region of concentrated strain lines; it did not form an obvious phantom (unlike the strain phantoms illustrated in, for example, the Fall 1993 [pp. 199–200] and Summer 1995 [pp. 120–121] Lab Notes sections).

Tairus synthetic diamonds in jewelry. Among the many synthetic materials produced by Tairus (a joint venture between the Siberian Branch of the Russian Academy of Sciences and Pinky Trading Co., Bangkok, Thailand) are synthetic diamonds grown in Novosibirsk. Tairus yellow synthetic diamonds are now being marketed in jewelry (figure 2) by Superings, Los Angeles, California. To the best of our knowledge, this is the first example of synthetic diamonds being marketed as such in jewelry. Although the jewelry is not yet available in mass-market quantities, advertising brochures that were distributed by Superings this past spring generated 2,000 calls for further information on these goods in one week, according to Walter Barshai, president of Pinky Trading. Individual samples (mounted in rings) seen at the JC-K Show in Las Vegas this past June ranged between 0.15 and 0.25 ct.

Mr. Barshai also provided details about Tairus's production of synthetic diamonds. Near-colorless, yellow, and blue synthetic diamonds are being produced at their factory in Novosibirsk using the BARS method; also, the yellow synthetics can be treated (by irradiation followed by heat treatment) to produce pink and red colors (see, e.g., Gem Trade Lab Notes, Spring 1995, pp. 53–54). As of early June 1996, Tairus was producing 10–20 colored synthetic diamond crystals per month, but the company hopes to increase production to 100–300 crystals per month by winter, and possibly to 1,000 crystals per month by the summer of 1997. The largest crystal grown by Tairus thus far weighs about 2.5 ct, with most crystals weighing between 1 and 2 ct; by late 1997, synthetic diamond crystals up to 5 ct may be produced. Growth times

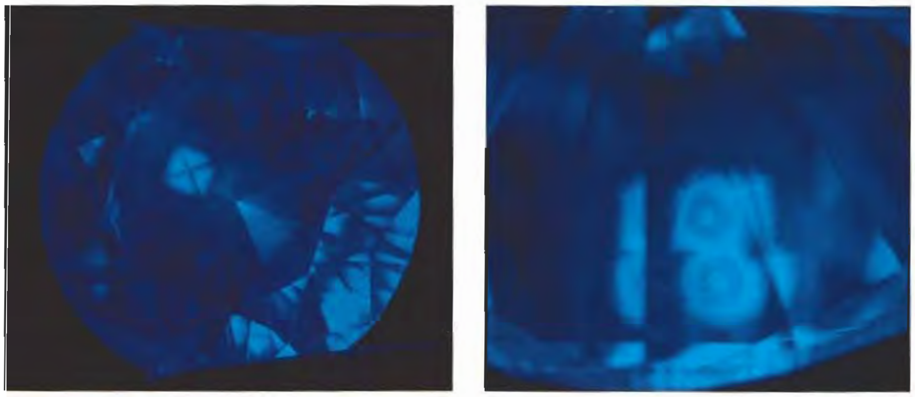


Figure 1. This 1.00 ct diamond (about 6.5 mm in diameter) contained an octahedral phantom crystal that was visible only when the stone was exposed to UV radiation. With higher magnification (right, 7×), the included crystal (also seen reflected in the table facet) showed a zoned fluorescence pattern. Photomicrographs, taken with shortwave UV illumination, by Shane Elen, GIA Research.

are surprisingly fast: in theory, a 5 ct crystal could be grown in three days. Most synthetic diamonds as grown are light yellow-brown to saturated yellow, but blue crystals can be grown if boron is added. Near-colorless stones require additives such as zirconium and special growing conditions; the largest near-colorless crystals grown by Tairus so far weigh only about 0.10 ct.

Approximately 100 carats of Tairus synthetic diamonds—of any color—have been placed in the market to date. Mr. Barshai believes that the market will be much more tolerant of colored than near-colorless synthetic diamonds, so Tairus is concentrating on the production of colored synthetic diamonds.

Figure 2. These three platinum rings contain fashioned yellow synthetic diamonds (0.30–0.40 ct). Courtesy of Superings, Los Angeles; photo by Shane F. McClure.

COLORED STONES AND ORNAMENTAL MATERIALS

Anorthosite rock with uvarovite garnet "speckles." In September 1994, contributing editor Henry Hänni received some pieces of rough from Tay Thye Sun, a Singapore gemologist. One of Mr. Sun's clients acquired the material in the Philippines because it looked like jade. On the weathered skin of the predominantly white samples, deep green idiomorphic crystals were visible. These 0.2–2.0 mm crystals showed excellent rhombic dodecahedron shapes (figure 3, left). Microscopic examination of a polished surface in reflected light (figure 3, right) revealed a granular groundmass that was occasionally interspersed with idiomorphic crystals (about 5% of the volume of the rock). The green crystals had a much higher luster than the matrix.

Raman spectroscopy quickly revealed that the groundmass was plagioclase and the crystals were garnets. Examination with an electron microprobe (by analyst J. Partzsch) determined the exact chemical composition. In fact, the groundmass was two different plagioclases: The main mass consisted of almost pure anorthite ($Ab_{02}An_{98}$: 2 mol.% albite [Ab] and 98 mol.% anorthite [An]), but oligoclase ($Ab_{77}An_{23}$) was present between these grains. The garnet crystals were strongly zoned; they were composed primarily of uvarovite with varying amounts of andradite in solution.

These pieces of rough may be the same material as the snuff bottle that was described and illustrated in the Spring 1994 Lab Notes section (pp. 42–43). The specific gravity of the rough material was 2.80, compared to the 2.76 reported for the snuff bottle.

Update on porous chrysocolla-colored chalcedony. In the Spring 1992 Gem News column, we reported on chalcedony colored by chrysocolla that changed appearance when soaked in water for several hours ("Chrysocolla-colored Chalcedony from Mexico," pp. 59–60). In that material, the soaking caused the blue color to intensify, the material to become more transparent (less opaque), and the piece to gain weight.

Late last year, Chris Boyd of CB Gems & Minerals, Scottsdale, Arizona, brought to our attention chalcedony colored by chrysocolla from Arizona, which showed a similar change in color and transparency that can also be produced by humidity alone. According to Mr. Boyd, this transition happens at about 55% humidity. Stones are "a nice semi-transparent blue" when exposed to humidity

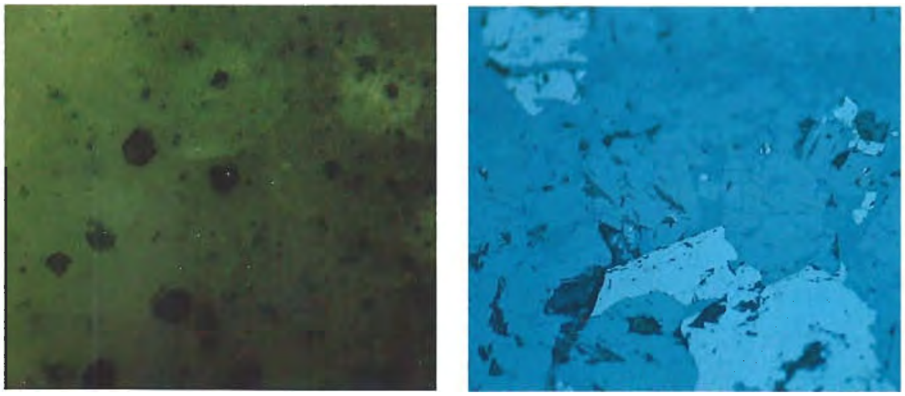


Figure 3. The green hexagons in this polished section of rock from the Philippines (left) are uvarovite garnets; the largest garnet is 2 mm across. In reflected light (right), the high-relief garnets (brightest reflectance) can be distinguished easily from the groundmass of anorthite feldspar (medium gray) and oligoclase feldspar (dark gray). Photomicrographs courtesy of the Swiss Gemmological Institute (SSEF), Basel.

Figure 4. This cabochon and the tablet are made of clinochlore, a chlorite mineral. Photo by Maha DeMaggio.

of 55% or greater, or if soaked in water; when these same stones are exposed to lower humidity, or left under a heat lamp, they lose color intensity and transparency. This process is repeatable.

Mr. Boyd also said that, in his experience, almost 90% of Arizona chrysocolla-colored chalcedony will dry out if exposed to less than 55% humidity.

Chatoyant clinochlore from Russia. One of the interesting "phenomenal" materials seen at the 1995 and 1996 Tucson shows was a chatoyant chlorite-group mineral from Russia. Two samples—a 7.65 ct triangular tablet and a 6.06 ct cabochon (figure 4)—were obtained from Heaven and Earth, Marshfield, Vermont, which was marketing this material as "Seraphinite." Gemological properties were as follows: color—green; diaphaneity—semi-translucent; color distribution—uneven (mottled, fibrous); pleochroism (visible in some more transparent areas) yellow-green/bluish green; optic character—doubly refractive with an aggregate structure. Individual fibrous crystals in the aggregates appeared chatoyant, with a pearly luster. One stone had poorly discernible R.I.'s of 1.580 and 1.585, and the other gave a spot reading of 1.58. Specific gravities were 2.62 and 2.66. Uneven luminescence was seen to both wavelengths of UV radiation: weak yellowish white to whitish yellow for long-wave UV, and very weak white to short-wave UV. In the spectroscope, one stone showed a cutoff edge at about 460 nm and a weak band centered at 500 nm; the other showed these bands as well as a faint band at 470 and 545 nm, and a cutoff edge at about 690 nm. With magnification, both stones showed a radial fibrous structure. Qualitative energy-dispersive X-ray fluorescence (EDXRF) spectroscopy revealed numerous elements in both: Mg, Al, Si, K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu (in one sample), Zn, and Ga.

X-ray powder diffraction patterns for both samples were consistent with that of the mineral clinochlore, $(Mg,Fe^{+2})_5Al(Si_3Al)O_{10}(OH)_8$, a member of the chlorite mineral group. The source of this clinochlore is the Korshunovskoye deposit, on the east side of the Bratsk Reservoir, east of Lake Baikal, in Siberia, according to an article by A. A. Evseev in the Russian mineralogical magazine *World of Stones* (1994, No. 4, p. 44). Standard mineralogical references give the hardness of clinochlore as 2–2.5. One sample had been wax treated.

Cat's-eye diopside from Southern India. Many materials that contain parallel acicular inclusions can be fashioned into cabochons to show a cat's-eye effect. Among the green cat's-eye stones are apatite, chrysoberyl, demantoid garnet, emerald, opal, tourmaline, zircon, and zoisite. We were delighted to see recently an unusually bright green example of another material—cat's-eye diopside (figure 5)—from a relatively new locality.

The 4.59 ct oval cabochon (12.70 × 5.70 × 6.57 mm), which was loaned to the editors by Maxam Magnata of Fairfield, California, was a translucent dark green, with weak pleochroism of green and slightly brownish green. Its optic character was aggregate—showing the presence of many individual grains. The refractive index measured 1.67, and a "blink" was seen at 1.70. The stone was inert to both long- and short-wave UV. With the spectroscope, we saw weak general absorption between 400 and almost 500 nm, with two lines at 495 (weaker) and 505 (stronger) nm. Three "chrome lines" were also seen at 640, 660, and 680 nm; despite this evidence of chromium, there was no reaction to the Chelsea color filter. These properties are consistent with those previously reported for chrome diopside. Magnification revealed a fibrous texture, with some coarse channels (or, possibly, needles) present.

The material comes from a relatively new mine near the small town of Iddipadi, in southern India, close to the

Figure 5. This 4.59 ct cat's-eye diopside is from a relatively new find in southern India, near the town of Iddipadi. Stone courtesy of Maxam Magnata; photo by Maha DeMaggio.

Figure 6. Mozambique is the country of origin for these two garnets (1.26 and 1.38 ct), identified as pyrope-almandine. Photo by Maha DeMaggio.

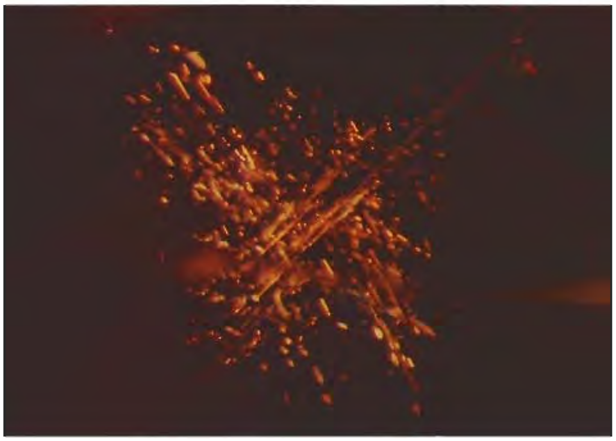


Figure 7. Acicular inclusions were the only internal feature seen in the Mozambique garnets shown in figure 6. Photomicrograph by John I. Koivula; magnified 30×.

cutting center of Karur Kangayam, according to Mr. Magnata. He believes the find was first made about six years ago, with the bulk of the cutting material sent to Hong Kong until recently. The mine is reportedly within 40 m of star diopside and cat's-eye enstatite deposits.

Garnets from Mozambique. African garnets were very much in evidence at the 1996 Tucson shows, including brownish yellow to bright green grossular-andradites from Mali (see, e.g., "Gem-Quality Grossular-Andradite: A New Garnet from Mali," *Gems & Gemology,* Fall 1995, pp. 152–167), orange spessartines from Namibia (Gem News, Spring 1996, pp. 56–57), and various color-change garnets from Tanzania (Gem News, Spring 1996, p. 53). A number of dealers also offered dark orangy red to slightly brownish red stones from still another locality, the southern African country of Mozambique.

Although this locality is not new, garnets from Mozambique have not been characterized in the gemological literature. To do just that, we purchased two brownish red modified triangular brilliant cuts (1.26 and 1.38 ct; figure 6) on which we determined the following properties (where there are two sets of values, the value for the 1.26 ct stone is first): R.I.—1.770, 1.776; S.G. (determined hydrostatically)—3.96, 3.89; singly refractive with strong anomalous birefringence noted between crossed polarizers; inert to both long- and short-wave UV radiation; and spectra (determined with a desk-model prism spectroscope) exhibiting strong bands at about 504, 520, and 573 nm. Magnification revealed a few acicular rutile crystals in one stone (figure 7). On the basis of these properties, and using criteria established by C. M. Stockton and D. V. Manson ("A Proposed New Classification for Gem-quality Garnets," *Gems & Gemology,* Winter 1985, pp. 205–218), we identified the garnets as pyrope-almandine.

Green-and-white jadeite from Russia. Ross Shade of the Addexton Company, Auburn, California, provided us with a 113.90 ct sample of green-and-white mottled jadeite (figure 8) that reportedly came from central Russia. Mr. Shade acquired the material through an (undisclosed) American company that imports stones for the building industry; it was originally imported for use as kitchen and bathroom tiles.

The gemological properties of our test sample were: clarity—semi-translucent to opaque; aggregate structure; R.I.—about 1.66 (some areas, 1.655 to 1.670; others, 1.48–1.50); S.G.—3.29; luminescence—moderate mottled blue-white to long-wave UV radiation, and very weak to weak mottled blue-white to short-wave UV; typical green jadeite spectrum when viewed with a handheld spectroscope.

Further tests helped explain some of these properties. X-ray powder diffraction analysis of scrapings from two areas gave patterns indicating jadeite (predominantly) and minor natrolite. The natrolite, which accounted for the 1.48–1.50 R.I. readings and the slightly low S.G., occupied about 5% of the sample by volume. The infrared absorption spectrum of a thin slice that had been cut and polished from this material showed no evidence of polymer impregnation. However, two small "wax peaks" were found at 2926 and 2855 cm^{-1}. These probably resulted from the oil used in cutting the thin slice.

Visit to Myanma Gems Museum. The October 1993 Emporium was the first such event held in the new Myanma Gems Enterprise (MGE) exhibition hall in Yangon (Rangoon), which was built solely for these biannual sales. In the summer of 1995, the Myanma Gems Museum opened in a building adjacent to the exhibition hall. One of the Gem News editors (RCK) visited this museum in November 1995 and provided the following report on this new facility.

Each of the first three floors consists of a large open showroom containing retail sales outlets for firms licensed by the Myanmar government to sell gems and jewelry (all sales require MGE receipts like those used at the emporia). Ornamental objects fashioned from silver were offered, in addition to loose gems and gem-set jewelry.

The top floor of the building houses the actual museum, which contains many interesting displays. Jadeite is very well represented. Along one wall are sawn jadeite

Figure 8. This 113.90 ct block of jadeite (here cut into three pieces) reportedly came from central Russia. Photo by Maha DeMaggio.

boulders, each identified by its locality. A display of cabochons illustrates the three categories of jadeite—"imperial," "commercial," and "utility"—used in Myanmar gem markets. An exceptional 4.7 kg boulder of imperial jadeite has its own display case. There are also attractive displays of fashioned jadeite, including a plate with chopsticks (total weight 2,390 g) and the remaining 106 kg "water jade" boulder from which they were cut.

Not surprisingly, there are a number of interesting ruby displays, including material from Mong Hsu, from the famous marble quarry at Sagyin in Mandalay Division, and from Pyin Lon in northern Shan State. Among the noteworthy gem-set items is a peacock fashioned from 61.86 g of gold and 256.84 ct of sapphires atop a jadeite base. Also on display is a large gold pendant set with a 329 ct oblong peridot cabochon (labeled as the world's largest cut peridot) and many smaller peridots. Other cases highlight the range of gems found in Myanmar, including zircon, iolite, danburite, diopside, tourmaline, garnet, lapis lazuli, moonstone, enstatite, albite, and fluorite. Cultured pearls from the gold-lipped oyster are also well represented.

A recent report provided by U Tin Hlaing of Taunggyi University, Myanmar (pers. comm., May 1996), lists the following large gems as being among those currently on display at the museum: a 21,450 ct (17.5 cm long × 11 cm wide × 10 cm high) rough ruby from Block No. 14 of the Mogok Stone Tract, which Myanmar officials believe to be the world's largest; a 63,000 ct sapphire from Mogok; and a 23,500 ct piece of jade from the Hkamti area.

Variegated translucent jasper from Mexico. One of the more notable trends at the Tucson gem shows this year was the rising interest in ornamental materials. In addition to the exotic materials seen—such as drusy vanadinite and clinochlore—varieties of quartz and chalcedony were quite prominent, especially those with aesthetic inclusions or patterns. One interesting example was so-called Imperial jasper (figure 9), reportedly mined in Mexico. Cathy Cwynar, of Minneapolis, Minnesota, loaned us three fashioned pieces for characterization.

The gemological properties of the three free-form cabochons (15.43, 16.28, and 17.86 ct) were as follows: color and clarity—variegated between translucent-to-opaque brownish (olive) green to green in some regions and to opaque greenish white in others; optic character—aggregate reaction; R.I. —1.54 in the green area, 1.53 to 1.55 in the white areas; S.G.—2.43 to 2.51 (the white regions were porous, and the more white material there was in the piece, the lower the S.G. was). For the most part, this material was inert to both long- and short-wave UV radiation, but some whitish areas showed a weak blue fluorescence to long-wave UV. Only the darkest (olive) green regions showed a distinct absorption spectrum in the handheld spectroscope, with a lower-wavelength cutoff at about 460 nm, and faint bands at 500 and 520 nm. Other than the typical chalcedony structure, no inclusions were evident with magnification.

Of particular note was the material's unusual behavior in transmitted light: The dark green areas were translucent, with yellow "rims" between the green and opaque areas (figure 9, right)—an effect not evident in reflected light. Qualitative EDXRF spectroscopy revealed no significant differences in chemistry between the white and green regions of one sample examined; both areas showed major silicon, minor potassium, calcium, iron, and titanium, and trace amounts of manganese, zinc, rubidium, and strontium.

An unusual morganite. In fashioned gemstones, fractures are generally considered very undesirable. One exception, however, is found in the variety of rock-crystal quartz known as "iris quartz" (not to be confused with "iris agate"), in which numerous air-filled fractures behave like thin films, imparting a rainbow-like iridescence when the gem is illuminated from above.

Recently, Edward Swoboda, a gem and mineral miner and dealer from Beverly Hills, California, showed the editors another form of "iris" gem. The light pink stone, a 157.19 ct oval step-cut morganite beryl, measured 42.69 × 32.34 × 19.28 mm.

During cutting, instead of removing the fractures and making a number of smaller stones from the rough, the lapidary went against convention and fashioned a single large stone, positioning the fractures so that their plane was just off parallel to the table facet. In this way, light reflected from the fractures was not simultaneously reflected from the table facet, which would otherwise mask or diminish the "iris" effect. As figure 10 shows, this cutting technique produced a morganite with a table that is vividly iridescent when the stone is viewed from above in virtually any direction. As the stone and/or light source is moved, both the pattern and position of the various colors change dramatically.

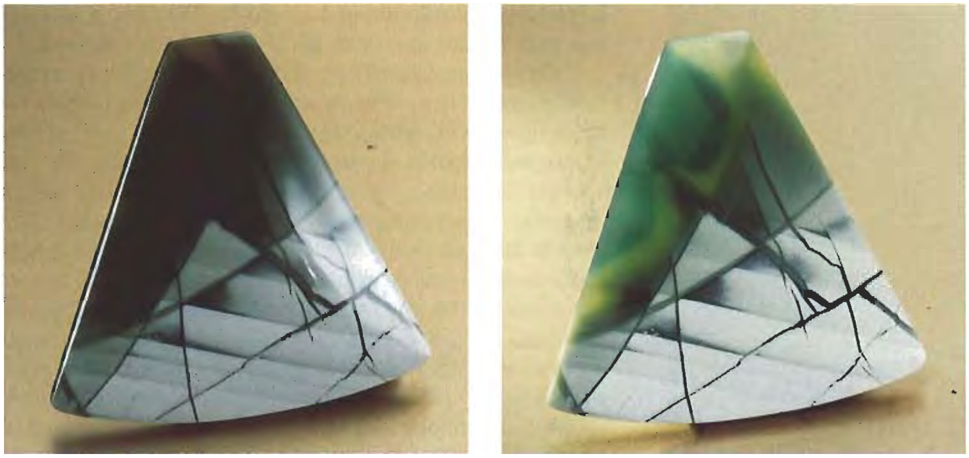


Figure 9. Among the many ornamental gem materials seen at the 1996 Tucson gem shows was this 17.86 ct cabochon of variegated jasper, fashioned by Cathy Cwynar, shown on the left in reflected light. In transmitted light (right), the dark green regions are translucent, revealing yellow rims that are not visible in reflected light. Photos by Maha DeMaggio.

Scottish pearls. One of the most interesting items seen at the February Tucson shows was a double strand of graduated pearls that ranged from 4 to 9 mm on one strand, and 4 to 10 mm on the other (figure 11). The pearls were accompanied by a report from the Gemmological Association and Gem Testing Laboratory of Great Britain in which they were identified as natural. Of particular interest, however, was their provenance: All were collected from freshwater mollusks in the rivers of Scotland, by veteran pearl fisher Bill Abernethy. These pearls, reportedly the result of 40 years of pearl fishing, are particularly well-matched rounds and show the attractive luster that is characteristic of Scottish pearls (see, e.g., E. A. Jobbins and K. Scarratt, "Some Aspects of Pearl Production . . . ," *Journal of Gemmology*, Spring 1990, pp. 5–7). The most important Scottish pearl recovered to date, called the Abernethy pearl, is 11.5 mm in diameter.

Rubies from Madagascar. Blue sapphires from Madagascar have received attention in the trade press since their 1992 arrival on the gemstone market (see the article by D. Schwarz et al. in this issue). However, southern Madagascar is also producing gem-quality rubies, according to Christopher P. Smith of the Gübelin Gemmological Laboratory, Lucerne, Switzerland. Although most fashioned stones weigh 1 ct or less, some as large as 20 ct have been encountered. Recently, the Gübelin laboratory had the opportunity to examine more than 40 faceted Madagascar rubies. These rubies had a richly saturated, even color; most resembled Thai or Cambodian rubies in this respect, although some lighter-toned stones looked like rubies from Burma or Vietnam.

Mr. Smith noted a distinctive combination of internal features in these rubies. Most had dense concentrations of fine needles and platelets that, for the most part, were dull in luster and slightly blue or white in color; they lacked the highly iridescent appearance of rutile needles and platelets observed in rubies from Burma, Sri Lanka, or Vietnam. (It is, therefore, more likely that they are ilmenite or hematite.) Doubly truncated hexagonal dipyramidal negative crystals, surrounded by equatorial thin films or fractures, were another common feature (figure 12). These inclusions are reminiscent of those seen in Thai and Cambodian rubies. In addition, the Madagascar rubies revealed very prominent internal growth structures that gave a roiled appearance with 10× magnification. Many of the rubies also had a distinctive series of linear growth boundaries that created the appearance of a "cellular structure" (figure 13).

Semi-quantitative chemical analysis performed on 30 samples revealed the following contents: 97.3–99.1 wt.% Al_2O_3; 0.27–1.68 wt.% Cr_2O_3; 0.45–0.74 wt.% Fe_2O_3; 0.0–0.07 wt.% TiO_2; 0.0–0.02 wt.% V_2O_5; and 0.0–0.01 wt.% Ga_2O_3.

From his extensive 1922–23 studies of the gem deposits of Madagascar, Lacroix described corundum deposits (ruby and sapphire) in the northern and central parts of the island (*Minéralogie de Madagascar*, Challamel Ed., Paris, 3 Vols.). Later, additional deposits were noted by Besairie in 1956 (*Carte géologique au 1/200000 de Sakoa-Benenitra, 2nd ed.)* and Noizet in

Figure 10. The lapidary fashioned this 157.19 ct morganite to display a pleasing iridescent, or "iris," effect. Photo by Maha DeMaggio.

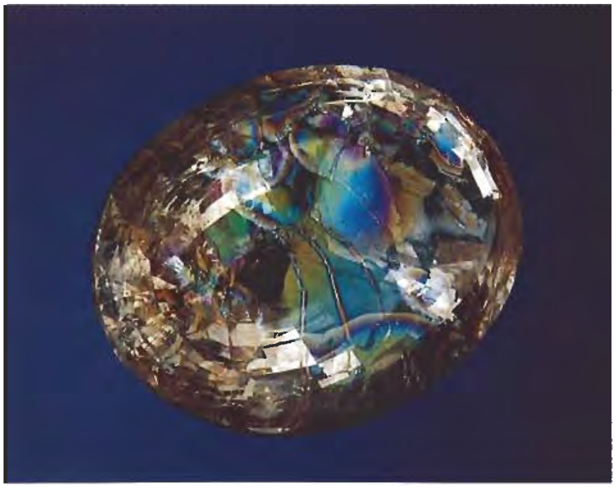


Figure 11. The 154 pearls (4–10 mm) in this double strand were reportedly fished from freshwater mussels in Scottish waters by Bill Abernethy. Courtesy of the Susan Clark Gallery of Gem Art, Vancouver, BC, Canada.

1958 (*Carte géologique au 1/200000 de Ampanihy-Bekily,* 2nd ed.), in the southern portion of the island. In a 1992 geologic report, Dr. Alain Mercier placed the ruby deposits east-southeast of the town of Tulear, in the Fotadrevo-Vohibory region of southern Madagascar, concentrated along northeast-trending faults. Some of the principal deposits include Anavoha, Vohitany, Vohibory, Marolinta, and Ianapcra.

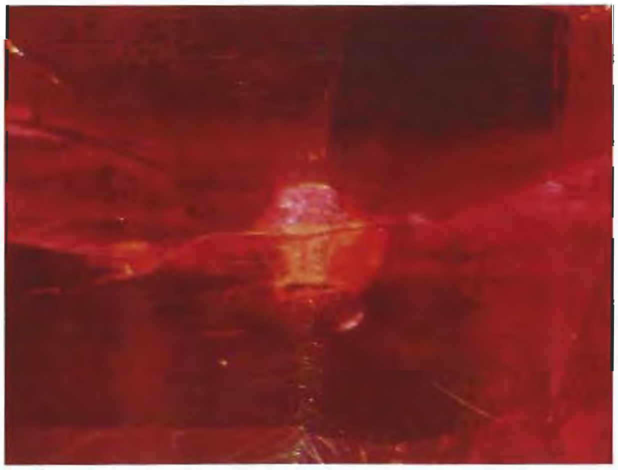
Sapphire mining in Kanchanaburi. The Winter 1990 Gem News section contained an entry on S.A.P. Mining Co., a large, mechanized sapphire-mining operation in Thailand's Kanchanaburi Province, about 100 km (60 miles) west of Bangkok. Mining takes place near Bo Phloi, a town about 40 km (25 miles) north of Kanchanaburi City. Last fall, one of the editors (RCK) revisited S.A.P. Mining and obtained updated information about that operation.

S.A.P. Mining has determined that black spinel is the best indicator mineral for finding sapphires, according to exploration and mining manager Rouay Limsuvan. In general, the larger the spinels found in an area are, the larger the sapphires recovered will be. Dark brown (to black) pyroxene also has proved to be a good indicator mineral. All of the sapphires recovered to date have been from secondary (alluvial) deposits. The actual gem-bearing gravel layers are typically about 1 m thick. They occur as shallow as 5–7 m, or as deep as 13–15 m, below the surface.

Once a prospected area has been selected for mining, modern excavators strip the overburden to reach the gem-bearing gravels, which are then loaded on large dump trucks and taken to the firm's modern processing plant. In a single day, some 250 truckloads of gravel—1,000 m^3 of material—are transported to the processing plant. The gravels are first dumped into a sheet metal–walled pen. High-pressure water cannons help wash material out of the trucks, remove the clay and sand from the gravels, and force the gravels via chute into a large rotating trommel, which removes the bigger rocks. The gravels then pass through one of two rotating trommels with a smaller mesh size (figure 14), after which they are processed in one of three vibrating jig systems (each of which consists of six jigs). The resulting heavy concentrate is then collected and taken to an on-site facility for hand sorting. The amount of rough sapphire recovered daily varies widely, from 200 grams to 2 kg. While the goal is to recover corundum, also found are sanidine, black spinel, garnet, magnetite, pyroxene, and olivine.

Although S.A.P. Mining is still very active, with a claim area covering 250–300 km^2, the overall level of mining activity in the area has decreased in recent years. In the past decade, no fewer than 47 companies have been involved in mining for sapphires in the area. Currently, however, only four firms work the Bo Phloi area; a year earlier, there were seven active operations, according to Mr. Limsuvan. As S.A.P. Mining plans for the eventual end of mining operations on its holdings, it is carrying out an extensive reclamation program. It has

Figure 12. This type of negative crystal—a doubly terminated hexagonal dipyramid with a surrounding equatorial thin film/fracture plane—was a common feature in the Madagascar rubies examined. Similar inclusions are found in rubies from Thailand and Cambodia. Photomicrograph by Christopher P. Smith; magnified 20×.



already developed mined-out portions of the lease area into a golf course.

Update on Tanzanite mining. Gem dealer Michael Nemeth, of San Diego, California, has provided an update on tanzanite mining at Merelani, Tanzania, following a visit there in late 1995. At that time, the D block contained about 200 mines and over 2,000 miners (see Gem News, Winter 1991, p. 262, for a description of the four main "blocks" for which mining rights have been granted at Merelani). "Vietnam Camp," a mine in the D block, was being worked by 28 miners and extended to 3,000 m in length. Mr. Nemeth learned that overall production had been good, and a "7 kg crystal" with excellent color and clarity had been found recently. However, local prices seemed high, probably inflated by the presence of foreign buyers.

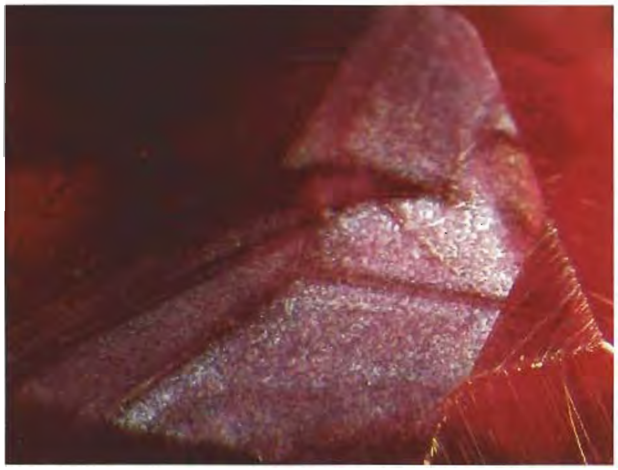
The Vietnam Camp mine was one of the few mines with a wooden ladder instead of a rope for access (figure 15). In general, though, mining conditions were primitive (the typical miner's headgear was a flashlight strapped on with a thick band of rubber). Throughout the visit, Mr. Nemeth heard and felt numerous dynamite blasts, after which glittering, graphite-rich dust filled the air of the mine shaft. He was told that "a few miners" are killed weekly by poor ventilation or by the blasts themselves. Some miners stay underground for two to three days at a time, eating only salt and *ugali* (a cornmeal-like porridge compressed into cakes in one's hand).

Figure 16 was taken at a depth about 250 m, at which point the mine shaft became less vertical. Further descent was accomplished by crawling head first down the steeply sloping adit. Over the next 50 m, the shaft narrowed from 1 m to about 60 cm (three to two feet), and turning around was impossible. Mr. Nemeth and his party stopped at this point, since the miners above ground had taken a lunch break and stopped pumping air below.

Mr. Nemeth was told that the miners were paid only with stones found in the mine, not currency. The age-old practice of high-grading by miners to supplement their meager incomes was tolerated as long as amounts were kept to a "single handful," as in general only the mine manager, not the owner, was present.

Figure 14. At S.A.P. Mining's modern washing plant near Bo Phloi in Kanchanaburi Province, Thailand, a huge rotating trommel (foreground, right) removes the larger rocks. The gravels then pass through one of two other trommels with smaller mesh sizes, one of which is at left. Photo by Robert C. Kammerling.

Figure 13. A distinctive cellular structure is apparent in this ruby from Madagascar. The linear growth features separate zones filled with fine needles and platelets (probably ilmenite or hematite). Photomicrograph by Christopher P. Smith; magnified 25×.



"Golden" tourmaline from Kenya. Tourmaline from a new find in Kenya is being described as "savannah" or "golden" tourmaline. Gemologist Yianni Melas recently sent us two samples of rough material for examination (figure 17). The larger (4.50 ct) piece was transparent brownish orangy yellow, with some green areas. The smaller (3.06 ct) piece was a crystal section with a brownish orangy yellow core and a green rim. External morphology of the (broken) crystal section consisted of prism faces only, which were not striated parallel to the c-axis.

We recorded the following gemological properties on the two samples: pleochroism—brownish orange (o) to yellow (ε) in yellow regions, and dark green (o) to light yellowish green (ε) in green regions; optic character—uniaxial; color-filter reaction—none (yellow regions), red (green regions); R.I.—1.630 to 1.650, and birefringence—0.020 (measured on green rim only); S.G.—3.05; fluorescence—inert to long-wave UV radiation (both colors), moderately chalky, moderately strong yellow (to short-

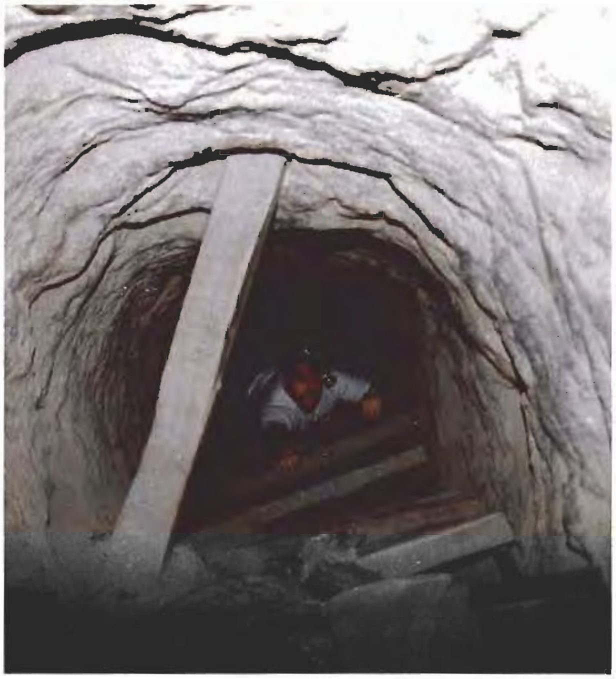


Figure 15. Gem dealer Michael Nemeth cautiously descends the upper shaft of the Vietnam Camp tanzanite mine, in block D at Merelani. Miners use the piece of wood in the foreground to rest during their long descents and ascents. Photo courtesy of Michael Nemeth.

wave UV), with stronger fluorescence in the green rim of one sample. Using a handheld spectroscope, we saw a general absorption in both stones to about 480 nm; the green rim also showed an absorption band between 590 and 630 nm, and lines at 650 and 680 nm. Magnification revealed a small anhedral crystal and a needle (or tube) in the larger piece; the smaller piece contained two-phase (liquid/gas) inclusions in healed fractures ("fingerprints") and hollow tubes.

Figure 16. The shaft of the Vietnam Camp mine continues to narrow as it approaches 300 m depth. Photo courtesy of Michael Nemeth.

Qualitative EDXRF spectroscopy revealed Mg, Al, Si, K, Ca, Ti, Fe, Zn, Ga, and Sr in both samples, with a small Mn peak in one spectrum. Cr was also detected in the green crust of the smaller piece, and the color-filter reaction and absorption spectrum were consistent with the presence of Cr, which causes the green color.

Three possible sources have been cited in the trade press for this or similar material: (1) the Kasigau Mine, 450 km from Nairobi in Kenya's Tsavo West National Park ("What's in a Name—Sales for Brown Tourmaline," *I.C.A. Gazette,* April 1995, p. 7), (2) the Mangari area of Tsavo West National Park, and (3) M'gama Ridge, south of the Taita Hills in south eastern Kenya (the latter two described in "New Find: East African Golden Tourmaline," *Jewelers' Circular-Keystone,* February 1995, p. 66).

TREATMENTS

Novel opal doublets from Brazil. In the editors' experience, two basic types of doublets using natural opal are encountered in the trade. The first type uses a black material—such as dyed chalcedony ("black onyx") or glass—as the backing material. (When the opal is fairly thin and translucent, the backing provides a dark background that accentuates the opal's play-of-color.) The second type of opal doublet uses as the backing material sandstone or ironstone matrix, typical of that seen at opal deposits, to reinforce the opal. If examined carelessly (or if mounted to obscure the demarkation between the two components), this second type can be mistaken for natural boulder opal. The opal in most doublets of both types that we have seen is usually Australian.

While examining gems at the Tucson booth of a Brazilian firm, one editor came across a type of opal doublet that he had not seen previously. These stones had been assembled from two Brazilian gem materials: milky white opal from Piauí State that was backed with sodalite from Bahia State (figure 18). The dark violetish blue of the sodalite provided a good contrast for the opal's weak play-of-color. It also produced a background color similar to that seen in many opal triplets.

As at many other gem shows, the editors also encountered assemblages made with synthetic opal. For example, Manning International, of New York, was offering both doublets and triplets constructed from recent-production Gilson synthetic opal. The backing material on the doublets was ironstone matrix from Australia.

Sapphires with "induced" stars. At the February 1996 Tucson show, one of the editors (DDG) saw several star sapphires. Accompanying literature claimed that the asterism was "induced," but without "additional chemicals." Since no "chemicals" were involved, the literature maintained, this process was different from diffusion treatment. Curious, the editor obtained some of these sapphires for examination (see, e.g., figure 19). One end of a stone was polished flat so that the properties of the interior could be compared to those of the "skin" region.

Gemological testing confirmed that the material was sapphire. With magnification, angular growth layers and two-phase and "fingerprint" inclusions were visible. When the stone was examined with fiber-optic illumination, silk in the outer layer looked similar to the silk seen in synthetic star sapphires. When the stone was immersed in a heavy liquid, a shallow brownish surface layer was evident.

To determine whether the treatment that induced the asterism had changed the stone's chemistry, we examined both the surface and the polished, exposed interior of the stone with quantitative EDXRF spectroscopy. (The penetration depth for X-rays is about 0.1 mm under our standard operating conditions.) We found five times more titanium on the surface of the stone than in its interior (0.19 wt.% Ti as TiO_2 on the surface; 0.04 wt.% TiO_2 in the interior.)

Because of the significant difference in titanium content between the two regions, we concluded that the TiO_2 "silk" must have been produced by diffusing titanium into the surface (despite the seller's claim to the contrary). However, diffusion treatment may not have been the intended result. Dr. John L. Emmett (co-author of "Heating the Sapphires of Rock Creek, Montana," *Gems & Gemology*, Winter 1993, pp. 250–272) remarked recently that he knew of a treater who packed some sapphires in a white titanium-dioxide-bearing powder for heat treatment, hoping that the powder would slow cooling and prevent breakage. When he examined the finished stones, however, the unnamed treater was surprised to discover that his blue sapphires were now both heat treated *and* diffusion treated.

SYNTHETICS AND SIMULANTS

Manufactured composite material imitating jadeite. A great many materials are used to imitate jadeite. These include such natural, untreated gem materials as massive grossular garnet and serpentine; such wholly manufactured materials as glass and plastic; and such treated, natural gems as dyed massive quartz and—more relevant to the following discussion—massive calcite that has been selectively dyed to resemble mottled green-and-white jade.

Figure 17. These two pieces of tourmaline rough (4.50 and 3.06 ct [the latter 12.60 × 6.67 × 5.63 mm]) are from a new find in Kenya. Photo by Maha DeMaggio.

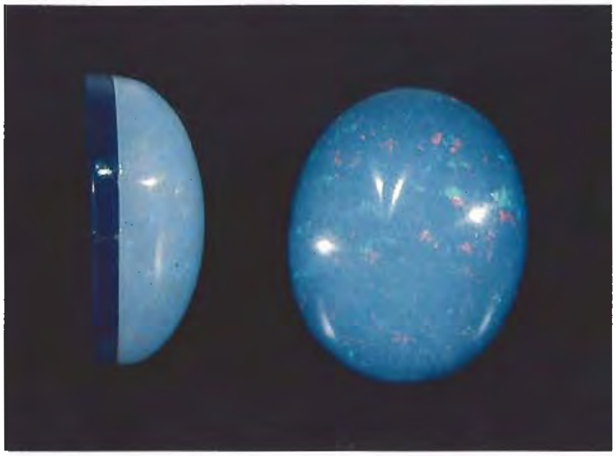


Figure 18. Opal from Piauí has been backed with sodalite from Bahia to produce these Brazilian opal doublets. Photo by Maha DeMaggio.

Last fall, one of the editors (RCK) acquired, from a street vendor in a Chinese neighborhood of Los Angeles, a 239.37 ct statuette (figure 20) that appeared quite similar to some of the mottled-colored, dyed calcite mentioned above. Gemological testing revealed the following properties: diaphaneity—semi-translucent; polariscope reaction—aggregate (appears light when rotated between crossed polarizers); Chelsea color-filter reaction—none (appears same color as the filter); specific gravity (determined by hydrostatic weighing)—1.98. Refractometer testing produced a birefringence blink. With a handheld spectroscope, green areas of the statuette showed a strong band centered at 650 nm, a weak band at 600 nm, and a faint absorption at 500 nm. The statuette luminesced a chalky, moderate-to-strong blue-white to long-wave UV radiation, and a chalky weak blue to short-wave UV. (The green areas had a weaker fluorescence to both wavelengths than the white areas had.)

With a microscope, we saw that the material consisted of white grains in a groundmass of transparent, colorless (or green) material with a resinous luster. X-ray powder diffraction analysis identified the white grains as calcite. The transparent groundmass burned readily when touched with a thermal reaction tester, producing an acrid odor and some liquid. Fourier-transform infrared (FTIR) spectroscopy, performed on a pellet of material scraped from the statuette, gave a spectrum that was very similar to that of an alkyd resin polymer, a synthetic resin used, for example, in house paint.

On the basis of this information, we identified the statuette as a calcite/plastic composite that had been selectively dyed to resemble jadeite. It may have been produced in a mold that was filled with the pre-polymerized resin and finely ground calcite. Although the color and color distribution made it a fairly convincing imitation of some mottled jadeite, both its resinous luster and "heft" (1.98 S.G.) would raise the suspicions of anyone familiar with jade.

Figure 20. This 239.37 ct imitation jadeite statuette (47.35 × 32.90 × 32.75 mm) is composed of finely ground calcite in a groundmass of alkyd resin polymer (plastic). The green areas were probably produced by selective dyeing. Photo by Maha DeMaggio.

"Drusy" silicon, a computer-industry by-product. The Summer 1992 Gem News section (p. 133) discussed and illustrated meteoritic iron used as a gem material. A manufactured material with a similar appearance is elemental silicon (figure 21); at the Tucson shows this year, we saw both fashioned and rough examples of this material.

Bill Heher, of Rare Earth Gallery, Trumbull, Connecticut, loaned us a 31.5 × 40.3 × 5.54 mm elemental silicon doublet for examination. Only a few gem properties from this assembled triangular tablet could be determined: color and luster—metallic gray (backing material—yellow and brown); color distribution—even; diaphaneity—opaque; fluorescence—inert to both long- and short-wave UV radiation. The R.I. was over the limit of our refractometer (greater than 1.81), and no absorption spectrum was detected using a desk-model spectroscope. We also purchased three chunks of elemental silicon from Gems Galore, Mountain View, California. One had a hardness of about 6½ and a specific gravity of 2.34 (hydrostatic method).

Some elemental silicon used in jewelry is different from that used to make computer chips; for instance, one distinguishing feature is the druse-like surface, consisting of many nearly flat-lying crystal faces, on some pieces. (This is the feature that resembles the Widmanstätten pattern observed on some etched iron meteorite surfaces, as in the Summer 1992 illustration.) To the best of our knowledge, the "drusy" elemental silicon is formed from the same starting material as the Czochralski-pulled elemental silicon boules that are the source material for computer chips; the drusy crystals form in the impurity-rich material left remaining in the "pot" after the purified boule is extracted. The trace-element content of the drusy material is thus higher than that of the boules; the silicon surface of the doublet we examined contained trace amounts of arsenic, as determined by EDXRF. Our one boule contained only silicon.

Figure 19. The star in this 3.73 ct (9.18 × 6.82 × 5.39 mm) sapphire was produced by a surface diffusion treatment. Photo by Maha DeMaggio.

The fashioned tablet had been backed with another material because elemental silicon is brittle. The material is popular in jewelry for people who work in computer fields, according to a Gems Galore representative.

A convincing tanzanite substitute. Bill Vance, a gemologist from Denver, Colorado, recently loaned us one of the most superficially convincing imitations of gem-quality tanzanite that we have ever seen. This new tanzanite substitute is now being sold at gem and mineral shows across the United States. Mr. Vance purchased it at just such a show in Denver in September 1995.

Figure 21. This tablet is assembled from drusy elemental silicon and an unidentified backing material. Elemental silicon (shown in its "raw" form on the right) is a byproduct of computer-chip manufacturing. Tablet courtesy of Bill Heher, Rare Earth Gallery; photo by Maha DeMaggio.

Natural tanzanite crystallizes in the orthorhombic crystal system; it is biaxial with strong pleochroism. In fact, strong pleochroism is one of tanzanite's most distinctive characteristics. It would seem unlikely, then, that an isotropic material with no pleochroism could convincingly masquerade as tanzanite. Nevertheless, as figure 22 shows, this new material is a most convincing violet-to-blue.

EDXRF analysis revealed that this manufactured material contains yttrium, aluminum, and europium. The sample we examined was a 7.07 ct transparent oval mixed cut (12.89 × 8.82 × 6.27 mm). The only internal characteristics that we could resolve microscopically were very weak curved striae visible at a slight angle when we looked down the long direction. Through a Chelsea filter, the sample appeared orangy red. Its R.I. was over the limits of a standard refractometer, and its S.G. was 4.62. With a handheld spectroscope, we saw five distinct absorption lines: the strongest at 530 nm, another strong one at 468 nm, two lines of moderate strength at 589 and 472 nm, and a weak one at 480 nm. The sample fluoresced a moderately chalky, strong reddish orange to short-wave UV radiation, with a similar but weaker reaction to long-wave UV. In fact, while all the above-mentioned properties will help separate this substitute from natural tanzanite, the fluorescence to short-wave UV radiation is the easiest test to distinguish the two materials

"Tavalite," cubic zirconia colored by an optical coating. Deposition Sciences Inc., of Santa Rosa, California, is marketing unusually colored cubic zirconia under the trademarked name "Tavalite." Recently, we examined several examples in the six available colors (figure 23). Color descriptions for this material are complicated, as the color is due to a thin optical coating that produces a different appearance in reflected and transmitted light.

Six round-brilliant-cut samples—one of each color—were studied: one 6.5-mm-diameter sample weighing 1.79 ct (not shown in figure 23), and five 4-mm-diameter samples weighing between 0.45 and 0.47 ct. The gemological properties were consistent with cubic zirconia. The color distribution was on the surface only, both crown and pavilion. With magnification, the surface coatings on two samples appeared "dusty," and a third showed a build-up of the coating material at the facet junctions. EDXRF spectroscopy of all six samples revealed yttrium, zirconium, and hafnium; these three elements are consistent with a base material of yttrium-stabilized cubic zirconia. Also discovered were tantalum and silicon, two elements that were probably components of the optical coating. In two examples, titanium was also detected, again probably as part of the optical coating. These coatings may also contain oxygen or nitrogen, but neither can be detected by our EDXRF instrumentation.

Figure 22. This 7.07 ct tanzanite imitation—which contains yttrium, aluminum, and europium—has a very convincing color. Courtesy of Bill Vance; photo by Maha DeMaggio.

As for durability, the surface coating was responsible for all of the color in these samples. The distributor cautioned that strong soaps might affect the surface of "Tavalite"; abrasives and polishing compounds should not be used. However, nonaqueous cleaners (such as rubbing alcohol and "gentle" cleaning with a mild soap—even in an ultrasonic cleaning unit) are acceptable, according to product literature supplied with the samples.

ANNOUNCEMENTS

Sixth annual Cutting Edge Awards. Judges chose 18 winners and 11 honorable mentions from 160 entries in this year's sixth annual Cutting Edge competition, sponsored by the American Gem Trade Association (AGTA) in Dallas, Texas, on April 27 and 28.

Mark Gronlund, of the Custom Jewelry Shop in Deltona, Florida, took three honors, including first place in the Faceting division with his 23.92 ct trillion brilliant-cut citrine. The citrine, when surrounded by specially cut amethysts, also won second place in the Pairs and Suites category (figure 24). First place in Carving went to William Cox, of William H. Cox Enterprises, Provo, Utah, for a 28.67 ct teardrop-shaped sunstone. A 79.10 ct ametrine—fashioned by Steve Walters, of Ramona, California—was awarded first place in the Combination category. Justina De Vries, of Bettenmann-De Vries, Medford, Oregon—who also took second place in the Classic Cuts category—won first place in Pairs and Suites with 7.76 ct and 8.07 ct tourmalines. Objects of Art first place (for the second year in a row) went to Gil Roberts, of North American Gem Carvers, Pilot, Virginia, for a carved chartreuse quartz perfume bottle; Stephen H. Newberg, of CCCC Company, Houston, Texas, was awarded first in Classic Cuts for his 2.52 ct pink spinel.

The competition was open to all colored gemstones of natural origin that were fashioned in North America by a professional lapidary artist. Entries were evaluated on originality of design, quality of work, technique, quality and rarity of the gem material, and overall beauty. The winning gemstones were displayed at the June JC-K Show in Las Vegas, Nevada; winners will be honored at a January 29, 1997, reception at the AGTA Gem Fair in Tucson.

Gem-related exhibits at American Museums. Several natural history museums currently have exhibits with gem and jewelry themes. In New York City, the **American Museum of Natural History** has "Amber: Window into the Past," which runs through September 2, 1996. It includes major sections on the natural history of amber (including a simulation of an ancient amber-producing forest environment), and on the use of amber in jewelry and decorative objects in many ancient and modern cultures; a catalog is available. In Cambridge, Massachusetts, the **Museum of Cultural and Natural History at Harvard University** is presenting an exhibit on birthstones that is scheduled to remain on display for the next five years. Finally, a traveling exhibit of more than 400 items from the studio of Peter Carl Fabergé, including several Fabergé eggs, is visiting the **Metropolitan Museum of Art** in New York City; the **M. H. de Young Museum** in San Francisco; the **Virginia Museum of Fine Arts** in Richmond; the **New Orleans (Louisiana) Museum of Art**; and the **Cleveland (Ohio) Museum of Art**.

Figure 24. This trillion-cut citrine took first place in the Faceting division of the 1996 AGTA Cutting Edge competition. The citrine with the amethysts took second place in Pairs and Suites. Stones faceted by Mark Gronlund; photo © Tino Hammid.

Figure 23. These six 4-mm-diameter samples (about 0.46 ct each) of a cubic zirconia marketed as "Tavalite" owe their colors to thin optical coatings. Photo by Maha DeMaggio.

Special synthetics exhibit at the Sorbonne. The Mineral Collection of the Université Pierre et Marie Curie, 34 rue Jussieu, Paris, features a special exhibit of historical and contemporary synthetic gem materials. (The first synthetic crystals were grown in France in the late 19th century.) This special exhibit, set among the fabulous specimens of this world-class collection, will be open through October 31, 1996.

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BOOK Reviews

SUSAN B. JOHNSON AND
JANA E. MIYAHIRA, EDITORS

THE ART OF JEWELRY DESIGN, Volume I

*By Maurice P. Galli in collaboration with Nina Giambelli, 224 pp., illus. by Maurice P. Galli, Dominique Rivière, and Fanfan Li, publ. by Schiffer Publishing, Atglen, PA, 1994.**

Promoted in the foreword by the Fashion Institute of Technology's Samuel Beizer as the first comprehensive reference for the jewelry design process, *The Art of Jewelry Design* accomplishes this objective visually, with minimal text. The approach is not only refreshing, it is also appropriate, given that the essence of a subject should be presented in its most effective and understandable format. This colorful volume is filled with illustrations of rendering techniques as well as fanciful paintings of jewelry designs that would be of interest to students, designers, artisans, and anyone who appreciates fine jewelry.

There is a fascination with jewelry design that is unique and personal. It is exciting to envision the creation of a work for human adornment, exquisite in detail and movement, from materials that are themselves beautiful, valuable, and rare. However, acquiring the ability to communicate this vision of a jewel through a striking illustration is even more compelling. This is the primary reason for the book's appeal. Much of the mystery behind the illustrative process is revealed, as the observer is invited to look over the shoulder of a professional jewelry designer and watch as the works unfold on paper.

The collaborating illustrators share their expertise and experience, which was honed in some of the trade's most prestigious jewelry design firms. Mr. Galli, who manages Tiffany's jewelry design department and teaches jewelry design at FIT in New York, has designed for Harry Winston, David Webb, and Van Cleef & Arpels. Ms. Li, an award-winning designer, currently creates for Van Cleef & Arpels in New York. Mr. Rivière, who has been associated with the top jewelry salons in the world, now designs for GemVeto of New York.

In Part I of this volume, the designers introduce the basics for experimenting with a classic rendering style. The sequential presentations of the general painting methods will be clearly understood by the novice but also offer alternative styles of rendering for the experienced illustrator. Several illustrations compare and contrast the application of various design principles.

Part II supports the principles touched on in Part I with a series of specific methods to paint gemstones and metal. Of importance to student designers are the helpful bits of information, such as the shapes and cuts of those gemstones that are most frequently used, the standard setting styles, guidelines for stone layout, and variations on basic shapes. The practical information on working with costing parameters, terminology, and history is also useful.

Unfortunately, I found the quality of the book itself—the printing, resolution of images, binding, and particularly the graphic design—to be incongruent with the authors' fine illustrations. Although each plate is thoughtfully arranged, with numerous and diverse examples, throughout the book there are inconsistencies in the graphics (e.g., some details are numbered while others are not) and the text layout, which often makes for difficult reading.

While the work of Galli, Rivière, and Li is worthy of a more professional presentation, I am reminded that the book was "conceived as a handbook and reference"; as such, it retains the overall impact of its content. *The Art of Jewelry Design* would be a beautiful and pertinent addition to any jewelry library.

LAINIE MANN
Curriculum Design Specialist
Course Development Department
GIA Santa Monica

COLLECTIBLE BEADS: A UNIVERSAL AESTHETIC

*By Robert K. Liu, 256 pp., illus., publ. by Ornament, Inc., Vista, CA, 1995. US $49.95**

Here is a book that every contemporary bead enthusiast should own. Robert Liu takes the reader through the actual process of collecting these portable, perforated artifacts—from those that date as far back as 40,000 years to those made by present-day artists.

Throughout history, beads have been an integral part of human existence. They reflect the development of societies and of the skills, art, and economies of various civilizations. They are also useful in tracing the interactions between civilizations. To illustrate these themes, Liu takes the reader on a country-by-country tour of major cultural and geographic bead regions: Africa, China and Taiwan, Japan, Korea, the Himalayan countries, Indonesia, Thailand and the Philippines, the Middle East, the Americas, pre-Columbian America, and Europe. It is more of a travelogue of beads than a strict chronology.

In his narrative, Liu covers mainly those beads that have gained appreciation as collectibles during the past 20 years of what he considers to be the rise of the bead movement. The actual process and strategies of collecting are discussed in depth in this beautifully illustrated reflection of the author's enthusiasm for the subject. The book also includes chapters on necklace design, various stringing techniques, and clasp design; a glossary of bead terminology, as well as a listing of bead societies, research organizations, and international bead publications; and many well-referenced quotations about beads that have appeared in the literature. This publication is definitely a prized addition to any "beadophile's" library.

ELAINE FERRARI
Instructor
GIA Santa Monica

**This book is available for purchase through the GIA Bookstore, 1660 Stewart Street, Santa Monica, CA 90404. Telephone: (800) 421-7250, ext. 282; outside the U.S. (310) 829-2991, ext. 282. Fax: (310) 449-1161.*

GEMOLOGICAL ABSTRACTS

C. W. FRYER, EDITOR

COLORED STONES AND ORGANIC MATERIALS

Captured in amber. D. A. Grimaldi, *Scientific American*, Vol. 274, No. 4, April 1996, pp. 70–77.

This short article about Dominican and New Jersey amber does not really furnish much essential news for gemologists, but it is impressive because of its many fascinating color photos of different insects in amber frozen forever in different acts (even sex). Also pictured are a gecko, frogs, and a feather (the latter the oldest terrestrial record of a bird in North America). David Grimaldi (amber expert and professor of entomology at the American Museum of Natural History in New York) describes how the excellent preservation of plant and animal tissues in amber allows examination of minute details by electron microscopy (illustrated here by a series of photomicrographs). Creating dinosaurs from DNA preserved in amber, as was done in the novel/movie *Jurassic Park*, may still be the stuff of fiction. However, it has been possible to analyze the DNA preserved in some cells and thus establish the evolutionary relationship between termites, cockroaches, and praying mantises. *RT*

Corundum from basaltic terrains: A mineral inclusion approach to the enigma. J. Guo, S. Y. O'Reilly, and W. L. Griffin, *Contributions to Mineralogy and Petrology*, Vol. 122, No. 4, 1996, pp. 368–386.

From over 1,000 corundum (predominantly sapphire) crystals and fragments associated with basaltic rocks, mostly from eastern Australia and China, 82 primary mineral inclusions were identified. Most abundant (65% of the total) were niobium (Nb) and tantalum (Ta) oxide minerals, of which columbite, ilmenorutile, and pyrochlore are the most important. Silicates (30%) were predominantly zircon and feldspar, and rare sulfide (pyrrhotite) and phosphate (brockite) minerals made up most of the remainder.

On the basis of known geochemical characteristics and geologic associations of these mineral inclusions, the authors postulate that at least two magmas are involved in the formation of the corundum crystals. For example, feldspar, zircon, and ilmenorutile are associated with alkaline felsic rocks, whereas the types of columbite and pyrochlore that occur as inclusions in the corundums are associated with carbonatitic rocks. From this they devel-

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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 abstracter and in no way reflect the position of Gems & Gemology *or GIA.*

op a "mixing-hybridisation" process to explain the origin of corundum at these localities.

The proposed process involves the interaction between a high-silica magma and a carbonatitic (or some other silica-poor) magma. From the resulting hybrid magma, corundum precipitates and gives rise to locally distributed lenses of corundum-bearing rock. Subsequent volcanic eruptions of basaltic magma, from mid-crustal levels within the Earth, bring the corundum as xenocrysts to the Earth's surface (the corundum-bearing rocks having been disintegrated by the basaltic magma and the sapphires released). Regrettably, the authors have not considered other recently proposed mechanisms for the origin of corundums from the same localities. *AAL*

Notes from the Gem and Pearl Testing Laboratory, Bahrain—5. A. Bubshait and N. Sturman, *Journal of Gemmology*, Vol. 25, No. 1, 1996, pp. 20–23.

This issue's Notes section focuses on amber and emeralds. An amber box, reportedly of Russian origin, was constructed primarily of natural amber, but darker-colored inlays in the lid proved to be pressed amber. The latter was identified on the basis of interference colors and typical inclusions—that is, minute brown to black impurities forming swirled, smoke-like patterns. The identification was made more challenging by the presence of a reddish brown dye in the adhesive. A string of prayer beads that were represented as amber proved to consist of amber particles embedded in molded plastic. The nature of the beads became evident with magnification, which revealed typical seam lines running around the midsection of each bead.

Recently, the lab has encountered a number of resin-filled emeralds, primarily of Colombian origin. One notable example exhibited a pronounced flash effect from numerous filled fractures, as well as moderate reactions to both long-wave and short-wave UV radiation—both fluorescence and (to short-wave) phosphorescence. Staff members at the Bahrain lab had previously not seen such luminescence in resin-filled emeralds. This entry also addresses the ongoing debate on disclosure, and closes by stating the lab's policy on such identifications: The report simply states that a filler is present (because of the difficulties in determining the exact identity of these fillers). When lab staff agree on a more exact identification for a filler, they report it verbally to their clients. *CMS*

DIAMONDS

1995 a record year for diamond imports, exports. M. K. Golay, *National Jeweler*, April 1, 1996, p. 76.

In 1995, American merchants imported 11.9 million carats of cut, unset diamonds valued at more than $5.3 billion, compared to 10.6 million carats valued at more than $4.9 billion in 1994, according to U.S. government information interpreted by the American Diamond Industry Association, New York. Both figures established year-to-year records—an 11.7% increase in carats and 7.6% in value. More than 39% of the diamonds by value ($2.1 billion) came from Israel. India ($1.4 billion) and Belgium ($1.3 billion) followed. Together, the three countries supplied more than 95% of the total weight in diamonds imported into the U.S. The average price of imported loose, polished diamonds dropped 3.7% in 1995, from $463 to $446 per carat. Of the top eight sources by value, the average price of diamonds imported from Switzerland was highest, at $6,978 per carat, whereas stones from India averaged $183 per carat.

Exports of cut, unset diamonds from the United States in 1995 set a record. Total shipments of 2.1 million carats ($2 billion) were all-time highs for both weight and value. Exports were up 62.2% by weight and 15.6% by value over 1994. Israel, Belgium, and Hong Kong were the United States' top export trading partners by value, at $478 million, $463 million, and $433 million, respectively. Shipments increased in value to each of these countries over 1994 by 22.9%, 15%, and 8.5%, respectively. Percentage increases were also seen in the value of diamonds exported to Singapore (58.4%), Japan (18.2%), and Canada (12.6%). U.S. diamond exports averaged $932 per carat in 1995, compared to $1,317 per carat in 1994. This 29% drop is a reflection of larger shipments of lower-priced goods to each of the top eight trading partners, except the United Kingdom and Canada. *MD*

Canadian diamond boom. S. Voynick, *Rock & Gem*, Vol. 26, No. 6, June 1996, pp. 21, 22, 24, 26, 68.

It is now about six years since the Lac de Gras kimberlite field in the Northwest Territories of Canada was discovered. It is anticipated that, in a few years, this locality will be producing about 3,000,000 carats of diamonds annually. This timely, well-written article repeats the saga of how Charles Fipke followed the trail of diamond-indicator minerals (pyrope garnet, ilmenite, chrome diopside) dispersed from kimberlites by glaciers, persevering over great adversities until he found the first of the many pipes in this inhospitable region. Mr. Fipke is now estimated to have a personal wealth of more than $300 million.

This article, however, differs significantly from most others written on this topic in that it begins with a summary of the basic facts of diamond formation and occurrence that were undoubtedly used by Mr. Fipke in his exploration concepts and decisions. These include the depth (at least 120 km) within the Earth at which diamonds form (diamond stability zones); the rapid rate at which diamonds must be carried to the surface by kimberlite magma (or else they will not survive the trip, because they will dissolve in the kimberlite); and the critical recognition that kimberlite is emplaced in specific geologic regions (archons).

The article also discusses the importance of geophysics (e.g, airborne magnetics) in exploration, how diamonds are recovered from kimberlite rock (e.g., dense-medium separation, X-ray sorters), and other topics of a general nature. *AAL*

Discard small diamonds—they're not worth the effort. *Diamond Industry Week*, Vol. 2, No. 39, October 9, 1995, p. 4.

The per-carat value of large diamonds compared to small diamonds is much greater than can be accounted for by the difference in carat weight alone. In recognition of this fact, Western Australia's Argyle diamond mine will no longer process ore to extract diamonds smaller than 1.5 mm. Although revenue is expected to increase as much as 10% because of this decision, the projected open-pit life of the Argyle mine will decrease by 10 months (ending in 2004).

Argyle's decision is likely to result in a slight increase in the price of small diamonds, which may hurt the diamond industry in India, where many such stones are cut. However, ignoring smaller diamonds is an action consistent with a "true market economy for diamonds." *MLJ*

Inclusions in precious stones. I. Solid inclusions in diamonds (Polish with English abstract). M. Plaszynska, *Mineralogia Polonica*, Vol. 26, No. 1, 1995, pp. 79–86.

Mineral inclusions identified in diamonds are listed and linked to their probable paragenesis. The author concludes (1) that the chemical nature of most of these inclusions does not depend on the mode of occurrence of the diamonds, and (2) that two distinct suites of primary inclusions in diamonds can be distinguished (on the basis of X-ray and microprobe analyses). *RAH*

New places to look for diamonds. B. Cordua, *Rocks Digest*, Vol. 8, No. 1, 1995, pp. 5, 8.

Very small diamonds (about 0.01 mm) have been found as perfect cubes and octahedra in garnet and zircon crystals recovered from metamorphic gneisses in the Kukchetin (or Kokchetev) block in Kazakhstan, about 800 km west of Novosibirsk. These rocks were first laid down as sediments about 2 billion years ago, and they were metamorphosed about 530 million years ago. In 1990, Sobolev and Shatsky concluded that the diamonds grew during the metamorphism of the rock, which occurred at temperatures about 900°–1000°C and pressures above 40 kbars (depths greater than 100 km). The diamonds survived the uplift interval, which should have converted them to graphite, because they were encased in the garnet and zircon; a short time-scale for uplift is also implied. *MLJ*

South Africa diamond plant success. *Mining Journal, London*, September 22, 1995, p. 216.

Dowding Reynard and Associates, in Johannesburg, South Africa, design mineral processing plants. In 1995, they reported sharply increased interest in modular diamond-recovery plants for delivery to Africa and elsewhere. A new product is a full-scale dense media separation plant that is exported in modular form. Traditional modular diamond plants can process up to 25 tons per hour of diamondiferous material; however, a 150-ton-per-hour plant has been ordered for De Beers in Namibia (Namdeb), a 120-ton-per-hour plant for De Beers in Tanzania, and two 100-ton-per-hour plants for Auridiam's River Ranch project in Zimbabwe.

Smaller plants require fewer resources. A jig plant for exploration in Mozambique, which processes 8 tons per hour, has an onboard diesel generator for stand-alone use; and a miniature DMS plant has been designed for field sampling and on-the-spot appraisal of resources in northern Canada. *MLJ*

Southern Era reports significant values at SUF-1. *Diamond Industry Week*, Vol. 2, No. 40, October 16, 1995, p. 3.

Southern Era Resources announced the most recent valuations of diamonds recovered from its kimberlite dike project in South Africa: The two lowest averaged US$85.29 per carat. As of mid-October 1995, 263.39 carats had been recovered from the main pit (average grade was 5.49 carats per metric ton); an additional 22.05 carats were recovered from 17.66 metric tons of fault breccia. The largest diamond weighed 10.51 carats, and about 94% of the diamonds were "cuttable gems."

Reconnaissance sampling indicates that the main fissure zone contains kimberlite and/or diamonds along its length for at least 30 km. Diamonds have also been recovered as far as 1150 m from the main fissure *MLJ*

Thinking the unthinkable: Argyle ponders a break from De Beers. R. Shor, *Jewelers' Circular Keystone*, Vol. 167, No. 5, May 1996, pp. 98–105.

Australia's Argyle diamond mine is weighing the pros and cons of going independent, as De Beers's Central Selling Organisation successfully concludes negotiations to continue distributing and marketing Russia's diamond production. An independent Argyle could fundamentally change the way rough diamonds are sold in the international marketplace. Foremost, De Beers's price-control policies would face the reality of actual supply and demand. An independent Argyle could help restructure control of the diamond trade, in essence allowing several large corporate mining companies to control the core trade in the future. Possible future "diamond czars" (along with De Beers) include RTZ-CRA, a British conglomerate and now the world's largest mining company; BHP, a large Australian mining group that controls the major Canadian diamond discoveries; and Ashton, a smaller Australian mining company with a 40% share of the Argyle Mine.

Argyle executives realize the importance of their decision and have been planning a possible break with De Beers for a long time. To this end, they have worked (successfully) to enlarge their customer base and improve the efficiency of their current mining operations. Even with a recent revamping of surface mining at Argyle, however, the future economic success of the mine will depend on whether the company can afford to develop an underground shaft, a decision that may have to be made as soon as next year. *JEC*

A year of overfeed. L. Rombouts, *Diamond International*, No. 39, January-February 1996, pp. 61, 62, 64–66, 68.

In 1995, more rough diamonds—130 million carats—entered the market than in any other year in history (108 million carats in 1994). Production statistics for 1995 are presented for 21 countries (which accounted for 111.5 million carats). The remaining 18.5 million carats are believed to have originated from Russia (as diamonds brought to the market via non-CSO channels, either from Russia's stockpile or through polishing joint ventures) and from artisanal mining in Africa and South America. Notwithstanding the large increase in "outside" rough, the diamond market absorbed the "overfeed" without serious problems. Statistics are also presented for the average value (US$ per carat) of each country's production and for production from the world's 18 major mines (mostly pipes, but also some secondary deposits, such as in Namibia). In 1995, CSO sales amounted to 63% of the world's total rough diamond supply.

The status of diamond exploration in numerous countries is reviewed with the purpose of predicting future diamond reserves. For the next 20 years, according to Dr. Rombouts, 98% of the world's diamond reserves by weight will be found in eight countries: Botswana (32%), Russia (21%), Australia (11%), Angola (10%), South Africa (9%), Zaire (8%), Canada (5%), and Namibia (2%). However, by value, the sequence is (for 97% of the total): Botswana (33%), Russia (26%), Angola (11%), South Africa (10%), Namibia (7%), Canada (5%), Zaire (3%), and Australia (2%). Relative to 1995 production statistics, the above 20-year reserve and value estimates show major reductions in the role of Australia and Zaire and, for the first time, a significant role for Canada (where production is expected to start in 1998). *AAL*

GEM LOCALITIES

Atop the Andes—mining Chile's mountain-high lapis. F. Ward, *Lapidary Journal*, Vol. 50, No. 3, June 1996, pp. 36–40.

I had always considered Chilean lapis lazuli to be somewhat "second-rate" until I read this enlightening article by a popular and well-known gemological author. Eight beautiful color photos illustrate quality lapis from this locality, now available in sculpture, accent tile, and a variety of other decorative objects. Covered are the geologic forces that form the lapis, the history of the Las Flores de los Andes lapis mine and methods of mining there, nomenclature, and differences between the classic Afghanistan deposit and its Chilean counterpart. *JEC*

Chad: Discovering new mineral wealth *Mining Journal, London* [advertisement supplement], September 22, 1995, 12 pp.

The geology and mineral potential of this land-locked African nation have not been investigated to any great extent; however, alluvial diamonds have been found in many regions. The main areas of alluvial diamond production are Abeche, Biltine, Am Zoer, and Adre in Ouadday, and Melfi-Bitkine in Guera. Some alluvial stones also have been found along the Lim River in Baibokoum (on the Central African border), but the lack of diamond-indicator minerals implies that these diamonds may have come from sources in neighboring countries. The Oadday and Guera stones are far from other drainages, however, and the primary sources, although not yet found, are believed to be in Chad. *MLJ*

The gems of Mont Saint-Hilaire, Quebec, Canada. W. Wight, *Journal of Gemmology*, Vol. 25, No. 1, 1996, pp. 24–44.

The common gravel quarry at Mont Saint-Hilaire is one of the world's richest sources for rare minerals, many of which have been faceted or polished as collectors' gems. Within this small (about 0.5 km^2) area, more than 300 species of minerals have been found, many for the first time and others in colors or qualities found nowhere else. Remarkably, this rich source has attracted the attention of mineral collectors only since the 1960s and lapidaries only since the 1970s. Among the notable (and facetable) minerals found at Mont Saint-Hilaire are serandite, willemite, siderite, rhodochrosite, carletonite, hackmanite, and shortite. These and others are illustrated. In addition, two tables list notable minerals recovered from this deposit, as well as identification properties for a considerable number of them. The author cautions that many of these minerals and gems can be very difficult to identify. *CMS*

A guide to new fossicking legislation. B. Neville, *Queensland Government Mining Journal*, Vol. 96, No. 1123, June 1995, pp. 5–9

"Rockhounding" in the United States is called "fossicking" in Australia. Many Australian states have laws to regulate this activity. In 1994, Queensland revised its fossicking law. Although fossicking is defined as purely an amateur activity, a renewable license is now required. Certain public lands are designated as Fossicking Lands and Fossicking Areas, collecting is permitted on private lands (with the owner's permission), and some areas—including national parks and lands under native title—are closed to collecting. There are limitations on the types of tools allowed, and fossickers must pay royalties to Queensland for quantities removed above exempted amounts. Among the places set aside especially for fossickers are some sapphire and opal fields. Vertebrate fossils and meteorite-related materials are not covered by fossicking regulations; however, this article does not say whether such materials may be collected legally. *MLJ*

India: A rich mining heritage. *Mining Journal, London* [advertisement supplement], September 15, 1995, 12 pp.

This review article contains some information (from India's Ministry of Mines via *Mining Journal* resource services) about diamonds and other gem materials found in

India. Primary diamond deposits (kimberlites and/or lamproites) are found in the states of Madhya Pradesh (the Panna district) and Andhra Pradesh (the Anantpur, Krishna, and Karnool districts); reserves are estimated at one million carats. One mine—the Majhgawan operation in Madhya Pradesh—produces 19,000 carats annually. Diamonds are also found in the "extensive" conglomerates in the Kurnool and Vindhyan basins, and in gravels along the Krishna and Mahanadi Rivers. India has the "world's largest diamond cutting and polishing industry," employing 600,000 people and producing 70% of the world's finished diamonds. Colored stones (such as emeralds, rubies, garnets, and cat's-eye stones) are mined in the Kalahandi and Bolangir districts of Orissa. *MLJ*

River pearls from Bavaria and Bohemia. H. Hahn, *Journal of Gemmology*, Vol. 25, No. 1, 1996, pp. 45–50.

The freshwater mussel *Margaritifera margaritifera* has long lived in the streams and rivers of northern Europe. During the Middle Ages, these mussels were exploited heavily for their pearls, and exquisite examples of their use—in both religious and secular pieces—can be seen in the museums of Germany and Austria in particular. Bohemia developed both a thriving pearl trade and an extensive jewelry manufacturing center in Prague. By the 19th century, *M. margaritifera* had become virtually extinct, largely as a result of industrial pollution of the rivers. In fact, recent interest in propagating *M. margaritifera* is due primarily to the fact that these mussels are so sensitive to water pollution that they are one of the best indicators available to ecologists concerned with river and stream conditions. Various government and educational groups throughout northern Europe are cooperating to expand the distribution of *M. margaritifera*.

The author also provides some fascinating information on these mussels, including their dependence on a particular species of trout for propagation. As this once nearly extinct animal again begins to thrive in European waters, gemologists can look forward to the bonus of seeing more of their exceptional by-product—pearls. *CMS*

The role of fluorine in the formation of colour zoning in rubies from Mong Hsu, Myanmar (Burma). A. Peretti, J. Mullis, and F. Mouawad, *Journal of Gemmology*, Vol. 25, No. 1, 1996, pp. 3–19.

The growth patterns and color zoning typical of Mong Hsu rubies suggest a complex growth history with compositional fluctuations in the formation environment. When both Ti and Cr are abundant, violet-to-black sapphire forms; when Cr is moderate to high and Ti virtually absent, ruby forms; and when Cr is moderate and Ti low, pink-to-violet sapphire forms. The great number of mineral inclusions found in these rubies confirm the complexity of their growth environment and provide information about that environment. Specifically, the presence of fluorite inclusions is evidence that fluorine (F) was an element of the growth solution. Likewise, fluid inclusions indicate the presence of water. On the basis of a preliminary model, the authors conclude that F concentrations played a major role in the development of the color zoning in Mong Hsu rubies. *CMS*

Shenzi: The politics of mining tanzanite. E. Blauer, *Lapidary Journal*, Vol. 50, No. 3, June 1996, pp. 42–45.

This beautifully illustrated, concise article chronicles the fascinating history of tanzanite mining in the country after which this distinctive blue gem was named. According to the author, *shenzi* is a Swahili word that translates roughly to "sleazy." After reading this article, it is not difficult to see why the word might apply to the subject at hand.

Discovered in 1967, tanzanite (a gem variety of the mineral zoisite) has suffered through periods of erratic supply because of government intervention. Since 1971, the Tanzanian government has tried to control and profit from mining and sales of tanzanite. The net result of these efforts has been rampant illegal mining and smuggling that, at times, only served to drive prices down, as large quantities of the gem entered the market with no regard to the sizes and qualities that were really needed.

Although goods are still plentiful, especially the big stones that have made tanzanite so popular with designers, there is concern that some areas at the Merelani mining district are worked out. Smaller stones appear to be in short supply, especially in light of the demand created by the home shopping networks. Reported new discoveries in Kenya and elsewhere in Tanzania, however, may help to keep the supply steady for now.

The final page of the article describes how Narottam Pattni discovered how to heat treat tanzanite, turning a near-worthless off-color crystal into the sought-after deep-blue treasure that it is today. *JM*

Treasures of Glen Innes. M. Kelly, *Australian Gold Gem & Treasure*, Vol. 11, No. 2, February 1996, pp. 32–37.

The New England region of New South Wales, Australia, has many different gem materials for the amateur collector. Buried alluvial beds at Wellingrove contain sapphire, topaz, and zircon; beryl is found in Torrington, and nearly all the streams in the Glen Innes area contain sapphires. Persistent searchers continue to turn up stones missed by commercial miners. Unlike Queensland, however, there are no large zones of free access for gem mining, so collectors must ask local landowners for permission to dig.

Although "cornflower blue" sapphires are easily recognized in washed gravels, other colors (and shades of blue) can be overlooked. One technique to spot these sapphires is the "old mirror trick": Take a large spoonful of gravel concentrate—washed "as clean as the water available to you will allow"—and spread it across the surface of a mirror in the sunlight. The sapphires become translucent from the light reflecting back through them.

The town of Glen Innes boasts "the best country museum in Australia," the Land of the Beardies Museum.

It contains displays of minerals, gems, and old mining equipment. *MLJ*

An unusual ruby-sapphire-sapphirine-spinel assemblage from the Tertiary Barrington volcanic province, New South Wales, Australia. F. L. Sutherland and R. R. Coenraads, *Mineralogical Magazine*, Vol. 60, No. 4, 1996, pp. 623–638.

Small, corroded, crystalline aggregates of ruby-sapphire-sapphirine-spinel occur in corundum-bearing alluvial deposits derived from the Barrington shield volcano. The sapphirine has a near 7:9:3 ($MgO:Al_2O_3:SiO_2$) composition and, together with the corundum, shows reaction rims of pleonaste. Spinel in these aggregates has a composition of $Sp_{68-73}Hc_{27-29}Cm_{0-3}$. Potential origins for these aggregates include metamorphic recrystallization of aluminous material (<1460°C) or high-temperature, high-pressure crystallization reactions related to lamprophyric or basaltic magmas (≤1300°C and 20 kbar). Sapphirine-spinel thermometry suggests final crystallization for the aggregates at ~ 780°–940°C and reaction with the host magmas at >1000°C. The Barrington gemfield includes two distinct corundum sites. One, typical in eastern Australia, is dominated by blue-green, well-crystallized, growth-zoned sapphire, commonly containing rutile silk and Fe-rich spinel inclusions. The other, an unusual site, is dominated by ruby and pastel-colored sapphires; these have little crystal shape or growth zonation, and they have limited mineral inclusions of chromian pleonaste and pleonaste. Chemical analyses are given for sapphirine and a range of spinels. It is tentatively suggested that sapphirine may be of use as an alluvial indicator mineral for ruby. *RAH*

INSTRUMENTS AND TECHNIQUES

Hanneman-Hodgkinson synthetic emerald filter. T. Linton and A. Shields, *Australian Gemmologist*, Vol. 19, No. 2, 1995, pp. 65–68.

The authors tested the Hanneman-Hodgkinson Synthetic Emerald Filter and found that it performed as stated in the instruction booklet. This new emerald filter is designed to be used with the well-established Chelsea filter, not as a substitute for it. While jewelers are always hoping for the so-called black box that will easily separate natural from synthetic emeralds, the Hanneman-Hodgkinson Synthetic Emerald Filter is not the all-inclusive answer. It is a gemological tool that works when used as specified. However, it does have certain limitations.

For instance, table 1 shows that six observers differed about what color they saw when examining the same test stone(s). They variously described the filter reaction for an emerald from Colombia as colorless, green, blue, and pink. The filter colors reported for some of the synthetic emeralds tested also varied somewhat. While all observers agreed that the Regency hydrothermal synthetic emerald appeared red through the filter, the visual color opinions on the Chatham and Inamori stones were far less consistent.

Another limitation, as stated by the filter's inventors, is that it does not work on Biron or Russian hydrothermal synthetic emeralds. These appear to have the same color through the filter (green) that most natural emeralds have.

With the Hanneman-Hodgkinson Synthetic Emerald Filter, if one observes a red color, then the stone is not a natural emerald. If a pink color is noted, then the stone is probably synthetic, but caution is in order. If the stone appears green, then other avenues of gemological testing are needed.

As with all gemological testing techniques that appear outwardly simple, the Hanneman-Hodgkinson filter actually requires a great degree of interpretive expertise and experience. The usefulness of this filter would be greatly enhanced if a set of reference emeralds of known natural and synthetic origin were available for direct comparison. *John I. Koivula*

New methods of photography through the microscope: Application to gem materials. K. A. Kinnunen, *Geological Survey of Finland, Special Paper 20* (Current Research 1993–1994), 1995, pp. 185–187.

New techniques are described for the photomicrography of macroscopic specimens, including crystal faces and gold nuggets, in their natural state. An acetate peel is obtained from the cleaned surface of the specimen, and the peel is mounted and studied in transmitted light and photographed. Color-filter shadowing is used to enhance the specimen's three-dimensional aspects. Examples given include photographing the rhombohedral faces of amethyst crystals. The method has been used to identify faked specimens and in criminological studies. *RAH*

PRECIOUS METALS

U.S. mines more gold. M. K. Golay, *National Jeweler*, April 1, 1996, p. 24.

The United States could top South Africa as the world's largest gold producer by the year 2000, if the current trend continues, according to the Gold Institute. It is projected that by 1998, U.S. gold production will supply 16% of the world's demand, as compared to 2% for 1979. However, South Africa's contribution has dropped from 53% to 21%. Royal Oak Mines, Kirkland, Washington, expects its 1996 gold production to reach approximately 425,000 ounces, about 15% more than its 1995 production of 371,151 ounces. Australia's gold production is also rising, from 1% of the world total in 1979 to an estimated 13% in 1998. Canadian output remained roughly the same, up just slightly from 4% to 6%. *MD*

World silver use. M. K. Golay, *National Jeweler*, April 1, 1996, p. 24.

Jewelry and giftware manufacturers in the United States used approximately 10.8% more silver in 1995 (a total of 4.1 million ounces) than in 1994, according to the *Silver Survey 1996*, by CPM Group, a precious metals research firm. The increase was due to greater consumer interest in silver jewelry, reports CPM. Worldwide silver use in jewelry and decorative objects was relatively stable last year, rising only 0.4% from 222 million ounces in 1994 to 222.9 million ounces in 1995. The major reason for the sluggish market was a 15% decline in silver use in India because of severe supply constraints there. U.K. jewelers and silversmiths continued to expand, consuming 3 million ounces of silver in 1995, an 11% increase. Italian jewelers increased their silver use by an estimated 14.5% to 46.6 million ounces last year, CPM said. Silver prices year-to-year ended up fairly even; 1995 was the sixth straight year in which silver fabrication demands exceeded total new silver supplies. *MD*

SYNTHETICS AND SIMULANTS

[New type of] synthetic alexandrite we encounter in gem ID lab lately (in Japanese). National Gemmological Association Technical Laboratory, *Gemmology*, Vol. 26, No. 308, May 1995, pp. 4–5.

This article describes a new type of synthetic alexandrite, which contains needle-like inclusions that are very similar to those seen in natural alexandrite. This material first caught the authors' attention in November 1994. Since then, they have tested several mixed-cut loose synthetic alexandrites, from 1 to 3 carats. All of the samples examined were of high clarity and showed a strong change-of-color from bluish green to purplish red, similar to that seen in natural alexandrite from Brazil.

Their refractive index was 1.738–1.746 ± 0.001, which were low values for their color (birefringence, 0.008). All of the samples fluoresced strong red to long-wave ultraviolet radiation; some showed strong red, and others showed moderately strong chalky yellow, to short-wave UV. With magnification, the authors observed randomly placed, needle-like metallic inclusions that were sometimes accompanied by gas bubbles. Immersed in methylene iodide, the stones showed curved color bands. The spectroscope revealed absorption at 680, 665, 655, 645, and 465 mm, but it did not reveal the 365 and 375 mm features almost always shown by natural alexandrites. In addition, the absorption cut-off in the violet was shifted toward the lower wavelenghts. From these testing results, the authors concluded that the samples were manufactured by the (Czochralski) pulled method. *HN*

TREATMENTS

Heat treating sapphires from the Anakie District, Australia. T. Themelis, *Australian Gemmologist*, Vol. 19, No. 2, 1995, pp. 55–60.

This article vaguely discusses the colors that resulted when 20,000 carats of rough sapphires were heat treated at various temperatures and atmospheres. The article looks very scientific and informative at first glance, but few practical details are given. For example, the author says that "careful controlled rates of heating and cooling" were used, but he does not say what the rates were. Nor does he elaborate on the "gas mixtures used [that] were poisonous." However, I did glean a few facts: A 20°C-per-minute rate of heating and cooling prevented recrystallization of rutile; strong reducing atmospheres during heating produced muddy green or black colors; blue-to-green sapphires turned a better color than green-to-yellow ones; and final color was established one to two days after treatment. *CEA*

MISCELLANEOUS

1995: The geosciences in review. [Various Authors], *Geotimes*, Vol. 41, No. 2, February 1996, pp. 17–54.

This compendium reviews trends and new discoveries in the geologic sciences during 1995; some of these insights may be relevant for gemologists. Perhaps the most significant change in recent years has been the drastic decrease in government funding for the geologic sciences, as evidenced by the recent closure of the U.S. Bureau of Mines Also included in the many topics covered:

- Information-science trends (reviewed by B. E. Haner) reflect the increasing importance of communication through computer networks, especially—but not limited to—the rising prominence of the World Wide Web. The invaluable *GeoRef* CD-ROMs (which this abstracter consults frequently) continue to be updated, and high-resolution scanning is being developed, leading to the preservation as digitized information of large-format illustrations, such as fragile geologic maps.
- Although planetary geology (reviewed by J. R. Zimbelman) leans toward the esoteric, one result this last year is that there are a calculated 72,000 tons of (admittedly tiny) 0.2 mm diamonds in the suevite rocks within the Ries impact crater, Germany. Similarly, meteoritics (reviewed by H. Y. McSween Jr.) reveals still smaller diamond, silicon carbide, and corundum grains (older than our solar system) found in chondritic meteorites.
- An exciting trend in exploration geophysics (reviewed by W. H. Dragoset) is the development of real-time, three-dimensional seismic characterization of subsurface rocks in the field.
- Exploration geochemistry (reviewed by J. E. Gray) continues to be invaluable in the search for diamonds in Australia, Brazil, China, Guyana, India, Indonesia, Namibia, South Africa, Tanzania, Venezuela, Zimbabwe, and several provinces of Canada.
- Satellite remote sensing data (reviewed by E. D. Paylor II and M. Baltuck) have been used for observation of paleodrainages (former river channels) along the Nile River.
- In the field of mineral chemistry (reviewed by C. Shearer), a research effort approaching fruition is the understanding of the rules governing trace-element distributions in minerals, especially for the rock-forming clinopyroxenes (such as diopside and jadeite).
- The growing development of microbeam analytical techniques (such as ion microprobes and laser ablation/mass spectrometry) has enabled the study of light

elements (H, Li, Be, B) in tourmaline, vesuvianite, and other minerals. The ion microprobe is also being applied to the study of changes in rocks and minerals induced by metamorphism (reviewed by G. E. Bebout). Computed X-ray tomography, another new technique, is currently being used to study the porosity of carbonate rocks (reviewed by C. Kerans, R. K. Goldhammer, and J. L. Banner).

- In clastic sedimentology (reviewed by M. H. Gardner), fluid dynamics models are being applied to stream flow, in the hopes of determining original depositional environments (e.g., valleys versus channel-fill deposits). *MLJ*

GPS: Useful, with care. L. R. Ream, *Mineral News*, Vol. 11, No. 4, April 1995, p. 10.

Global Positioning Satellite (GPS) receivers, which can pinpoint a position on the basis of data received from several orbiting satellites, are a wonderful way to find out where you are on the Earth's surface. Now they are commercially available at modest ($300) to immodest ($15,000) prices. However, some factors limit their usefulness. These include interference from dense foliage, narrow views of the sky, and signals bounced off mountainsides and canyon walls (not to mention the fact that the U.S. Department of Defense purposely degrades the accuracy of publicly accessible satellite signals). The more expensive units are generally more accurate.

The author recounts several anecdotes regarding false GPS readings. He notes that a GPS unit is generally more accurate than precise (i.e., although the readings may not be the same each time, they will be "in the vicinity" of correct) and is subject to long-term drift in its information. He suggests that, if you buy one of the lower-end GPS units, you first take several readings and average them, to learn the limitations of the device and how to work with them. *MLJ*

Minerals in rock mass hold clues to 400-kilometer ascent. R. A. Kerr, *Science*, Vol. 271, March 1996, p. 1811.

Mineralogists are agog over the discovery of a large chunk of garnet peridotite in the mountains of southern Switzerland, 400 km above the strata in the Earth's mantle where all mineralogical knowledge says it should be.

The Alpe Arami massif, which measures 800 × 500 m, has traveled to the surface from the mantle transition zone, 400 to 670 km down. Researchers determined its original depth of formation from the presence of ilmenite inclusions in olivine—some rod-shaped and some of a structure previously unknown—all indicating formation below 300 km.

Researchers can only tentatively explain this phenomenon as "deep subduction"; that is, the peridot massif was surrounded by much lighter sedimentary crustal rock and buoyed to the surface. To the question of why this lightweight sedimentary rock from the Earth's crust was in the deep mantle zone in the first place, some mineralogists have proposed "the Ivory soap principle." According to this theory, light crustal rock was driven downward by the collision of continents, then warmed up and bobbed back to the surface (like Ivory soap), carrying chunks of heavier mantle with it.

Diamonds, which occur in the only other rocks known to have pulled off the trick, arrived by a different mechanism (having been blasted up from more than 100 km depth through narrow volcanic conduits, or pipes). There are, however, similarities between the odd mixture of minerals in these rocks and that in the one from the Alpe Arami massif. Although "the Ivory soap principle" to explain the massif rock is controversial, the discovery has major implications for scientists' understanding of the subduction process, and of the mineralogy and chemistry of the Earth's mantle. *AC*

Twisted and contorted plants. E. B. Heylmun, *International California Mining Journal*, Vol. 65, No. 1, September 1995, pp. 30–31.

This short summary of the 1983 textbook *Biological Methods of Prospecting for Minerals*, by R. R. Brooks, describes plants that are found preferentially in regions where the soil contains economically valuable elements. California poppies indicate copper, alyssum indicates silver-lead-zinc or nickel (and nickel is often associated with platinum), pennycress can indicate silver-lead-zinc, wild buckwheat is associated with silver, and wild rye grass occurs with sulfur. Equisetum (horsetails), wild onions, and "miner's moss" are claimed by some to be associated with gold. In general, any poisonous, hallucinogenic, or foul-smelling plant (except poison ivy and poison oak) may indicate that the soil is rich in unusual elements.

Another indicator of mineralization is unusually "stressed" plants—especially composites (daisies)—showing features such as stunted growth, twisted or contorted growth, yellow foliage, or unusually colored flowers; or plants that are unusually early or late blooming. Boron, radioactivity, and bitumenous hydrocarbons may cause gigantism in plants. *MLJ*

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