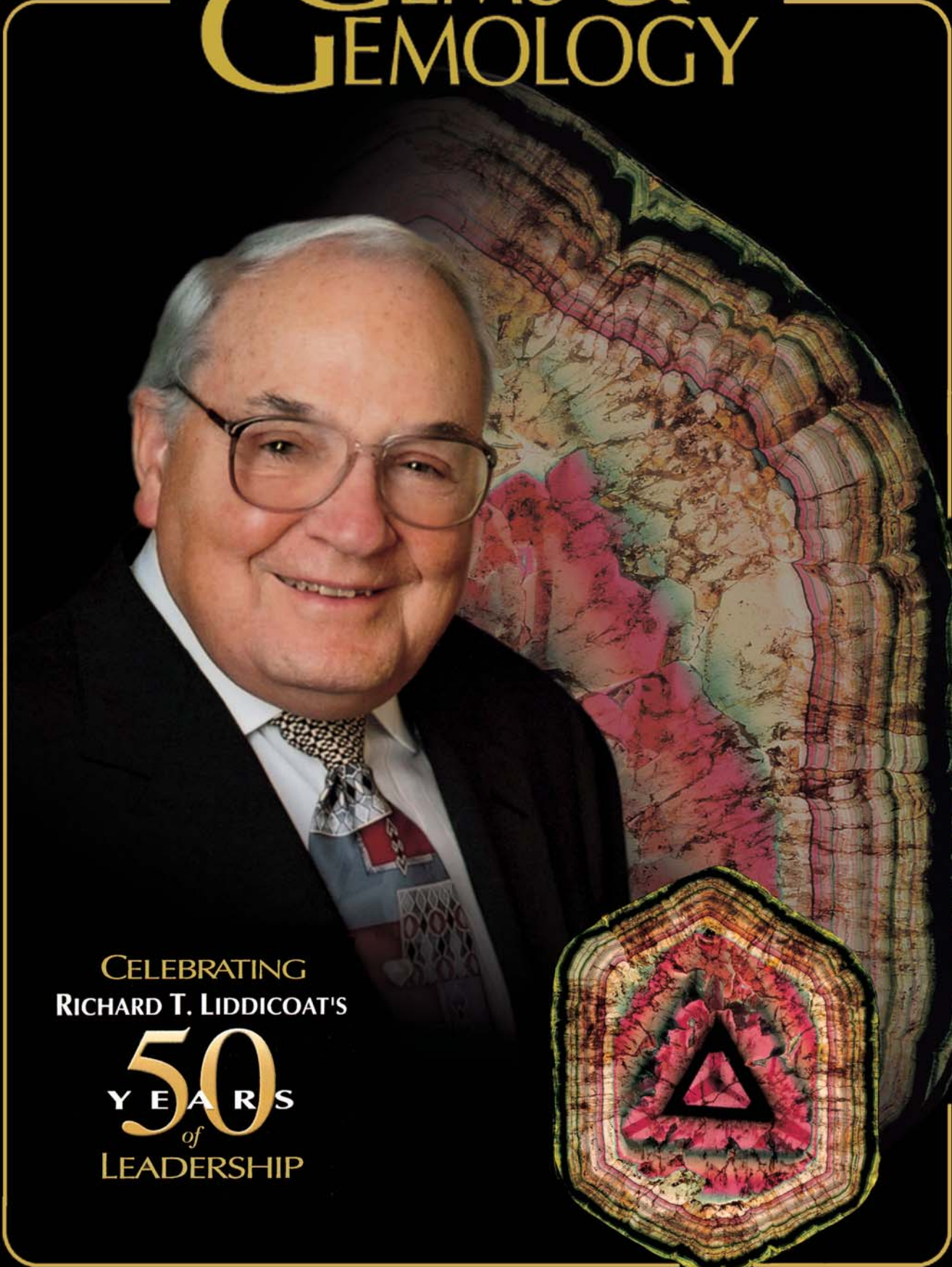


VOLUME XXXVIII

GEMS & GEMOLOGY

SPRING 2002



CELEBRATING
RICHARD T. LIDDICOAT'S

50
YEARS
of
LEADERSHIP

THE QUARTERLY JOURNAL OF THE GEMOLOGICAL INSTITUTE OF AMERICA

GEMS & GEMOLOGY

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RICHARD T. LIDDICOAT: CELEBRATING 50 YEARS OF LEADERSHIP

Rarely does one encounter an individual who alters the course of history. It is even more rare to know a person of such stature, or to have the chance to work under his or her leadership.

I have been privileged to work for, and alongside, Richard T. Liddicoat throughout my nearly 27 years at GIA. I have seen him, in good times and bad, endure challenges and tribulations, and never falter. I know him to be a man of extreme intelligence, impeccable character, and genuine humility. He is a unique combination of warmth and charm, drive and dedication.

This issue of *Gems & Gemology* honors Richard Liddicoat's 50 years as chief editor of the journal. Each paper represents a different aspect of his contribution to gemology. The lead article, by Dona Dirlam and others, gives us a glimpse into his life, his passion, and his accomplishments in an industry he loves and for the public he serves. In honor of his leadership in the field of gemology, researchers at the Smithsonian Institution bestowed the name *liddicoatite* on a new gem tourmaline species in 1977. The article on liddicoatite in this issue contributes greatly to our understanding of this beautiful but enigmatic gem.

Throughout his career, Richard Liddicoat has focused on gem identification and instruments to make this process easier and more efficient, sharing knowledge that greatly influenced the development of the contemporary field instruments and techniques discussed in Edward Boehm's piece. But he is also fascinated with the lore of fabulous stones, like the Star of the South diamond described by Christopher Smith and George Bosshart, that have contributed so much to the rich history of our industry.

The issue rounds off with short articles on two topics of particular interest to Richard Liddicoat—pearls and new gem materials. Although a mineralogist by training, he has long had a fondness for organic

materials and especially the intricacies of pearls such as the "Tahitian" yellow cultured pearls described by Shane Elen. I wonder, though, if there is a greater thrill for any gemologist than the opportunity to examine a new gem material, as with the serendibites characterized by Dr. Karl Schmetzer and Mr. Liddicoat's colleague for more than 60 years, Dr. Edward Gübelin, along with other prominent gemologists.



I suppose it would be enough to have established diamond grading and other standards for the gem and jewelry trade, to have educated countless thousands in the field, or to have contributed mightily to the gemological literature over the course of his long and successful career. But perhaps the greatest gift Richard Liddicoat has given us is the example he set for an industry and its professionals. Not only

is he a beloved and respected leader, but he also has lived out a work ethic and a commitment to purpose that are both rare and resounding.

As we look back over the years, and his achievements, we recognize that they are unparalleled: a gem mineral named after him; awards and honors from GIA, the American Gem Society, the American Gem Trade Association, and numerous other organizations; and a lasting impact on thousands who revere him as the "Father of Modern Gemology."

Yet one of Richard Liddicoat's most appealing qualities is that he has never realized how great he truly is. This issue of *Gems & Gemology* is a tribute to his character and to what makes him, in my mind and in the minds of all who know him, a man who has altered the course of history in the gem and jewelry world.

William E. Boyajian, President
Gemological Institute of America

THE ULTIMATE GEMOLOGIST: A TRIBUTE TO RICHARD T. LIDDICOAT

By Dona M. Dirlam, James E. Shigley, and Stuart D. Overlin

*"If I have seen farther . . . it is by standing on the shoulders of giants."
Isaac Newton*

On this occasion—the celebration of Richard T. Liddicoat's 50 years guiding *Gems & Gemology*—it is fitting to review his enormous impact on the field of gemology. This includes the development of GIA's education program, the creation of the quality-grading system for polished diamonds that is now accepted worldwide, numerous contributions to the gemological literature, involvement in new gem-testing techniques and instruments, and the establishment of a formal research program. His greatest achievement, however, has been his personal influence on the professionalism and ethical standards of the international gem and jewelry industry.

With this special issue of *Gems & Gemology*, we celebrate the 50th anniversary of Richard T. Liddicoat (figure 1) as editor and now editor-in-chief of GIA's quarterly professional journal. This *festschrift*, or special celebratory issue, provides a welcome opportunity to review his contributions to gemology, especially in five main areas: education, diamond quality grading, gem identification, instrument development, and global information outreach. Following the lead of GIA's founder, Robert M. Shipley, Liddicoat positioned GIA as a leading international educational institution, grading laboratory, manufacturer of gem instruments, and research center. Those who have had the privilege to know and work with him have been able to expand the frontiers of gemology "by standing on the shoulders" of this giant.

THE EARLY YEARS

Robert M. Shipley founded the Gemological Institute of America in Los Angeles, California, in 1931. His vision was to create an institution that would promote professional education in gemology for jewelers in the United States, allowing them to buy and sell with increased knowledge and confi-

dence. At the time, no such organization existed in the U.S. In the early 1930s, Shipley—working in partnership with his wife Beatrice—stimulated interest among jewelers by traveling across the U.S. to retail stores, where he would preach the benefits of gemological education. In the evenings in his hotel room, Shipley would write courses for jewelers to take through correspondence. He established the beginnings of an educational institute in Los Angeles with a small staff that grew slowly over the next decade as resources allowed. Together, he and his staff created lessons, gave instruction on gemstones and their properties, and began the process of helping jewelers correctly identify the gem materials they handled (Gilbert, 1977).

By 1940, Shipley realized the need for additional leadership at GIA. His son, Robert Shipley Jr., who had worked closely with him in recent years, had signed up for military service. Shipley contacted Chester B. Slawson, a mineralogy professor at the University of Michigan in Ann Arbor who was

See end of article for About the Authors and Acknowledgments.
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Figure 1. Since 1940, Richard T. Liddicoat's contributions to gemological education, diamond quality grading, gem identification, and gemological research and instrument development have advanced the study of gemology throughout the world. As a former president of GIA, now Chairman of its Board of Governors, and chief editor of *Gems & Gemology* for five decades, he has had a profound influence on the gem and jewelry industry.



co-author of one of the leading gemology texts at that time, *Gems and Gem Materials* (Kraus and Slawson, 1939), as well as one of GIA's educational advisors. In his letter, Shipley asked Slawson to recommend a mineralogist to join the GIA faculty. Dr. Slawson suggested one of his graduate students, Richard T. Liddicoat. As Liddicoat recalled, "Slawson thought that I was wedded to graduate school and headed for a Ph.D. in mineralogy, so he didn't think I'd be interested. But he showed the letter to me anyway. After years of school, I was ready to do something else. The idea of gems and Los Angeles really had appeal" (Youngs, 1980, p. 40).

Liddicoat drove with his wife Mary Imogene ("Gene") Liddicoat to Cincinnati, Ohio, for an interview with Robert Shipley and then-chairman of GIA's Board of Governors, Edward Herschede. He found both men impressive, with Shipley especially charismatic in his passion for education and gemstones.

Richard Thomas Liddicoat Jr. was born on March 2, 1918, in Kearsarge, Michigan, the son of a professor of engineering at the University of Michigan, Ann Arbor, and Carmen Beryl Williams Liddicoat. Both his grandfathers were miners from Cornwall, England, who had immigrated to the upper Keweenaw Peninsula of Michigan in the latter half of the 19th century. These two men inspired their grandson to explore the geology of his surroundings. Liddicoat attended the University of Michigan, from which he received a bachelor's

degree in geology in 1939 and a master's degree in mineralogy in 1940.

On June 28, 1940, Liddicoat joined the GIA staff as assistant director of education, beginning a 60+ year career of service to GIA and the jewelry industry (see highlights in the timeline). In those days, the Institute was a family affair: Beatrice Shipley managed the office, while Shipley Jr. focused on developing gemological instruments and techniques, as Shipley Sr. continued with education and attracting jewelers to the GIA programs. (Also involved was Beatrice's nephew Al Woodill, who briefly worked at GIA in 1940–1941. In 1947, Woodill became the executive head of GIA's sister organization, the American Gem Society [AGS], which Shipley Sr. had established in 1934 as a professional guild of jewelers.)

Liddicoat's first priority was to take the GIA courses, which he completed in less than three months. As an instructor, he was responsible for grading GIA correspondence exams—on average, 225 tests per week. "When I first came out here, I used to grade all the papers. They were all essay questions in those days. I would take all the papers home with me, one day a week, and just keep going until I finished them. Sometimes, it was pretty late when I got through with them all," Liddicoat later recalled (Youngs, 1980, p. 40).

Within a year of his hiring, Liddicoat was named director of education, the first person outside the Shipley family to hold a major position within GIA.



Figure 2. Standing in the back of a February 1949 gemology class at GIA's New York office are G. Robert Crowningshield (in front of the chalkboard) and Richard T. Liddicoat (back row, far right).

CONTRIBUTIONS TO GEMOLOGICAL EDUCATION

One of Liddicoat's first innovations in gemological education was an intensive one-week class that was launched at the AGS Conclaves in Philadelphia and Chicago in 1942 (Federman, 1985a). He developed this class to enable students to complete the prerequisite Diamond and Colored Stone training of Shipley's original fundamental course in a one-week resident education format. This class also gave jewelers the opportunity to work with equipment in a classroom setting under the guidance of GIA instructors (figure 2). Liddicoat would become a mainstay as a speaker and instructor at these Conclaves, and in 1997 the AGS honored him for having attended 50 of them ("A special tribute...", 1997).

During World War II, from August 1942 until

January 1946, Liddicoat left GIA to serve in the U.S. Navy. After working for a few months in a shipyard, he eventually was assigned to the Pacific fleet as a weather officer on aircraft carriers and at Pearl Harbor ("Liddicoat resumes work at headquarters...", 1946).

Upon his return from military service in February 1946, Liddicoat was named director of research and, later, director of education and research. The March 1946 issue of the AGS magazine *Guilds* described him as "an extremely popular leader and instructor who proved his ability to project his personality into instruction in the mail courses" ("Liddicoat resumes work at headquarters...", 1946, p. 5). In June 1946, he helped launch the first evening gemology class in Los Angeles, which allowed local GIA correspondence students to gain hands-on experience while continuing to work in their jewelry stores during the day.

Recognizing the need for an inexpensive handbook for GIA students, Shipley assigned Liddicoat the task of creating it. This new gem identification reference book was the first directed to the needs of the practicing gemologist. Closely tied to the GIA course work, it also was unique in organizing the gemstones by color. Liddicoat spent almost a year on the book, dictating sections to his wife Gene in the evening (R. T. Liddicoat, pers. comm., 2002). In August 1947, the first edition of his *Handbook of Gem Identification* was published (figure 3). This book, one of the first to include photomicrographs of inclusions as identifying characteristics, supported GIA education classes that increasingly focused on gem identification and gem-testing instrumentation. It continues to be one of the most widely used textbooks in gemology, now in the fourth printing of its 12th edition.

1940 1941 1942 1943 1944 1945 1946 1947 1948 1949 1950 1951 1952 1953

June 28, 1940 Joins the staff of GIA as assistant director of education



Fall 1941 Helps develop the Diamolite; publishes (with Shipley) his first article for *Gems & Gemology*: "A Solution to Diamond Color Grading Problems"



August 1947 Publishes first edition of the *Handbook of Gem Identification*

February 1946 Returns to GIA as director of research



1948 Named assistant director of GIA

1949 Named director of GIA New York and GIA Gem Trade Laboratory

April 1, 1952 Named executive director of GIA; assumes editorship of *Gems & Gemology*

April 1953 Officially introduces the GIA diamond grading system as part of new educational class in New York

Beginning in 1948, GIA granted the title *gemologist* to those students who had completed all of the home study courses, and awarded the title *graduate gemologist* (G.G.) when students completed the additional class training and passed the 20-stone exam. Since the inception of the graduate gemologist diploma, approximately 25,000 students have gained this important industry recognition. Later in 1948, Shipley turned over much of the day-to-day operation to Liddicoat (“Executive staff changes...,” 1948). GIA student enrollment grew substantially during the postwar years, influenced in large part by the G.I. Education Bill, by which the U.S. government gave financial support to its military veterans. To meet the needs of a growing student population, more instructors were added to the GIA staff to teach the students both in “extension” classes at the Los Angeles headquarters and through home study education. During the latter half of the 1940s, the GIA staff doubled from 20 to 40. When the G.I. Bill’s benefits ended in the early 1950s, however, enrollment fell off sharply, and GIA faced a financial challenge just as Shipley was planning to retire.

Liddicoat, Shipley’s handpicked successor, became executive director of GIA on April 1, 1952. He moved quickly to address the Institute’s financial problem by focusing GIA’s education on a key concern of jewelers: diamond grading.

In the early 1950s, jewelers were calling for a standardized diamond grading system to counter the fanciful and often inconsistent terminology then being used to describe polished diamonds. Such descriptions only made effective communication between dealers and customers more difficult. Liddicoat tackled the problem with Los Angeles colleagues Lester Benson and Joe Phillips, with

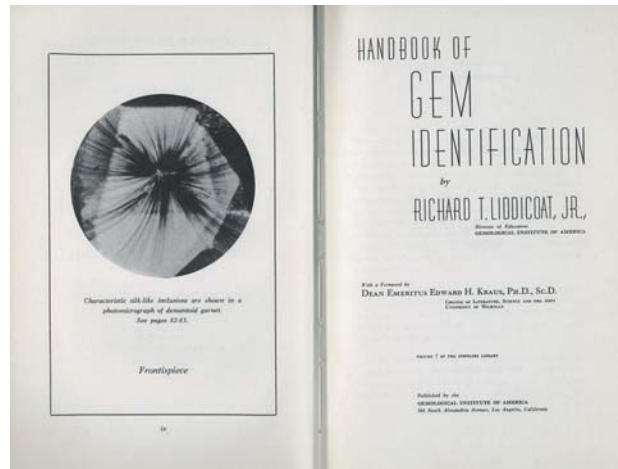


Figure 3. The first edition of Richard Liddicoat’s Handbook of Gem Identification, published in 1947, presented “simple and often conclusive” tests to identify gems. Now in its 12th edition (4th printing), it is one of the most widely read textbooks in gemology.

input from the New York laboratory’s Bob Crowningshield (then director of GIA’s Eastern Headquarters and Gem Trade Laboratory and later vice president of GTL Gem Identification) and Bert Krashes (who retired in 1987 as managing director of the GIA Gem Trade Laboratory). Together, they developed a diamond grading and evaluation appraisal program based on the color, clarity, cutting, and carat weight of diamonds. To unveil the class, they decided to go to the heart of the diamond district in New York.

Liddicoat and Crowningshield taught the first one-week classes on the new diamond grading system in April 1953 at the Roosevelt Hotel in New York City (figure 4 shows a one-week class from 1954). This diamond grading class became part of

1954 1955 1956 1957 1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969

1955 GIA Gem Trade Laboratory issues its first Diamond Grading Reports

1960 Co-authors first edition of *The Diamond Dictionary*

1962 Devises the “rapid sight” system for estimating diamond-cutting quality

1964 Co-authors first edition of *The Jewelers’ Manual*



Figure 4. GIA instructors Bert Krashes, Eunice Miles, and G. Robert Crowningshield stand in the center of a group of students taking a one-week class at GIA New York in June 1954, a year after the introduction of the GIA diamond grading system.

GIA's regular gemology program in 1955. Liddicoat also established a new traveling one-week class, Diamond Evaluation, to bring an understanding of the benefits of this new diamond grading terminology to jewelers throughout the United States (Shuster, in press). Glenn Nord, who was then taking the new diamond course, recalls: "GIA was introducing an entirely new culture to the jewelry industry with its education, and it was Dick Liddicoat's leadership that helped people accept these changes" (pers. comm., 2002).

In 1955, 14 of the 45 lessons—or nearly a third of GIA's home study diamond courses—were rewritten. Liddicoat personally revised 10 of them. During the same time period, he expanded the education program by adding a jewelry retailing home study course. The first jewelry design course, long presented in Brooklyn by Christian Jakkob, was turned over to GIA and reorganized by Lester Benson, a



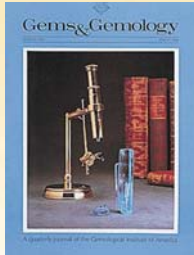
GIA educator and inventor. Liddicoat reflected, "I always had the feeling that once the gemology program was in place, we should offer a complete curriculum for the retail jeweler" (pers. comm., 2001).

To further meet the need for a standardized terminology for its students and members of the trade, GIA began working on a glossary of diamond terms. Out of these efforts came the first *Diamond Dictionary* (1960), by Lawrence Copeland with Richard Liddicoat and other staff members (see Copeland et al., 1960; figure 5). Later that same decade came Liddicoat and Copeland's *The Jewelers' Manual* (again, see figure 5). Published in 1964, it was an expansion of Shipley's earlier *Jewelers Pocket Reference Book* (1947).

Liddicoat worked closely with Lester Benson to produce a revised course structure for the gemology program ("GIA courses to have new look," 1958). In 1962, after providing a variety of supplemental classes for students to obtain additional training time, GIA began to offer a full-time resident G.G. program in Los Angeles. Before then, students could obtain this diploma only through home study, supplemented by short-term classes.

During this same period, Liddicoat (1962) wrote an article for *Gems & Gemology* on the "rapid sight" system for judging diamond cut quality. According to Nord (pers. comm., 2002), "After Dick developed the system, he and I would sit and trade diamonds back and forth for hours. We could judge so many factors, including proportions and angles, very accurately. It was an important teaching tool that is still a key part of the diamond program today."

In the late 1960s and early 1970s, Liddicoat oversaw Nord's development of corporate training classes for Zales, one of the largest retail jewelry store

1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
	<p>1971 First GIA gemology courses in Japan taught (by an affiliate)</p> 					<p>Creates the GIA Research Department under the leadership of Dr. D. Vincent Manson</p> 			<p>Spring 1981 Publishes first issue of <i>Gems & Gemology</i> in an expanded and redesigned format</p> 			<p>1982 Creates the GIA Alumni Association under Robert Earnest</p>		
<p>1970 Series of extension education classes in Israel taught by Glenn Nord marks GIA's first global outreach</p>				<p>1976 Receives the American Gem Society's Robert M. Shipley Award</p>									<p>1983 Steps down as president of GIA; named chairman of the GIA Board of Governors</p>	
												<p>1982 Chairs GIA's first International Gemological Symposium in Los Angeles</p>		<p>Named Honorary Member of AGTA</p>

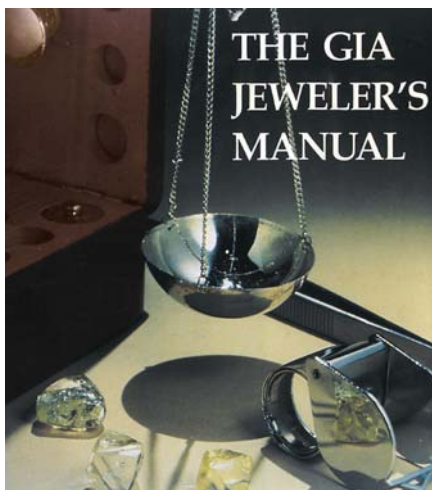
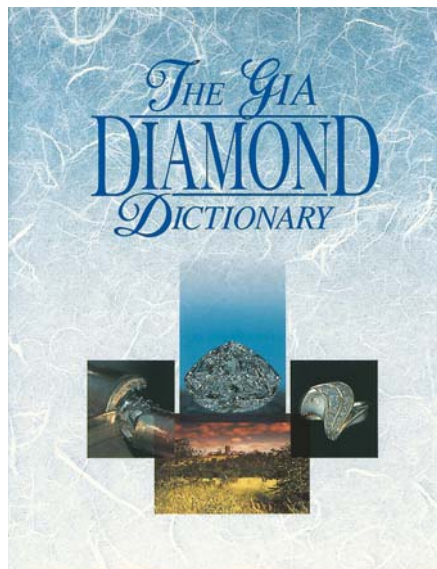


Figure 5. The Diamond Dictionary, first published in 1960 and now in its 3rd edition (1993), provides a standard reference for diamond terminology. The Jewelers' Manual, a handy reference guide to gemology and jewelry for the working jeweler, was first published in 1964 and is now in its 3rd edition (1989).

chains in the U.S., a program that continues today with a number of major businesses.

Also in the late '60s, Liddicoat made several trips to Japan in an effort to glean the information necessary to develop a cultured pearl course and, ultimately, GIA's first pearl grading system.

Richard Liddicoat took Shipley's concept of home study (or "distance") education beyond North America when, in 1970, he sent Nord to Israel to teach the first diamond course outside the U.S. A year later, with Liddicoat's endorsement, GIA courses were being taught in Japan (figure 6). Yoshiko Doi, a former GIA staff member who had returned to Japan, and Kenzo Yamamoto established the Association of Japan Gem Trust (AGT), a non-profit organization with exclusive rights to administer GIA courses in Japanese ("Focus on: Kenzo Yamamoto," 1984). Doi translated all course materials into Japanese, thus beginning GIA's ability to offer courses international-

ly and in other languages. Currently, GIA programs are offered in 11 countries outside the U.S.

ARCHITECT OF THE GIA DIAMOND GRADING SYSTEM

Early GIA efforts to establish a system to describe the quality of polished diamonds can be traced back to the 1930s, when Robert M. Shipley Sr. and De Beers collaborated to develop the concept of the "Four Cs": color, clarity, cut, and carat weight. In 1939, the AGS adopted this terminology for describing diamonds. A 1941 article in *Guilds* describes a nine-year process by GIA to develop a unit for color grading diamonds and efforts to standardize color grading ("Standardization of color grading...", 1941). That same year, Shipley Sr. and Liddicoat published an article on diamond grading that described the use of a standardized light source (the Diamolite) and a prototype colorimeter for grad-



1984 Named Man of the Year by the Consolidated Jewelers Association of New York

Named a Founding Organizer of ICA

1985 Receives *Modern Jeweler* magazine's Lifetime Achievement Award

1987 Receives the Morris B. Zale Lifetime Achievement Award

Becomes the first Honorary Lifetime Member of the Gem Testing Laboratory of Great Britain

August 21, 1989
Honored with the dedication of the Richard T. Liddicoat Gemological Library and Information Center at GIA



1991 Named to the National Home Study Council's Hall of Fame

1992 Named GIA Chairman of the Board for Life

1995 Receives GIA League of Honor Lifetime Achievement Award

June 10, 2000 Life-size bronze statue created by staff member Michael Clary placed at the entrance of GIA Carlsbad



July 31, 2001
Receives the AGS Lifetime Achievement Award



Figure 6. One of GIA's early global outreaches was in Japan, where Kenzo Yamamoto (second from the left, next to his wife) and Yoshiko Doi (third from the left, next to former GIA president Glenn Nord) began teaching GIA courses in 1971. Since its inception, nearly 3,000 graduate gemologists have been trained at the Japanese affiliate. In the inset photograph, Richard Liddicoat is shown with a group of Japanese students.

ing diamond color against a graduated color scale (Shipley and Liddicoat, 1941). This same research by Shipley, Dorothy Jasper Smith, and Liddicoat led to the creation of the first master set of color comparison diamonds for diamond grading in 1941 (R. T. Liddicoat, pers. comm., 2002).

Nevertheless, as indicated above, ongoing confusion and inconsistency in diamond grading terminology brought about the demand for a new vocabulary to more clearly express the color, clarity, and cut of individual diamonds. As Bert Krashes (pers. comm., 2001) notes, "There was a lot of ambiguity and confusion when it came to trade grading of diamond color and clarity, so there was a significant need for GIA to create this system."

Liddicoat became the architect of the GIA diamond grading system, developing a practical approach to quality grading colorless to light yellow polished diamonds on the basis of color, clarity, and cut. A central feature was the D-to-Z color grading system for faceted, colorless to light yellow diamonds, which comprise the vast majority of diamonds seen in the trade. The letter *D* was chosen as the starting point (colorless) to avoid confusion with other, more loosely defined classification systems being used, which typically began with the letter *A* (King et al., 1994). Liddicoat remembers that at the time the diamond companies had their own descriptions, which included *A* and *AA*, so it was felt that *D* would be less confusing (R. Liddicoat, pers. comm., 2001).

Having discussed quality grading of diamonds at earlier AGS Conclaves, Liddicoat introduced the GIA diamond grading system at the 1953 Conclave in Philadelphia. "Richard Liddicoat deserves the credit for developing the diamond grading system. He had some assistance from Lester Benson, but it was mainly Liddicoat" (B. Krashes, pers. comm., 2002).

Beginning in 1953, GIA instructors taught this grading system to hundreds of students so they could evaluate their own diamonds. Subsequently, many of these students requested that GIA set up a procedure whereby they could submit their grading worksheets, and eventually the diamonds themselves, for an independent assessment.

Bert Krashes recalls the transition (pers. comm., 2002): "It began as a service we offered students. After they took the courses, whether correspondence or one-week classes, we agreed to double-check their grading of their own diamonds. We would make our comments on the diamond worksheets. Eventually, word reached the industry that we were capable of doing this work, and soon there was a demand for a more formal presentation." Liddicoat teamed with Crowningshield, Krashes, and Eunice Miles to design and develop the Diamond Grading Report (Christie, 1988), the first of which was issued in 1955.

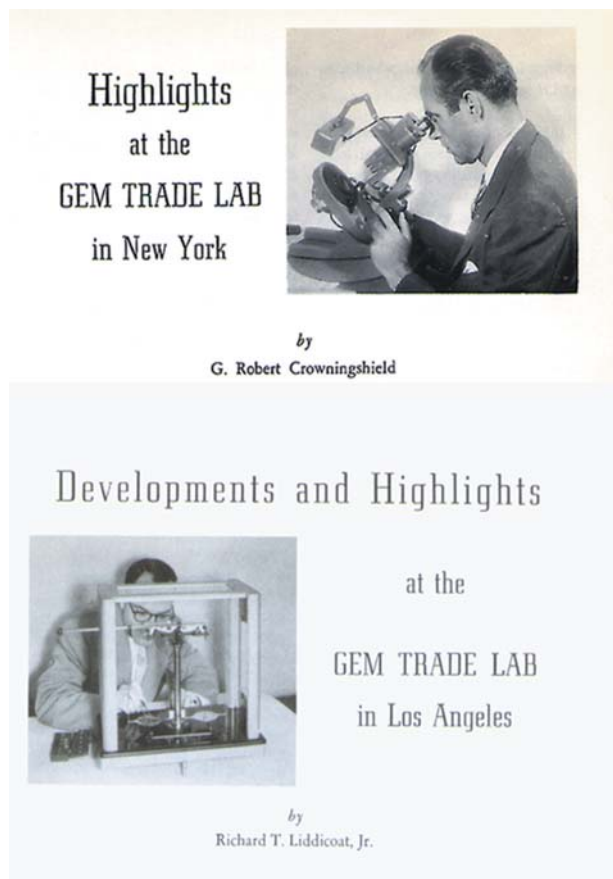
UNLOCKING THE MYSTERIES: GEM IDENTIFICATION AND GEMS & GEMOLOGY

Gem Identification. When Robert M. Shipley set up his Los Angeles laboratory in the early 1930s, the Institute's resources were devoted to identifying gems and to documenting the properties and techniques that would aid in their separation (Jasper, 1948). Late in 1948, following the unexpected resignation of Dr. Mark Bandy as director of the fledgling New York laboratory, Shipley assigned Liddicoat to New York to lead the expansion of that new branch. Liddicoat and his wife Gene drove across the country and arrived there in early January 1949. While Liddicoat and Crowningshield took care of the gem identifications and taught classes at night, Gene was the office administrator (R. T. Liddicoat, pers. comm., 2002). The resources of the New York operation were further enhanced when the Gem Trade Laboratory, which had been established by A. E. Alexander, was turned over to GIA in October of that same year. As director of GIA New York and the GIA Gem Trade Laboratory, Liddicoat was responsible for integrating the facilities of the two labs ("Richard T. Liddicoat Jr.

appointed...," 1952). The early identification work was typically a group effort among staff members who became known as the "Liddicoat brain trust" (Federman, 1985a).

By the 1970s, the GIA Gem Trade Laboratory staff was examining large numbers of gemstones, including the grading of diamonds and the identification of colored stones and pearls. Sensing the need for a group of scientists who would focus on the many emerging technical challenges in gemology, Liddicoat formally established the current GIA Research Department in 1976. Dr. D. Vincent Manson, formerly curator of gems and minerals at the American Museum of Natural History, was named its director.

Figure 7. Along with G. Robert Crowningshield and Lester Benson, Richard Liddicoat pioneered the Gem Trade Lab Notes section of *Gems & Gemology*. These reports of new findings from the GIA Gem Trade Laboratory first appeared as "Highlights at the Gem Trade Lab" from both New York and Los Angeles. Today, the Lab Notes section remains one of the journal's most popular features.



Gems & Gemology. Robert Shipley's early efforts in gem testing and characterization were incorporated not only into updates of the GIA courses, but also (starting in 1934) into the pages of *Gems & Gemology*, GIA's quarterly journal. Richard Liddicoat continued this legacy through articles that he wrote and co-authored in *G&G*, reporting on his activities to improve the ability of jewelers to properly identify gems. (An extensive bibliography of his publications is provided at the end of this article.)

Liddicoat became editor of *Gems & Gemology* on Robert Shipley's retirement in 1952, with Jeanne G. M. Martin as his associate editor. Liddicoat himself led a procession of notable mineralogists, gemologists, and other scientists who contributed groundbreaking articles to the journal. Subsequent associate editors included Dr. Robert Gaal (1973–1977) and John I. Koivula (1978–1980). In 1981, Alice Keller was brought on as the journal's managing editor to oversee its redesign; she was subsequently promoted to her current position as editor and director.

Liddicoat encouraged Crowningshield and Benson to write their "Highlights at the Gem Trade Lab" columns—Crowningshield in New York and Benson in Los Angeles—which debuted in the Winter 1958–59 issue of *Gems & Gemology* (R.T. Liddicoat, pers. comm., 2002). Liddicoat took over the Los Angeles column in 1962 (figure 7). "Highlights at the Gem Trade Lab" later became the Gem Trade Lab Notes section, which continues to describe interesting gem materials that have been seen in the GIA Gem Trade Laboratory.

Five times in the last decade, *Gems & Gemology* has won the American Society of Association Executives Gold Circle Award for best peer-review journal in America. Liddicoat continues to serve as editor-in-chief, writing editorials, reviewing books and articles, and setting editorial policy for the award-winning publication.

CONTRIBUTIONS TO GEMOLOGICAL INSTRUMENTATION

Liddicoat presided over four decades of innovation in gem instrument development at GIA, and established gem instruments as one of the Institute's highest priorities (Federman, 1985b). In addition to his early work with Shipley to develop the Diamolite (figure 8), Liddicoat worked with various GIA scientists on a number of other instruments. Liddicoat's own scientific background enabled him to foster the development of instruments such as the prism spec-

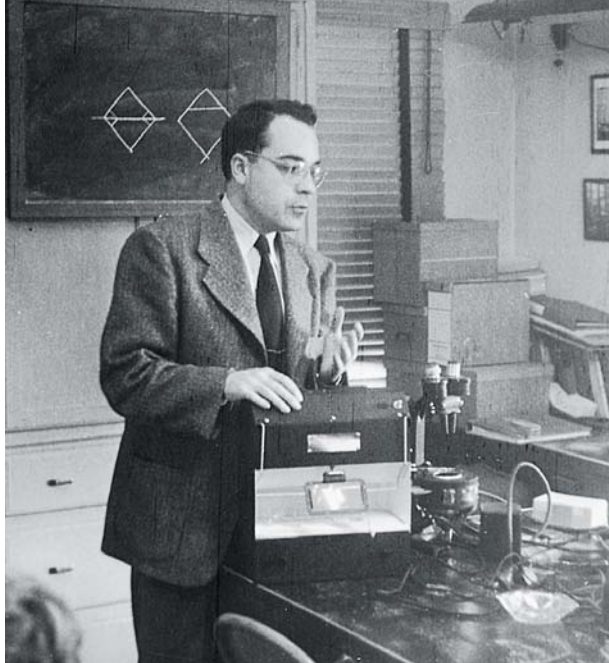


Figure 8. Richard Liddicoat, shown teaching the use of the Diamolite in 1946, helped develop the instrument in 1941.

troscope and the ProportionScope (GIA *Diamond Grading* course, 1994). His objective throughout instrument development at GIA was to provide jewelers with practical tools that could help them in the day-to-day operation of identifying gemstones.

GLOBAL INFORMATION OUTREACH

In the early 1980s, Liddicoat championed the use of computer networks to connect jewelers and gemologists to a vast array of knowledge. In a 1985 inter-

Figure 9. The world's largest collection of gemological books and articles, the Sinkankas Collection, was acquired for the GIA library in 1988. Photo by Shane McClure and Robert Weldon, © GIA.



view in *Modern Jeweler*, he predicted that one day jewelers across the country would be connected to GIA through such a network: "Imagine not having to leave your store or business to consult with GIA" (Federman, 1985c, p. 56). That idea became reality in 1986 with the creation of GIA-Net under the leadership of Dennis Foltz, then director of education and operations at GIA, and has evolved today into GIA Virtual Campus (for students) and the GIA Web site: <http://www.gia.edu>. Approximately 150,000 people access the GIA Web site monthly.

Liddicoat's contributions to spreading gem and jewelry knowledge were immortalized with the creation of the Richard T. Liddicoat Gemological Library and Information Center in 1989. Although Robert Shipley had built the beginnings of a library from the very first days of GIA, Liddicoat was the one who envisioned a world-class, state-of-the-art library that would serve not only GIA staff and students, but also jewelers, gemologists, and consumers worldwide. This repository was greatly expanded under the direction of one of the authors (DMD) with the purchase of the 15,000-volume John and Marjorie Sinkankas Gemology and Mineralogy Library in 1988 (figure 9). Located at the Institute's headquarters in Carlsbad, California, the Liddicoat Library is now the largest gemology and jewelry library in the world. At almost 836 square meters (9,000 square feet), it houses over 30,000 volumes and journals as well as extensive collections of photos, videotapes, and other media resources.

As director of education and later president, Richard Liddicoat was GIA's ambassador to many gemology and jewelry associations. As indicated earlier, he was a mainstay at AGS Conclaves for more than 50 years, frequently accompanied by GIA's finest gemologists (figure 10). He attended industry meetings and then incorporated the information he gathered into *Gems & Gemology* and the education program. He actively participated in the International Kimberlite Conferences and the International Gemmological Conferences (IGC), as well as a variety of trade association events. In 1983, Liddicoat retired as president of GIA, but was subsequently named chairman of GIA's Board of Governors, a position that he still holds. Liddicoat is a founding member of the International Colored Gemstone Association (ICA) and the American Gem Trade Association (AGTA). In recent years, he has continued to attend trade shows and visit gem mines, in addition to his involvement with GIA and *Gems & Gemology* (figure 11).

THE “FATHER OF MODERN GEMOLOGY”

In recognition of his more than 60 years of service to the gem and jewelry industry, Liddicoat has received many awards and commendations. Among the most prestigious are:

- American Gem Society Honorary Certified Gemologist (1947)
- American Gem Society Robert M. Shipley Award (1976)
- Honorary Fellow of the Gemmological Association of Great Britain (1981)
- American Gem Trade Association Honorary Member (1983)
- Consolidated Jewelers Association of New York’s Man of the Year (1984)
- *Modern Jeweler’s* Lifetime Achievement Award (1985)
- The Morris B. Zale Lifetime Achievement Award (1987)
- Honorary Lifetime Membership of the Gem Testing Laboratory of Great Britain (1987)
- National Home Study Council’s Hall of Fame (1991)
- GIA Board of Governors’ Chairman for Life (1992)
- GIA League of Honor Lifetime Achievement Award (1995)
- American Gem Society Lifetime Achievement Award (2001)

Liddicoat received special recognition in 1977 with the naming in his honor of a new gem species of tourmaline (figure 12). Dr. Pete J. Dunn and his colleagues from the U.S. National Museum of Natural History (Smithsonian Institution; Dunn, 1977) named “the mineral liddicoatite [the calcic lithium-tourmaline end member], in recognition of his contributions to gemological knowledge and education.” Liddicoat is one of only a few gemologists ever to be so recognized (Federman, 1985a).

When Liddicoat was honored as Man of the Year by the Consolidated Jewelers Association of New York in 1984, *National Jeweler* publisher Milton Gralla said of him, “There is not a community of any size anywhere in the United States where one or many jewelers have not been touched, influenced, educated, upgraded or professionalized by the thinking of this particular industry leader—Richard T. Liddicoat” (“Liddicoat honored . . .,” 1985).

In 1994, GIA established the Richard T. Liddicoat Award for Distinguished Achievement to acknowledge those GIA staff members who have provided unique talent and demonstrated unparalleled commitment to the Institute.



Figure 10. Since the inaugural American Gem Society Conclave in 1937, GIA educators have taught gemological courses and seminars to AGS jewelers. In this photo, Glenn Nord, Chuck Fryer (then head of Gem Identification in Los Angeles), Richard Liddicoat, Bert Krashes, and G. Robert Crowningshield participate in a GIA panel at the 1972 AGS Conclave in Washington, DC.

Figure 11. Richard Liddicoat has remained an active figure in the gemological community. In this 2001 photo, Liddicoat is seen touring the historic Tourmaline Queen pegmatite mine in the Pala district of San Diego County, California, with mine owner Ed Swoboda. This mine has produced large amounts of gem tourmaline, for cut stones and mineral specimens. Photo by Brendan Laurs, © GIA.





Figure 12. Liddicoatite, the calcic lithium-tourmaline end member, was named in honor of Richard Liddicoat in 1977. In 1985, while attending the ICA Congress, Liddicoat was photographed examining slices of liddicoatite—with its dramatic color zoning—while visiting gem carver Gerhard Becker (left) in Idar-Oberstein, Germany. Photo by Charles Carmona of Guild Laboratories, Inc.



Figure 13. Richard T. Liddicoat, the “Father of Modern Gemology,” was honored with the American Gem Society’s Lifetime Achievement Award on July 31, 2001.

During his 60-plus years with the Gemological Institute of America, Richard Liddicoat has brought practical gemology to hundreds of thousands of students and industry colleagues. Just as GIA has touched the lives of thousands in the industry, so has Liddicoat with the wisdom he graciously shares.

When Liddicoat received the AGS Lifetime Achievement Award on July 31, 2001 (figure 13), more than 300 jewelry industry professionals stood in ovation. GIA president Bill Boyajian said, “Richard Liddicoat’s achievements and contributions to the world of gemology and jewelry have been monumental. The living title ‘Father of Modern Gemology’ pays tribute to his success, yet only begins to describe the extent to which his efforts on behalf of an entire industry and the consuming public have changed the course of history.”

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PORTABLE INSTRUMENTS AND TIPS ON PRACTICAL GEMOLOGY IN THE FIELD

By Edward W. Boehm

Buying gems or jewelry can be challenging even when one has access to a fully equipped lab. However, most purchases are actually made in environments that make it difficult to carry anything more than a loupe, a flashlight, and a pair of tweezers. Practice with these and the additional portable gem instruments described in this article will enable the buyer to develop the keen senses needed to better ascertain the identity and quality of the material being considered. Practical tips that may be applied in the field are also included in each section. Common sense must dictate how a clue is applied, and some tests will merely help narrow down the possibilities.

The use of practical gemological techniques is essential when purchasing gems at the source, in a dealer's office, or at trade shows. Applying common sense and a few simple tests often reveals the true nature of the gem being considered, thereby providing the buyer with important knowledge for negotiating a purchase (see Matlins and Bonanno, 1997). The instruments required to perform these gemological tests in the field must be portable and easy to use (figure 1). Advances in desktop gemological instruments over the past two decades have greatly influenced the evolution of portable instrumentation (Liddicoat, 1981, 1982). Smaller circuits and batteries, as well as more durable lightweight materials, have allowed for the development of more practical and compact instruments to keep pace with today's well-traveled gemologists.

There are several steps that should be taken to determine the properties of a polished gem or piece of rough. These steps should progress in the following order: observing transparency, color, and luster, as well as searching for obvious surface clues that might reveal fracture, cleavage, or hardness; louping the stone for internal characteristics; using a dichroscope to determine the material's general optic character; and gathering the information provided by a handheld spectroscope, polariscope, ultraviolet

lamp, refractometer, and the like, to further narrow down the possibilities. It is important not to reach a conclusion too quickly and to perform further tests if there is any doubt. By careful process of elimination, in most cases a knowledgeable gemologist can determine the correct identity of a gem material. Even avoiding an unconfirmed identity by creating a reasonable doubt can prevent a bad purchase. In addition to using the proper portable instruments, it is essential to maintain current and in-depth knowledge of gemological properties and treatments. Practicing with gems most often sought on buying trips will enhance the identification skills necessary to make quick and informed decisions.

The present article looks at each of these steps as they are commonly performed in the field, and briefly describes field uses for both traditional and relatively new portable gemological instruments. Note that while brand names are mentioned in a number of instances (because these are instruments the author has used), often there may be similar instruments available from other manufacturers.

See end of article for About the Author and Acknowledgments.
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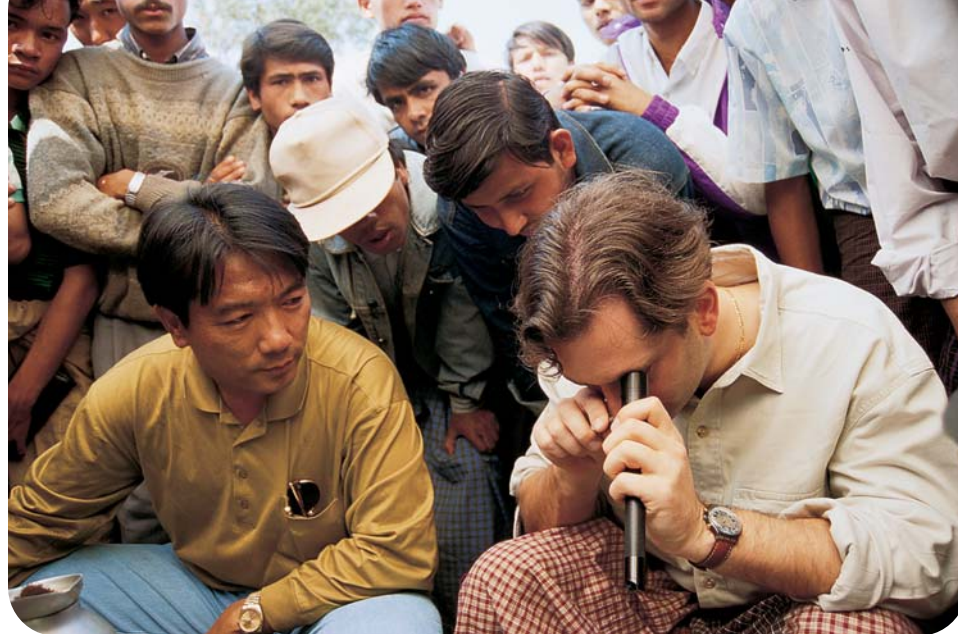


Figure 1. Shown here buying gems in a Mogok, Myanmar (Burma) gem market, the author uses a 10× darkfield loupe to view the interior of a red spinel crystal being offered for sale.

SEARCHING FOR CLUES WITH LITTLE OR NO INSTRUMENTATION

The initial determination of basic gemological properties without the aid of instruments plays a key role in identifying any gem material. This is also the time to determine the quality of the gem or (in the case of rough) potential yield and durability issues that might arise in the cutting process (Sinkankas, 1955). Some rough (in crystalline form or on matrix) may actually be more valuable as a specimen than a faceted gem. Understanding crystal morphology and associated matrix minerals is often necessary to identify rough specimens properly. A shrewd buyer who can quickly assess the nature of the gem material being considered will have a great advantage over the seller or competing buyers. However, it is absolutely essential to go through all the critical steps in the identification process to be sure of what one is purchasing. Much can be ascertained by first examining the gem without the aid of any instruments and by observing its reaction to various natural and artificial lighting conditions.

Observing the color (hue, tone, and saturation), as well as how light travels through it (i.e., brilliance, or degree of refraction) and is reflected off the surface (i.e., luster) of the material in question can narrow the field considerably. Gems with a higher refractive index will have a higher luster and be more reflective, and gems with higher dispersion will exhibit more colorful spectral flashes from the crown facets (Hanneman, 2001). Benitoite, with an extremely high dispersion of 0.046, is easily distinguished from sapphire (0.018), but it might be confused with a blue diamond (0.044). Further visual observations would reveal the pleochroism and lower hardness (in

its sub-adamantine luster) characteristic of benitoite. When possible, a clean cloth should be used to remove any grease or dust from the gem to provide a more accurate determination.

At the 2002 Tucson gem and mineral shows, I showed colleagues a particularly interesting gemstone that was a rare color variety of one of the most popular gems on the market today. The gem in question (figure 2) is brownish yellow, trichroic, and has a relatively high refractive index. Because of its unique optical characteristics, three well-respected scientist-gemologists were able to identify the gem in five minutes or less without any clues other than their keen senses and practical knowledge of how light interacts with various gem materials. Each first noted the brilliance and dispersion, which indicated the high R.I, and rotated the gem to reveal its trichroic nature. Recognizing the three unique colors was key to the identification for two of the gemologists. The third applied the Hodgkinson “Visual Optics” method to make his identification (see section below on “Filters and the Hodgkinson ‘Visual Optics’ Method”).

Remember always to check if a gem exhibits change-of-color or even a shift in color. These excellent clues to a gem’s identification are often overlooked. I have seen numerous color-change sapphires that were sold as blue sapphires because the sellers had no incandescent light source to view the change. I now regularly bring flashlights as gifts when traveling in remote gem-producing countries because I want the miners to know what to look for and to let me know when they find something unusual. Sharing information with your suppliers will create an atmosphere of trust that will often result in seeing special or unusual gems that other buyers may not be



Figure 2. This 16.90 ct triangular cut zoisite has been cleverly faceted so that the three optical directions are parallel to the table and perfectly oriented down the three points. While it shows a brownish yellow face-up color, when viewed through the crown down each optical direction it reveals the pinkish blue, green, and yellow pleochroism that helps identify this rare color variety of zoisite. Photos by Maha Tannous.



given the privilege of viewing. An astute gemologist does not even have to travel far to uncover a rare treasure. Gemologists have been known to find chameleon diamonds in estate mountings because the seller had not bothered to check or had no knowledge of color-change diamonds.

When examining a piece of rough, it is important

to notice any silky or cloudy areas that may indicate chatoyancy or asterism, thereby narrowing down the possibilities while also providing a better knowledge of the potential value of the finished gemstone. A cat's-eye chrysoberyl or star sapphire typically will not look very attractive in the rough, but examination of the material with a simple pocket flashlight

Figure 3. This chrysoberyl preform shows a silky area (left) that may produce a cat's-eye effect on polishing. A drop of safflower oil (center) reveals the potential cat's-eye, which proved to be very sharp in the polished 13.68 ct stone (right). Photos by Maha Tannous.

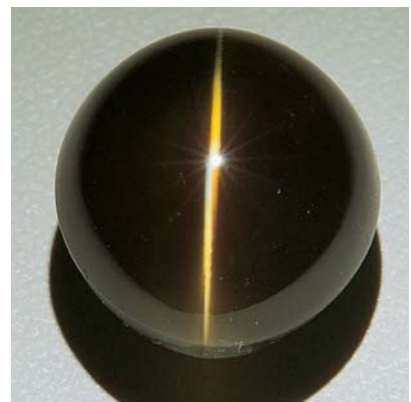




Figure 4. Surface abrasions can be a key indicator of hardness, but they do not always represent a soft stone. For example, the sapphire on the left shows a significant amount of surface abrasion, like the (much softer) zircon on the right. Abrasion and scratches are related to the amount of wear and tear, as well as to a stone's hardness. Photos by Nicholas DelRe (left) and Tino Hammid (right); © GIA.

can reveal the stone's true potential. The application of a drop of water or vegetable oil on the surface of a rough gem will often help reveal these optical phenomena (figure 3).

Other initial observations that may be made using only the gemologist's powers of visual examination and knowledge of gem properties include cleavage, fracture, relative hardness, and relative density. Cleavage and fracture are fairly straightforward, but they require practice to discern. Studying the various types of fracture (e.g., conchoidal, step-like, granular) and the directions of cleavage by actually breaking or chipping rough will provide excellent hands-on experience that may then be applied in the field.

Relative hardness and density are much more difficult to master, but they can be very important when searching for initial clues for eventual identification. Although portable hardness kits are available for rough gem materials (see "The Last Resort. . ." section), polish, luster, and the sharpness of facet junctions are important indicators for cut stones. Abrasions or scratches, along with rounded or worn facet junctions, usually indicate a softer stone. However, in the case of estate jewelry, it may merely indicate a gem that has been subjected to greater wear and tear. Common sense must dictate how a clue is applied in the identification process (figure 4). Judging relative hardness is a subjective matter, which requires practice and experience through practical application.

The relative density of a gemstone or piece of rough may be measured by its heft or weight in one's hand as compared to other gem materials of similar size. Although this determination is also very subjective and difficult to master, it may be useful for identifying gems that have very high or very low densities, such as zircon versus sapphire, or glass versus plastic. With its higher specific gravity, zircon

will have a greater heft than a sapphire of equal size. Likewise, glass will have a greater heft than an equal-size piece of plastic. With extensive practice, it is possible to distinguish density even between such similar materials as aquamarine (S.G. 2.65–2.75) and topaz (S.G. 3.50–3.60).

Upon examining what had been represented as an important piece of tsavorite in Tanzania, I held it in my hand and noticed that it was appreciably heavier than what I expected, given the size of the rough. Further testing, which included the use of a Chelsea filter (figure 5), revealed that it was a piece of YAG (yttrium aluminum garnet, much denser than natural grossular garnet) that had been "fashioned" to look like it was fresh from the mine.

Some gemologists and gem dealers have developed a keen sense of heft by placing the gem in question on their tongue. Since many native miners and dealers carry the gems they find or trade in their mouth for security purposes, they often become

Figure 5. Green YAG (yttrium aluminum garnet; here, 3.65 ct) will appear red through the Chelsea filter. Photo by Maha Tannous.

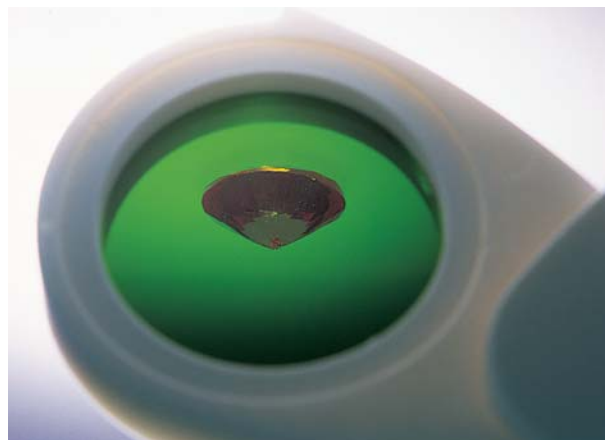




Figure 6. These two practical and very portable labs—the PortaPac and the PocketLab—provide most of the instruments needed to make proper identifications in the field or at trade shows. Courtesy of Gemological Products (left) and GIA Gem Instruments (right).

acutely aware of the subtle differences in relative heft. Some diamond dealers have been known to estimate the weight of a diamond to within points by this method.

The feel or even smell of a gem material also may provide essential clues. For example, the warm soft feel of amber or glass contradicts the cool hard feel of quartz or tourmaline. The resinous, burnt-hair smell of amber when touched with the point of

a hot sewing needle is noticeably different from the acrid smell of plastic.

PORTABLE INSTRUMENTS FOR FIELD IDENTIFICATION

The most important portable instrument is the loupe; when it is used with a good light source and a pair of tweezers, an experienced gemologist can discern many key characteristics. Other useful portable instruments include a dichroscope, polariscope, spectroscope, refractometer, UV lamp, immersion cell, and hardness testers. Some gem instrument manufacturers provide a kit with miniature versions of the standard gemological instruments, such as the GIA Gem Instruments PocketLab and the Gemological Products PortaPac (figure 6).

Figure 7. The loupe is a gemologist's most useful and portable tool. Shown here are a GIA Gem Instruments 20.5 mm, 10× triplet corrected loupe and a 10-20-28× corrected loupe from A. Krüss Optronic (Hamburg, Germany). Photo by Maha Tannous; the pink spinel trilliant weighs 4.95 ct.



Loupe. There are several types of loupes being employed by gemologists and gem dealers around the world (figure 7). The hand loupe is the most versatile and most commonly used. A corrected loupe (e.g., triplet) is best, since it minimizes distortion around the edges of the viewing area. Darkfield (surrounding indirect diffused) or oblique (side) illumination provides the best view of the interior of the stone in question. Many gemologists and dealers use the 10× loupe attached to the end of a small flashlight to provide oblique illumination. However, in this author's opinion, a darkfield loupe most closely approximates a microscope for the examination of loose stones up to 20 ct (figures 8 and 9). When a darkfield loupe is not available, place the gemstone on its side directly

on top of the light source and then cover the upper portion with a finger while viewing the gem through its table with a standard loupe. By directing light obliquely through the pavilion, the gemologist will be better able to examine the interior of the gem (figure 8 inset). The loupe also should be used to confirm observations of surface characteristics previously made with the unaided eye.

A keen understanding of inclusions and other internal characteristics is essential when viewing the interior of a stone. Several inclusion reference books (see, e.g., Gübelin and Koivula, 1986; De Goutière, 1996; Shida, 1996, 1999; Koivula, 2000) should be reviewed when preparing for a buying trip. If you are looking for rubies and sapphires, for example, it may be prudent to color-photocopy the relevant sections from your favorite inclusion text to take along into the field. It is essential to practice identifying inclusions using a loupe. While still in the office or lab, after observing an inclusion scene with the microscope, practice viewing the same scene with a loupe. John Koivula, GIA's senior research gemologist, uses only his 10× loupe to locate the unusual inclusions he discovers every year at the Tucson shows.

Figure 8. It is the author's opinion that the darkfield loupe, with the standard flashlight attachment, is the single most significant development in portable gemological instruments for the serious gemologist. Inset: In the absence of a darkfield loupe, the effect may be approximated with an oblique illumination technique that simply requires placing the gem material in question on the glass of the light source and covering the exposed portion with a finger to create a shadow effect while simultaneously securing the gem in place. Photo by Maha Tannous; inset by Jason Stephenson.



Figure 9. Proper use of the darkfield loupe (here, by GIA Gem Instruments) requires practice holding the gem in one hand and the loupe and flashlight together in the other at a distance of about one to two inches (3–5 cm) from the eye. In the inset, a typical inclusion scene of negative crystals is readily visible with a darkfield loupe in this 4.95 ct lavender spinel from Sri Lanka. Photo by Maha Tannous; inset by Edward W. Boehm.

It is important to recognize the entire inclusion scene as well as individual inclusions or features. For example, partially exsolved (dissolved) rutile needles alone suggest heat treatment, but when they are combined with altered crystals and tension halos, the entire inclusion scene provides definitive proof of a heat-treated stone.

Identification of treatments continues to be one of the most difficult challenges for today's gemologist. A loupe, combined with a strong light source, can also be of great assistance in this regard. Note that treatments are as important a concern when judging rough as they are with faceted stones, since they may hide flaws or the true color of the rough gem material. An unsuspecting buyer would be very surprised to cut into a fracture-filled emerald crystal or a dyed ruby crystal, or to discover that a piece of "aquamarine" rough was actually just a chunk of greenish blue glass. Strong back lighting or the use of a more powerful flashlight will help the gemologist view the interior of the rough in question (figure 10). Dyes, altered inclusions, glass fillings, and

even the flash effect characteristic of fracture-filled diamonds may be easily seen with a darkfield loupe.

Likewise, the identification of many synthetics (e.g., curved striae or flux in some synthetic corundums, and metallic inclusions in some synthetic diamonds) can be made with a simple loupe. Also, the doubling of back facets in doubly refractive synthetic moissanite will easily separate this imitation from singly refractive diamond.

Lighting. Often overlooked, lighting conditions must always be observed and often manipulated to provide proper viewing of external and internal characteristics. Be aware of natural or extraneous lighting conditions. Various parts of the world have natural and artificial lighting that will make the gem look different there than at home. Natural lighting in northern hemispheres tends to favor the blue end of the spectrum, while natural lighting in southern hemispheres makes red, orange, and yellow stones look more attractive. Carrying a daylight-equivalent light source combined with a set of reference stones will minimize error. Many corundum dealers carry small samples of the colors they prefer.

Most third-world countries use fluorescent lighting that is either too blue or flickers due to inconsistent power supply. This can present disastrous results if one is not prepared. Trade shows, typically in large convention halls not designed for displaying gems, can be just as challenging. Again, being aware of the conditions and insisting on viewing a gem in

Figure 10. The gas bubbles in this glass imitation of aquamarine (4.0 × 4.0 cm) are easily visible with the aid of a 10× loupe and a powerful portable light source such as the Sure Fire light by Laser Products of Fountain Valley, California. Photo by Maha Tannous.



Figure 11. The most portable and lightweight lights currently available are manufactured by LRI Photon Micro-Lights, Blachly, Oregon. The output of each consists of (from left to right) 6500K white light, 372 nm long-wave ultraviolet blue light, and 584–592 nm monochromatic yellow light. Photo by Maha Tannous.

daylight or controlled light may prevent a disappointing purchase.

Buyers of gem rough require much stronger portable lights than are needed for examining faceted gems. While the Sure Fire light (again, see figure 10) is one of the better flashlights available, even stronger illumination is sometimes needed for darker or larger rough. Welch Allyn, of Skan Falls, New York, produces a number of high-powered rechargeable lights with focus adjustments or fiber-optic attachments (initially developed for the medical industry) that are very useful for viewing rough gem materials.

Figure 12. The lipstick-size (5.5 × 1.5 cm) long-wave portable ultraviolet lamp from Nebula, Redwood City, California, is one of the most durable UV lamps introduced in the last few years. Inset: Natural amber generally fluoresces blue under long-wave UV fluorescence. Photos by Maha Tannous.



Among the most convenient new portable instruments are the Photon Micro-Lights, which are sold individually or as a set. The three most useful (figure 11) are the blue YAG phosphor diode lamp that provides long-wave UV radiation at 372 nm, a yellow lamp at 584–592 nm, and a white-light lamp with an ideal daylight color temperature of approximately 6500 K (D. Allen, pers. comm., 2002). Each unit requires only two 3-volt lithium coin cells, which makes them light and compact (with an active “life” of approximately 1,000 hours). The white light is useful to view gems such as alexandrite and diamond, which require daylight to make a proper assessment of quality and value. The monochromatic yellow light is the perfect complement to a portable refractometer and even works well with the desktop version.

Fluorescence. In addition to the Photon Micro-Light blue YAG phosphor diode lamp noted above, a number of long-wave (approximately 370 nm) ultraviolet lights are now available to gemologists (see, e.g., figure 12). A gem’s response to UV radiation must be used only as an indicator, not as proof, but it can provide useful information. In locality determinations, for example, a fluorescent (chromium-rich, iron-poor) ruby may come from Myanmar or Vietnam, while a nonfluorescent (iron-rich) ruby may originate from Thailand or East Africa. Strong red fluorescence should always be cause for extra scrutiny, since almost all synthetic rubies exhibit this property. Amber generally fluoresces yellowish green (see figure 12, inset), while plastic rarely does. Heat-treated sapphires often show orange fluorescence in zones previously occupied by rutile needles. Glass fillings in ruby can be detected when they fluoresce differently from their host. Many of the adhesives used to assemble crystals fluoresce green or yellow when exposed to long- or short-wave UV radiation.

Dichroscope. One gemological instrument that is portable, easy to use, and informative is the dichroscope (figure 13). If optic character is not readily apparent, the dichroscope should always be the second instrument used in the field. A dichroscope can readily distinguish between natural and imitation tanzanite or aquamarine (figure 14). This small, simple instrument often proves indispensable when judging tumbled rough that offers no clear view into its core. A dichroscope also helps the buyer determine the pleochroic colors that must be taken into consideration when the rough is to be fashioned.



Figure 13. The OPL (Orwin Products, Ltd.) calcite dichroscope (left, 4.0 × 1.4 cm) is one of the smallest dichroscopes on the market. It is most useful with faceted gems under 10 ct. The OPL diffraction grating spectroscope (right, 5.5 × 1.3 cm) is the smallest and most portable spectroscope on the market. Mastering this instrument takes practice, but it can be one of the most important tools for the traveling gemologist. Photo by Maha Tannous.

The directions of these colors relative to the shape of the rough are critical in the placement of the table, thereby dictating the yield and ultimate value of the finished gem.

The dichroscope made by Orwin Products Ltd., England (OPL) is excellent for viewing fashioned gems smaller than 10 ct. The new London Dichroscope, in the familiar “Chelsea” filter casing,

Figure 14. Natural aquamarine (left), glass imitation aquamarine (middle), and glass imitation tanzanite (right, 4 × 3 cm) are all easily separated by a dichroscope. Aquamarine, like tanzanite, will show the characteristic pleochroism of the natural gem, while the glass imitations will show no pleochroism. Photo by Maha Tannous.





Figure 15. The new London Dichroscope, distributed by the Gemmological Association of Great Britain, has an expanded field of vision that makes it ideal for viewing larger gems or rough, such as this tanzanite (left, 2.57 grams) and pink zoisite (right, 2.9 grams). Stones courtesy of H. Krupp; photo by Maha Tannous.

uses crossed polarizers to provide a larger field of vision, making it more useful with rough and larger gems (figure 15). The Grieder dichroscope, available through Eichhorst Gem Instruments (Hamburg, Germany), uses the same technology to provide a similar field of vision. What is most important is to use the instrument that you are most familiar with and that gives you the best results.

Polariscope and Polarizing Filters. A polariscope attachment for a Mini Maglite or even just the lenses in a pair of polarized sunglasses can be used in place of a dichroscope or when more detailed information on optic character is needed (figure 16). For example, amethyst and scapolite have almost iden-

Figure 16. Attaching a polariscope to the end of a Mini Maglite provides an excellent portable tool for determining pleochroism and optic character. Photo by Maha Tannous.

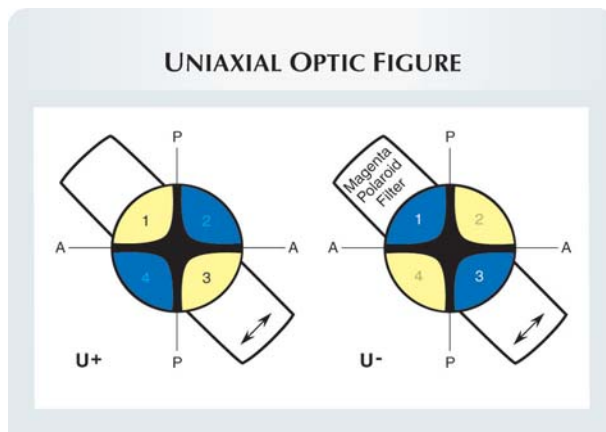


tical properties with the exception of their optic sign and scapolite's two directions of cleavage (typically evident only when viewing rough). Since amethyst is uniaxial positive (U+) and scapolite is uniaxial negative (U-), a polariscope combined with a condensing sphere and a magenta Polaroid filter may be used to differentiate them (figure 17).

Polarizing filters are useful for spotting the "tata-mi" or "tabby extinction" pattern in synthetic spinels, which are used to imitate many gems such as aquamarine (see, e.g., Gübelin and Koivula, 1986, p. 515). Such internal irregularities often may be seen only with crossed polarizers, and may also aid in judging the potential instability of highly strained rough as is often encountered in tourmaline and diamonds.

Spectroscope. Although the hand-held spectroscope is one of the most difficult portable gemological instruments to master, it also can be one of the most powerful in the field instrument arsenal. The prism and the diffraction-grating spectroscopes are the two types available. The diffraction-grating spectroscope (again, see figure 13) is smaller, more portable, and offers an even distribution of the visible color range, which makes it easier to see absorption lines in the red region. On the other

Figure 17. This illustration shows an optic axis figure as it would appear through a portable polariscope attachment using a glass condensing sphere and a magenta Polaroid filter to distinguish between uniaxial positive (U+) or uniaxial negative gems (U-). If the optic figure of the gem in question advances to a blue color in the 1st and 3rd quadrants (parallel to the direction of the filter), as is the case with scapolite, then it is U-. A yellow color in the 1st and 3rd quadrants indicates a U+ gem such as quartz.



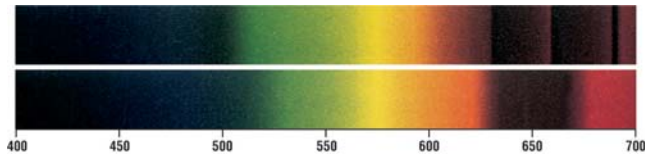


Figure 18. A spectroscope can readily separate natural-color jadeite (top) from typical dyed jadeite (bottom).

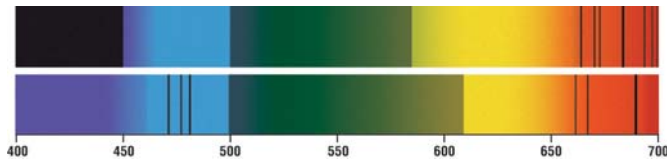


Figure 19. Also easily separated on the basis of their spectra are red spinel (top) and ruby (bottom). Spectra adapted with permission from Günther (1988).

hand, there are more published spectra available for the prism spectroscope. Again, take the instrument with which you have the most experience. It is very useful to take high-quality drawings or photos of spectra for reference in the field. In addition, a strong light source is essential to see the subtle spectral characteristics for most stones.

As with the loupe, a great deal of practice is required to master the spectroscope. And, as with inclusion scenes, key spectral patterns must be committed to memory before this instrument can provide its full potential. However, a knowledgeable gemologist can readily identify rough or polished zircon by virtue of its unique “organ pipe” pattern. Sometimes only one absorption line is needed to tell the buyer to beware of a dye, as with green jade (figure 18). Ruby and red spinel are easily distinguished by their characteristic spectra (figure 19).

Note, however, that some features may weaken or disappear when the gem is heated by the light source, as is the case with yellow diamonds that have been irradiated and annealed. (This also is true for some naturally occurring spectral features, such as “Cape lines.”) Therefore, it is important to recognize the telltale characteristics as quickly as possible (see, e.g., Günther, 1988; Anderson, 1990). Placing a yellow diamond on a cube of ice will delay the warming effect of the incandescent light.

Refractometer. Although a portable refractometer can be indispensable in certain situations, carrying

R.I. fluid and finding the time and a place to use this instrument can pose problems in a field setting. There are a few miniature refractometers on the market (such as the GIA Gem Instruments Duplex III pocket refractometer and the Gemological Products GemPro portable refractometer), and some fortunate gemologists still own the early-model GIA Gem Instruments refractometer designed by Robert Shipley Jr. and introduced in 1949 (figure 20; Shipley Jr. and Alton, 1949). Again, it is important to practice using this instrument and to note the subtle differences when monochromatic light is not available (Mappin, 1945). The perfect compliment to a field refractometer is the new yellow Photon Micro-Light shown in figure 11.

Figure 20. Among the portable refractometers currently available is the GIA Gem Instruments Duplex III (shown with a 4.95 ct spinel). The inset shows the GIA Gem Instruments refractometer designed by Robert Shipley Jr. that was introduced in 1949. At 5.2 × 4.8 cm, it is still considered one of the most durable and portable refractometers ever made (E. Gübelin, pers. comm., 2002). Photos by Maha Tannous.





Figure 21. In the photo on the left, a faceted red spinel and a red spinel crystal both appear dark gray through the Hanneman Ruby Filter, whereas a faceted ruby and a ruby crystal on calcite matrix both appear blue through the same filter. In the center photo, a large red beryl crystal and faceted red beryl both appear grayish through the Hanneman Ruby Filter. On the far right, a faceted green YAG and a Chatham synthetic emerald crystal both appear pink when viewed through a Hanneman-Hodgkinson Synthetic Emerald filter. Photos by Maha Tannous.

Filters and the Hodgkinson “Visual Optics” Method.

The versatile Chelsea filter (again, see figure 5) and the numerous filters invented by Dr. W. Hanneman and Alan Hodgkinson are among the many filters that are valuable when used properly.

Some filters target specific gems (e.g., ruby, tanzanite, and aquamarine). The Hanneman Ruby Filter is quite useful in distinguishing between ruby

and other red gems (figure 21, left and center). The Synthetic Emerald Filter, invented by Alan Hodgkinson, can separate a synthetic from a natural emerald even through a glass window or showcase (Hodgkinson, 1995a). If the total body color of the emerald appears pink through the filter, then it could be a synthetic emerald or perhaps a YAG (A. Hodgkinson, pers. comm., 2002; figure 21, right). In contrast, natural emerald appears greenish or loses its body color. Dr. Hanneman recently developed a filter for distinguishing tanzanite from its two most common imitations, glass and synthetic forsterite (Hodgkinson, 2001).

It is important to recognize that filters can assist in the identification process, but they are not to be used for definitive determinations. Nonetheless, they are valuable aids to identification and can save time. In practiced hands, these filters allow for instantaneous, inexpensive screening of entire parcels.

Hodgkinson (1995b) also has developed an overall optical system of gem identification, which he named “Visual Optics.” By holding the table facet of a gem (loose or mounted) close to the eye and looking at a distant bright light source, the gemologist can observe and estimate refraction, dispersion, and birefringence. In some cases—as with ruby, diamond, darker tourmalines, and lead glass—recognition may be instantaneous. Any gemologist who has taken the time to train his or her eye to this method may also quickly eliminate other possibilities.

A pinhole instrument has been developed that, used in conjunction with standard focused illumination, permits side-by-side demonstration of the Hodgkinson method (A. Hodgkinson, pers. comm., 2002). This instrument is especially useful to sepa-

Figure 22. The narrow white flares from a faceted diamond (left) readily separate it from the broad spectral flashes of a faceted synthetic moissanite (right)—illustrating the differences in dispersion—when the two round brilliants are submerged in water and illuminated from above through a pinhole with a focused light source. This concept of optical dispersion is the essence of the Hodgkinson “Visual Optics” method. Photo by Alan Hodgkinson.





Figure 23. Diffusion detectors can be very useful for detecting surface-diffused gems, even when water or oil is used as the immersion medium rather than methylene iodide. Surface-diffused sapphires (here, a blue sapphire on the left showing blue color concentrations along the facet junctions, next to an orangy pink sapphire with a distinctive rim of surface color) continue to pose identification challenges for gemologists. Photo by Maha Tannous.

rate diamond from its closest imitation, synthetic moissanite (figure 22). The synthetic moissanite disperses light into broad spectral flashes, whereas the diamond disperses narrower white flashes (A. Hodgkinson, pers. comm., 2002). It is essential to notice the relative angle and spread of the spectral colors as light passes through the sample. In essence, since light travels slower in highly refractive gems such as a diamond or cubic zirconia, the spectral clusters will be more spread out. In contrast, gems with lower refractive indices, such as quartz or peridot, will not spread light as much and thus will exhibit a tighter grouping of spectral clusters. This test is only useful for faceted gems and requires considerable practice, but it can provide a quick clue to a stone's refractive properties.

Diffusion Detectors. Several practical containers—"immersion cells"—that are useful for viewing potential diffusion-treated sapphires or rubies were introduced a number of years ago. The stone is placed in the upper compartment containing a liquid to reduce reflection. Methylene iodide (diiodomethane) is most useful because its refractive index of 1.74 is so close to that of corundum and other gem materials. However, even water (R.I.=1.33) or olive oil (R.I.=1.47), which are less toxic and easier to come by in the field, may be used. These diffusion detectors can reveal concentrations of color along pavilion facet junctions (in the case of blue diffusion-treated sapphires) or surface layers of

color (in the case of the new orangy pink to orange treated sapphires), as illustrated in figure 23. Immersion also may help expose curved striae in flame-fusion synthetic rubies that have been tumbled to resemble waterworn rough crystals (Koivula et al., 1992). Such rough corundum imitations are sometimes offered at the source to either deceive or test the buyer. Usually, if a buyer can show gemological expertise, fewer and fewer synthetics and imitations will be included in the goods offered.

Two well-known immersion instruments are the GIA Gem Instruments diffusion detector with a self-contained light source (again, see figure 23) and the ROS/Gem Optics diffusion detector with the smallest of the Maglites, the Solitaire. The latter is somewhat more portable because of the external light source.

The Last Resort: Hardness Testers. Hardness may be detected visually by rounding of facet junctions and scratches on stones, as described earlier, and provides helpful clues in narrowing the field of possibilities. As a last resort, when judging rough, a portable hardness kit can also be quite useful (figure 24). Local crystals of known hardness may be just as effective as a hardness kit. Faceted gems should never be subjected to scratch testing; there are so many other (nonde-

Figure 24. As a last resort, a portable hardness testing kit (here, 6.5 × 4.0 cm) can aid in identifying rough when visual testing is reduced due to a rough surface or natural tumbling. Hardness testing should not be done on fashioned gems. Photo by Maha Tannous.



structive) ways to identify them. As with heft, judging the relative hardness of a gem requires practice at home that could be applied in the field.

Recent Additions. Among the newest instruments to enter the field arsenal is the SSEF Diamond Spotter (figure 25)—which is a useful first step in identifying HPHT-treated diamonds. This practical instrument, developed by the SSEF Swiss Gemmological Institute in Basel, Switzerland, in collaboration with Dr. Emmanuel Fritsch at the University of Nantes in France, may be used to distinguish type IIa (those that may undergo or have already undergone HPHT treatment) and type IIb diamonds, both of which transmit short-wave ultraviolet radiation, from their more common type I counterparts (J-P. Chalain, pers. comm., 2002). The diamond is secured with BluTack over the opening on the cylinder and then exposed to short-wave UV. If the diamond transmits short-wave UV, then the UV-sensitive area will fluoresce green. If the diamond absorbs short-wave UV, then the UV-sensitive area will remain white. Ideally, the diamond should be positioned so the incident UV light is perpendicular to the crown, pavilion, or girdle, allowing the light to travel directly through the stone with minimal reflection.

Although extremely rare, type IaB diamonds also transmit short-wave UV; however, thus far no HPHT treatment has been described in the gemological literature as being applied to natural type IaB

diamonds. This instrument also may be used to separate natural colorless corundum, which absorbs short-wave UV, from Verneuil synthetic corundum, which transmits short-wave UV. Cubic zirconia and synthetic moissanite both absorb short-wave UV (Hänni and Chalain, 2002).

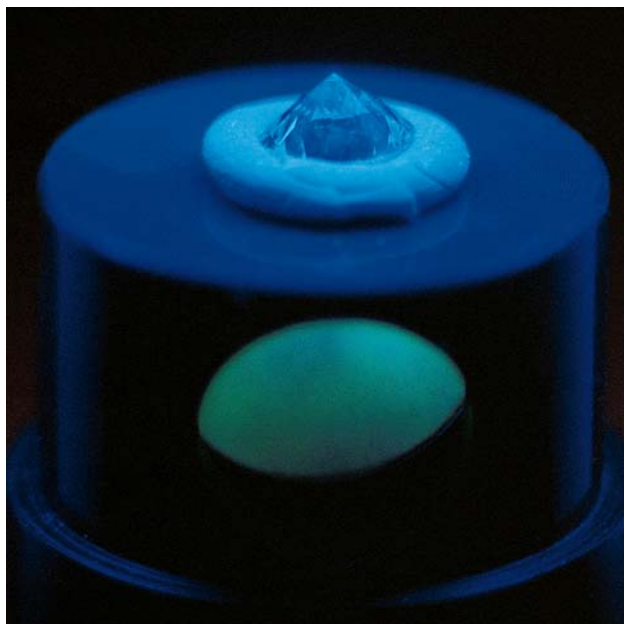
Important References. While suitable portable instruments are essential, a reference manual also may save time and money. There are numerous books that can assist in honing your field gemology skills, such as Liddicoat (1989), Anderson (1990), Hurlbut and Kammerling (1991), Webster (1994), GIA's *Gem Reference Guide* (1995), and (the most compact) Schumann (1997).

The single most important reference items are gemological property charts, such as the "A" and "B" charts published by GIA. High-quality drawings of gem spectra and inclusions also are very useful.

CONCLUSION

The use of portable instruments and field methods requires time and patience to master. Yet some of the most significant developments in gemology, such as the darkfield loupe, have occurred while trying out new testing techniques when standard lab equipment was not available. As with all identifications, it is essential to follow four basic steps, in the following order:

Figure 25. The SSEF Diamond Spotter (left, 4.0 × 2.8 cm diameter) is one of the newer instruments invented to help gemologists deal with some of the latest identification challenges. Even with the table down, the green fluorescence visible on the screen below the 1.08 ct diamond on the SSEF Diamond Spotter (right) indicates that the diamond is type IIa or IIb. Photos by Maha Tannous.



1. Search for obvious surface clues.
2. Loupe the stone for internal characteristics.
3. Determine the material's general optic character.
4. Gather additional information with a handheld spectroscope, polariscope, ultraviolet lamp, refractometer, and the like, to further narrow down the possibilities.

A portable laboratory, such as the MaxiLab or PortaLab (figure 26), can be indispensable when making purchases in the field or at trade shows. However, it usually is not practical to carry an entire kit on every buying trip. Thus, skill in using pocket-sized portable instruments is essential. Practicing the use of these portable instruments long before you plan a gem-buying trip will greatly heighten the skills and senses needed to make the quick decisions in the field that could save you time and money.



Figure 26. Prominent gemologist Dr. Edward Gübelin is shown here using a Portalab in Yangon, Myanmar (Rangoon, Burma) at the 30th Myanmar Gems, Jade, & Pearl Emporium in 1993. Photo by Edward W. Boehm.

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LIDDICOATITE TOURMALINE FROM ANJANABONOINA, MADAGASCAR

By Dona M. Dirlam, Brendan M. Laurs, Federico Pezzotta, and William B. (Skip) Simmons

Liddicoatite, a calcium-rich lithium tourmaline, was recognized as a separate mineral species in 1977, and named in honor of Richard T. Liddicoat. Most of the remarkable polychrome tourmalines with varied geometric patterns that are characteristic of this species were produced during the 20th century from the Anjanabonoina pegmatite deposit in central Madagascar. To best display its complex color zoning and patterns, the tourmaline is commonly sold as polished slices or carvings. Liddicoatite exhibits physical and optical properties that overlap those of elbaite, so quantitative chemical analysis is required to distinguish these species; both may occur in a single crystal. The most common internal features are color zoning, strain patterns, partially healed fractures, feathers, needle-like tubes, negative crystals, and albite inclusions.

For decades, liddicoatite from Madagascar has been prized for its dramatic color zoning. Among the myriad geometric patterns displayed in polychrome slices cut perpendicular to the c-axis (figure 1), triangular zones and three-rayed “stars” resembling a Mercedes Benz symbol are the most recognizable features of this remarkable tourmaline. The diversity of colors and patterns shown by Madagascar liddicoatite has not been seen in tourmaline from other localities. The Anjanabonoina pegmatite deposit in central Madagascar is one of the world’s most important historic sources of liddicoatite.

The tourmaline group is extremely complex. Liddicoatite, $\text{Ca}(\text{Li}_2\text{Al})\text{Al}_6(\text{Si}_6\text{O}_{18})(\text{BO}_3)_3(\text{OH})_3\text{F}$, is a calcic lithium-tourmaline end member that was identified as a separate species 25 years ago (Dunn et al., 1977). These authors named the mineral after Richard T. Liddicoat, then president of GIA, in honor of his enormous contributions to gemological knowledge and education. At the time it was only the sixth tourmaline species to be recognized; currently 13 end-member species are known (see Hawthorne and Henry, 1999). Liddicoatite is one of

three *lithium tourmalines* with the general formula $(\text{Ca}, \text{Na}, \text{K}, \square)(\text{Li}, \text{Al})_3\text{Al}_6\text{Si}_6\text{O}_{18}(\text{BO}_3)_3(\text{OH})_3(\text{OH}, \text{F})$, which are defined on the basis of their X-site occupancy: Ca = liddicoatite, Na = elbaite, and a vacant (\square) X site = rossmanite. Elbaite is the most abundant gem tourmaline, whereas rossmanite has so far been identified from few localities (Johnson and Koivula, 1998b; Selway et al., 1998), and typically is not of gem quality. However, neither can be separated from liddicoatite without quantitative chemical analysis. Therefore, in this article we use the group name *tourmaline* to refer to material that has not been chemically analyzed.

Although liddicoatite is well characterized mineralogically, little has been published about the history, sources, and gemology of this tourmaline species in particular. This article focuses on liddicoatite from Madagascar—which is the principal historic source—and in particular on the Anjanabonoina pegmatite,

See end of article for About the Authors and Acknowledgments.
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which has been the most important producer of liddicoatite-elbaite tourmaline from that country. Chemical data for liddicoatite from other world localities (i.e., Brazil, Canada, "Congo," Czech Republic, Mozambique, Nigeria, Russia, Tanzania, and Vietnam) are included in Appendix A.

HISTORY AND MINING

Gem Tourmaline in Madagascar. In the 1500s and 1600s, French explorers reported topaz, amethyst, aquamarine, and other gem minerals from Madagascar (Lacroix, 1913a, Wilson, 1989). However, initial investigations found little gem-quality material, apparently because they focused on river mouths and areas close to the coast. In 1890, a colleague of French scientist A. Grandidier brought a large rubellite crystal from the Mount Ibity area (also spelled Bity; figure 2) south of Antsirabe to the National Museum of Natural History in Paris (Lavila, 1923). By 1893, Grandidier had found colored tourmaline *in situ* at pegmatites in the Betafo region (west of Antsirabe). The first significant pegmatite mining occurred in the early 1900s (Besairie, 1966).

Alfred Lacroix, a professor at the National Museum of Natural History in Paris, provided some of the first descriptions of Madagascar tourmaline and other gem minerals. His comprehensive work on the mineralogy of France and its colonies included descriptions of the crystallography, morphology, and color zoning of tourmalines brought back to France by early colonists (see Lacroix, 1893, 1910). Dabren (1906), a French mining engineer in Madagascar, described several localities for gem tourmalines, including the important pegmatite areas around Antsirabe and Fianarantsoa. A detailed early description of polychrome tourmaline from the "Ankaratra" area was given by Termier (1908). (Note that the Ankaratra massif, which is located about 50 km north of Antsirabe, is a volcanic area that is not a known source of tourmaline; the locality was probably reported in error.) That same year, Lacroix (1908) described gem-tourmaline-bearing pegmatites in the Sahatany Valley area (south of Antsirabe).

In 1910, Lacroix illustrated a slice of polychrome tourmaline from Anjanabonoina as part of his description of the geology, localities, and properties of tourmaline from the Vakinankaratra (Antsirabe), Ambositra, and Fianarantsoa districts. In describing the color zoning, he noted the distinctive star shape made by three red bands intersecting at 120° in

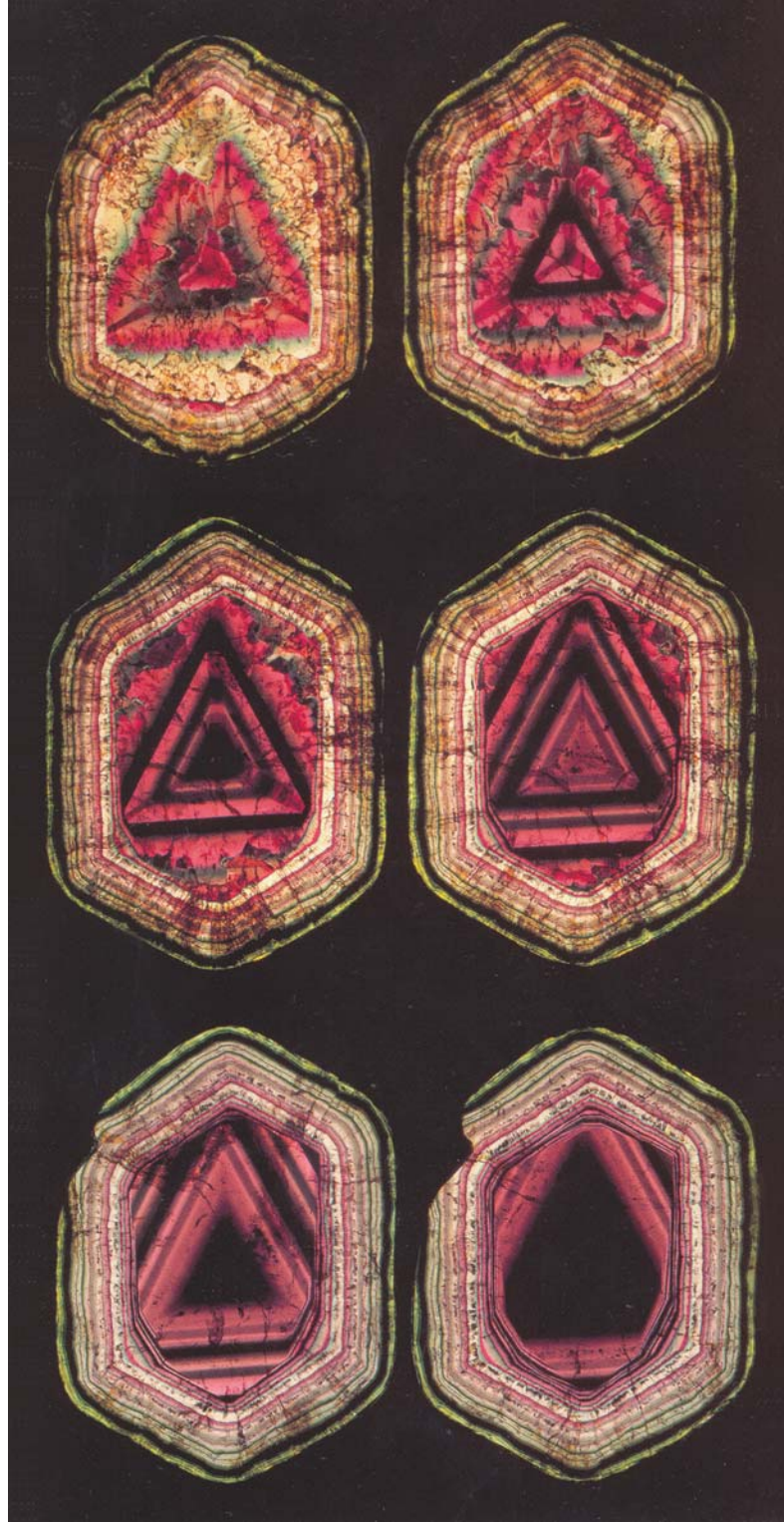


Figure 1. These slices of tourmaline from Anjanabonoina were cut from a single crystal, and show the dramatic progression of color zoning seen perpendicular to the *c*-axis (from top to bottom). The top two slices display a trigonal star pattern and "aggregate type" zoning (see Benesch, 1990). All have an outer region consisting of fine-scale color zoning that is roughly parallel to the prism faces. The slices measure 10 cm in longest dimension and are courtesy of Pala International; composite of photos © Harold and Erica Van Pelt.

some Madagascar tourmaline sections cut perpendicular to the c-axis (see, e.g., figure 3). Physical and chemical data also were included, and two chemical analyses—for a pink crystal from “Maroando” and a red sample from “Antaboka”—correspond to those of tourmalines that later came to be identified as liddicoatite. (Maroandro and Antaboaka, as they are typically spelled today, are located near Tsilaisina and southern Antsirabe, respectively, on opposite ends of the Sahatany Valley.) The data were reprinted from work done by L. Duparc at the University of Geneva (see, e.g., Duparc et al., 1910). Lacroix (1913b) illustrated the diverse morphology shown

Figure 2. The Anjanabonoina mine is located in the central highlands of Madagascar, approximately 55 km west of Antsirabe. This region hosts numerous gem-bearing pegmatites that are famous for producing beautiful tourmaline, morganite, kunzite, and other minerals for over a century.

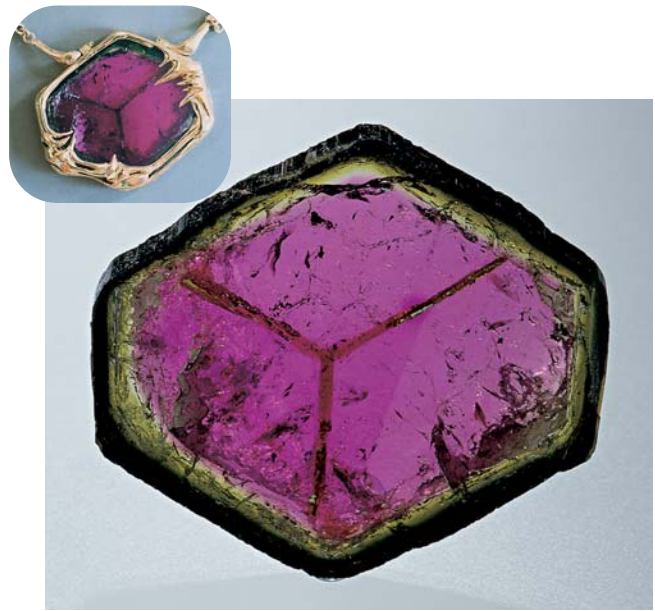


Figure 3. A trigonal star pattern formed by red color bands is evident in the pink portion of this tourmaline slice (5.5 × 4.5 cm) from Anjanabonoina. Courtesy of Allerton Cushman & Co.; photo © Robert Weldon. The inset shows this same slice set in an 18K gold pendant; courtesy of Rodney Blankley, Blankley Gallery, Albuquerque, New Mexico.



by Madagascar tourmaline. While all of this early work is published in French, some of the information has been summarized in articles in English (see Lacroix, 1913a; Gratacap, 1916).

Lacroix undertook the first detailed mineralogical expedition to Madagascar in 1911 (see Lacroix, 1913a), and a decade later he published the classic

Figure 4. Some of the typical crystallographic forms of tourmaline from Anjanabonoina are shown here (after Lacroix, 1922a). The crystals are bounded mainly by the prisms $a\{11\bar{2}0\}$ and $m\{10\bar{1}0\}$; the rhombohedrons $r\{10\bar{1}1\}$, $o\{02\bar{2}1\}$, and $k\{05\bar{5}1\}$; and minor scalenohedrons $t\{21\bar{3}1\}$, $e\{15\bar{6}2\}$, and $n\{24\bar{6}1\}$.

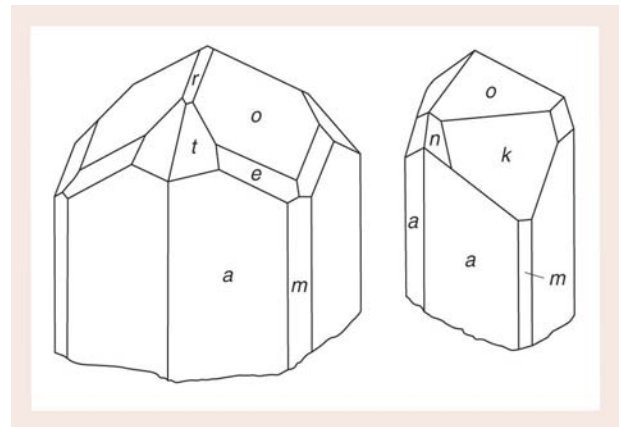


Figure 5. The historic Anjanabonoina mining area is situated on a low hill that contains several pegmatites and associated eluvial deposits. This view of the northeastern side shows a portion of the eluvial workings (right), as well as several white dump piles from pegmatite exploration activities in 1995–1996. The lower dump in the center marks the entrance to a 185-m-long prospect tunnel, and those further up the hill show the location of exploratory shafts (up to 45 m deep). Photo by Federico Pezzotta, January 1996.



three-volume reference work on the minerals of Madagascar (Lacroix, 1922a,b, 1923). In the first volume, he reported that the original tourmaline deposits were depleted, and that Anjanabonoina was the only deposit being mined for tourmaline. He illustrated the common crystallographic forms of this tourmaline (figure 4; see also Goldschmidt, 1923), and noted that particularly large and beautiful crystals were found in the eluvial workings there. Detailed descriptions of the color zoning and corresponding physical properties in Madagascar tourmaline (including crystals from Anjanabonoina) also were provided. Chemical analyses in this report revealed the relatively calcium-rich composition of Anjanabonoina tourmalines.

Several decades passed before the next important mineralogical work on Madagascar tourmaline was published, by Besairie (1966). Not only did this work mention the colored tourmalines and associated minerals found at Anjanabonoina and other pegmatites in central Madagascar, but it also included detailed locality maps. Later, from his 1976 visit, Strunz (1979) described the situation at the Anjanabonoina mine, and in 1989 W. E. Wilson provided a detailed account of the mineralogy. More recently, the color zoning of Madagascar tourmaline has been beautifully depicted (see, e.g., Benesch, 1990; Wöhrmann, 1994; Zang, 1996).

The Anjanabonoina Deposit. The Anjanabonoina mining area (figure 5) reportedly was discovered in 1894 by Emile Gautier (Bariand and Poirot, 1992). Léon Krafft began intensive mining in the early 1900s. The greatest activity occurred between 1920

and 1925, with 80 workers on site (Guigues, 1954). Large quantities of multicolored tourmaline and exceptional morganite were recovered (Wilson, 1989). By the time operations ceased in 1930, miners had explored only the eluvial portion of the deposit along the eastern slope of the hill (figure 5). (For mining methods used at the time to recover gems in Madagascar, see Lacroix [1922a] and Besairie [1966].) Very limited surface digging by local miners continued until the 1960s.

In 1965, Eckehard Petsch of the Julius Petsch Jr. Company (Idar-Oberstein, Germany) traveled to Madagascar and learned about the unusual color-zoned tourmalines from Anjanabonoina. With the assistance of Madame Liandrat of Antananarivo (Krafft's daughter), Mr. Petsch visited the mining area in 1967, after an arduous trip that involved nearly two days of walking. He found tourmaline crystals in the dumps of the abandoned mine and determined that a significant portion of the deposit still had not been mined (Bancroft, 1984).

Mr. Petsch's Madagascar company, Société Germaadco, acquired the Anjanabonoina deposit in 1970. This venture established roads, built housing and a school for the miners and their families, and began mining tourmaline in 1972 from the dumps and eluvial deposits downslope of the pegmatites. By 1974 there were more than 100 workers on site (Bariand and Poirot, 1992), and the mine was mapped in detail. Further mining of the pegmatites themselves took place in the upper-middle portion of the hill (figure 6). Some of the tunnels driven at this time reached up to 100–200 m long. He operated the mine until 1979, when the government of

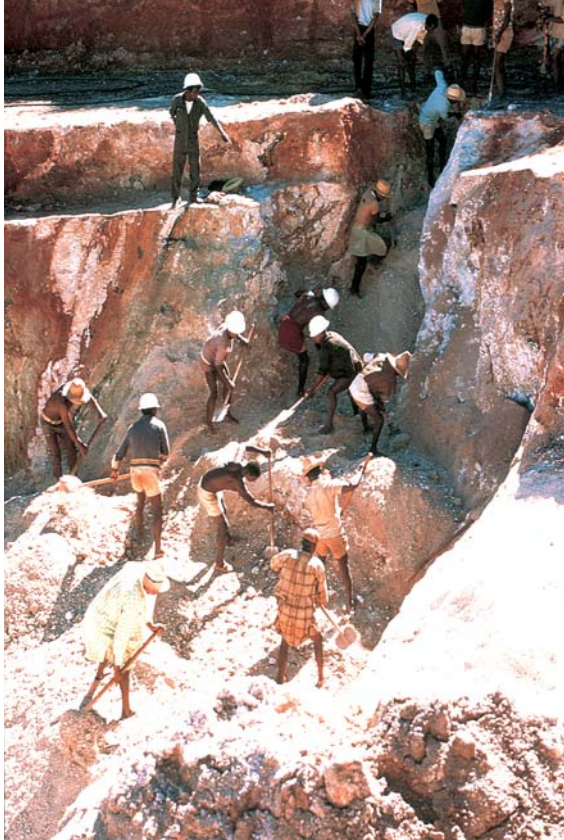


Figure 6. Miners excavate one of the pegmatites at the Anjanabonoina deposit for Société Germa dco in 1975. Photo by Eckehard Petsch.

Madagascar imposed a new law that required the transfer of ownership of all foreign mining companies to Malagasy nationals. Société Germa dco was placed under the control of a Malagasy engineer, Randrianariso lo Benjamin (a previous employee of E. Petsch), together with a Bulgarian partner.

The new owners focused on mining the large pegmatite dikes still in place, as well as tunneling to explore the potential of the deposit at depth. In addition, they dug an open pit 1.6 km southwest of the historic mine to investigate some large pegmatite veins that probably form a continuation of the Anjanabonoina pegmatites. Although this pit was unproductive, in 1984 a large tourmaline pocket was discovered on the western slope of the hill, near the original mining village. Crystals from this pocket were exported by the Bulgarian partner, but he was forced to leave Madagascar shortly thereafter due to problems with Société Germa dco and the local people. Société Germa dco remained the legal owner of the claims, but lost control of the mine when hundreds of people, excited by the discovery, began digging there illegally.

Locals continued to work the area manually for many years, resulting in hundreds of dangerous pits up to 40 m deep. The roads and structures built during past mining activities were destroyed by erosion

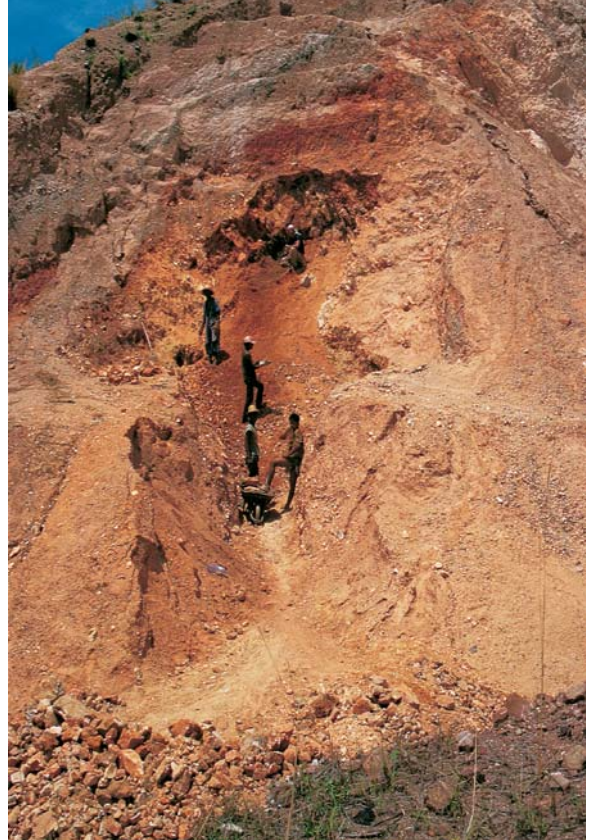


Figure 7. Relatively recently, the Anjanabonoina deposit was explored by Fretosoa Co. Here, deeply weathered pegmatite is mined from the upper-eastern part of the deposit (Sarodivotra workings, December 1995). This area produced significant crystals of dravite and liddicoatite. Photo by Federico Pezzotta.

during the rainy seasons, making it necessary for the miners to transport their gems on foot to be sold in the villages of Ambohimambola and Betafo. In 1991, the discovery of another large pocket led to a new period of unrest in which several miners were killed. When no significant new discoveries were made during the next few years, many of the miners abandoned the locality.

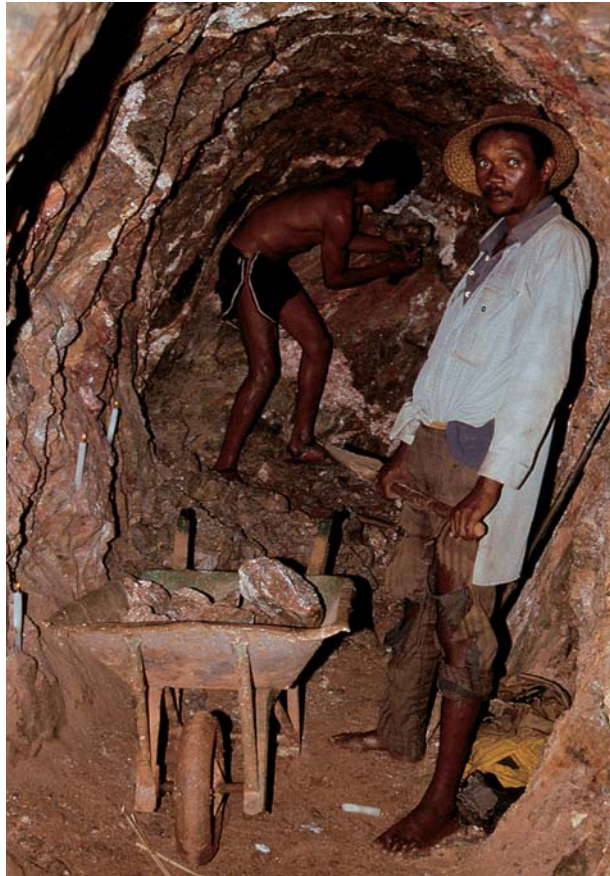
In 1995, one of the authors (FP) led Fretosoa Company, an Italian-Malagasy joint venture, in evaluating the gem potential of the central highlands. After visiting Anjanabonoina, he contacted Germa dco's Benjamin and a partnership between Germa dco and Fretosoa was formed. In the next two years, they developed a series of surface and underground workings (figures 7 and 8), which included four shafts that were 45–55 m deep and a 185-m-long subhorizontal tunnel that reached the pegmatite core zone. From these workings, FP collected enough geologic and structural data to create a three-dimensional model of the deposit and recognize that a significant portion of the gem-bearing core zone was still unmined. However, activity halted following the 1997 deaths of Mr. Benjamin

(who was also mine engineer) and Fretosoa chief Guisepe Tosco. With the mine no longer under strict control, the equipment owned by Fretosoa Co. was subsequently stolen, and the tunnels and pits collapsed or were destroyed by the activities of local miners. Currently, the mine is nearly abandoned, with only a few locals digging on the surface during the rainy season, when there is water available for washing the mined material (figure 9).

LOCATION AND ACCESS

The Anjanabonoina mine is located about 55 km west-southwest of Antsirabe in the Antananarivo

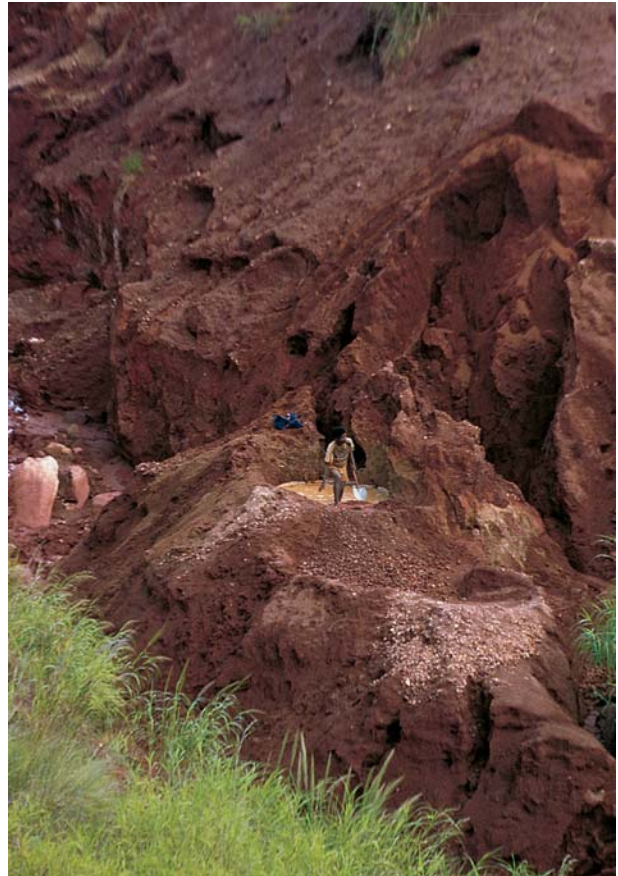
Figure 8. An exploration tunnel was dug by hand from the northeastern side of the Anjanabonoina deposit by Fretosoa Co. during October 1995 to December 1996. Shown here at 160 m from the surface, small kaolinized pegmatite veins can be seen crosscutting the weathered quartzite. Note the candles on the left that were used for illumination. Photo by Federico Pezzotta.



Province of central Madagascar (again, see figure 2). The deposit is situated on a hill (1,400 m elevation) at 19°55' S and 46°32' E, 2.5 km east of Ikaka Mountain (1,781 m). From Antsirabe, a national highway leads 56 km to the intersection with the paved road that proceeds 10 km southwest to the village of Ambohimambola. From there, a track originally graded by Société Germaadco in the early 1970s continues south-southwest for about 32 km, crossing the Ipongy River to the mine. Today, this track is impassable by vehicle, so access to the mine is possible only by foot. The journey from Antsirabe takes about two days, with the trip feasible only during the dry season, from late April until the beginning of November.

The authors do not recommend traveling to the Anjanabonoina area. Because of potential security problems, any foreigner who wishes to visit the

Figure 9. In recent years, the surface deposits at Anjanabonoina have been worked by local people, who use pools of rainwater to wash the material. Photo by Federico Pezzotta.



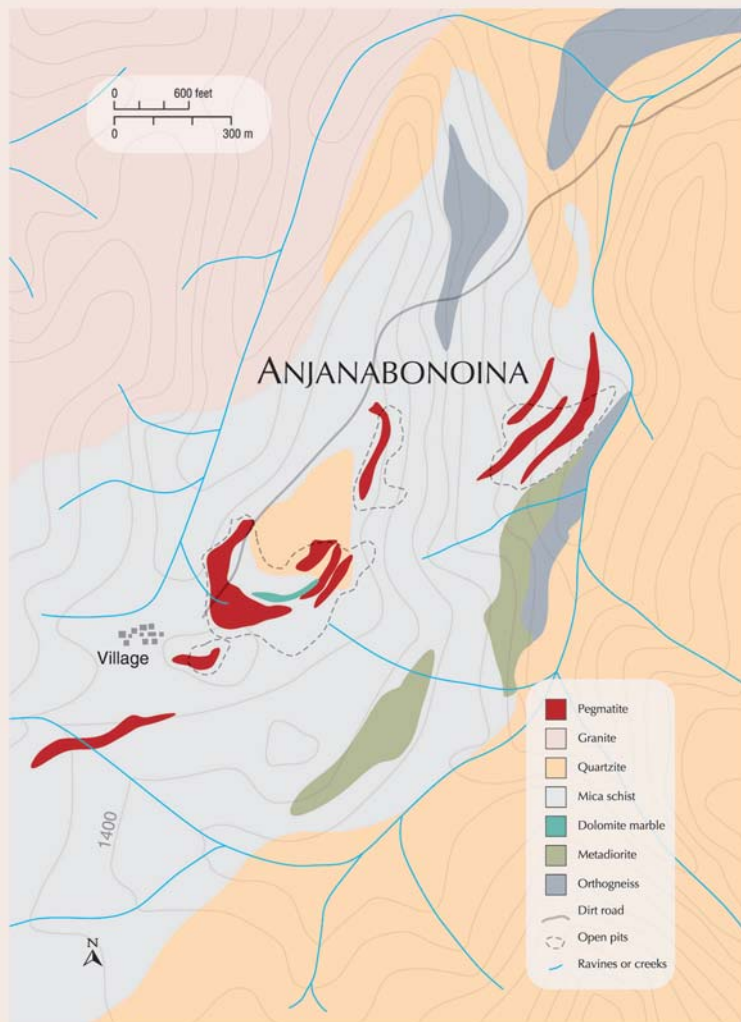


Figure 10. This generalized geologic sketch map of the Anjanabonoina deposit shows a series of south-southwest-trending pegmatites that have intruded schist, quartzite, and marble of the Itremo Group. The main eluvial deposits are located on the southern side of the hill near the village. Map by Federico Pezzotta.

region must first inform the local police. Note, too, that travelers to this area are at risk for malaria, especially during the rainy season.

GEOLOGY

Regional Geology. The western part of Madagascar consists mostly of Mesozoic sedimentary rocks, whereas the central and eastern portions consist mainly of Proterozoic metamorphic and igneous basement rocks (see, e.g., Ashwal and Tucker, 1999). The crystalline basement is part of the Mozambique orogenic belt (or East African Orogen), which originally extended through eastern Africa and Madagascar, Sri Lanka, India, and East Antarctica when they were still part of the Gondwana supercontinent (see, e.g., Petters, 1991). A large vari-

ety of gem deposits are associated with the Mozambique Belt (see Malisa and Muhongo, 1990; Menon and Santosh, 1995; Dissanayake and Chandrajith, 1999; Milisenda, 2000). The rocks in this belt underwent extensive metamorphism, plutonism, folding, and faulting during the latter part of the Pan-African orogeny, which occurred over an extended period from at least 950 to about 450 million years (My) ago (see, e.g., Petters, 1991). The last magmatic cycle of the Pan-African event occurred from about 570 to 455 My (Paquette and Nédélec, 1998; Fernandez et al., 2001), and generated granitic plutons and associated pegmatite fields (Zhdanov, 1996; Pezzotta, 2001). The gem-bearing pegmatites are undeformed by large-scale tectonic processes, and are thought to have formed in the later part of this cycle (i.e., younger than 490 My—Giraud, 1957; Fernandez et al., 2000).

Many of the gem-bearing pegmatites in central Madagascar, including Anjanabonoina and the famous localities in the Sahatany Valley, are hosted by rocks of the Itremo Group, in a tectonic unit known as the Itremo thrust sheet (see, e.g., Collins, 2000). The Itremo Group is characterized by a lower unit of gneiss and an upper unit of quartzites, schists, and marbles (see Fernandez et al., 2001). Both units are locally intruded by the pegmatites, which probably formed via fractional crystallization

Figure 11. Extensive hydrothermal alteration of the host rock occurred adjacent to the Anjanabonoina pegmatites. The calcium needed to form liddicoatite was probably derived from the metasedimentary host rocks. Here, the contact between a pegmatite (top right) and marble (bottom left) is shown. Black tourmaline veins can be seen along the contact and penetrating into the marble. Photo by Federico Pezzotta.



of granitic plutons emplaced at relatively shallow depths (Pezzotta and Franchi, 1997).

Geology of the Anjanabonoina Area. Laplaine (1951) described the general geology of the Anjanabonoina region. The pegmatites composing the historic part of the mining area are exposed over an area measuring 800 × 300 m (figure 10). These dikes form part of a larger aplite-pegmatite system that extends south-southwest of the Anjanabonoina area for about 2 km. (Aplite is a light-colored igneous rock characterized by a fine-grained texture composed primarily of quartz, potassium feldspar, and sodic plagioclase; Jackson, 1997.) For simplicity, the dikes will be referred to simply as pegmatites here. The major pegmatites dip gently north-northwest and range from 2 to 12 m thick.

The pegmatites were emplaced in a complex geologic environment, probably at the contact between the lower and upper units of the Itremo Group. The host rocks consist of quartzites, schists, and marbles that are locally tourmalinized near the pegmatites (figure 11). Large areas of the pegmatites are deeply kaolinized by the activity of late-stage hydrothermal fluids (De Vito, 2002). The rocks are also deeply weathered—to depths exceeding 20 m—particularly in the southern portion of the mining area where extensive eluvial deposits were worked.

Lacroix (1922b) classified the Anjanabonoina pegmatites as “sodalithic” (i.e., sodium- and lithium-rich). According to the modern classification of pegmatites proposed by Černý (1991), the Anjanabonoina pegmatites have mineralogical characteristics intermediate between the LCT (lithium, cesium, and tantalum) and NYF (niobium, yttrium, and fluorine) families of the Rare-Element and Mirolitic classes (Pezzotta, 2001).

Gem-bearing “pockets” or cavities are rather rare in these pegmatites, but they may be very large (i.e., several meters in maximum dimension). The pockets are surrounded by kaolin clay and contain assemblages of quartz, microcline feldspar (amazonite), albite feldspar (cleavelandite), dravite-elbaite-liddicoatite tourmaline, spodumene (kunzite), native bismuth, spessartine, beryl (morganite), hambergite, danburite, phenakite, and scapolite (Pezzotta, 1996; De Vito, 2002). The tourmaline crystals are large (typically weighing up to 20 kg each; see, e.g., figure 12), and most have a black outer “skin” (E. J. Petsch, pers. comm., 2002). The largest tourmaline crystal recovered by Mr. Petsch measured 80 cm tall and 32 cm in diameter.



Figure 12. Tourmaline crystals from Anjanabonoina are typically large. This doubly terminated liddicoatite crystal weighs 17.8 kg, and measures 33 cm tall and 22 cm wide. Although the crystal appears dark, if sliced it would probably yield spectacular slabs. Courtesy of Eckehard Petsch; photo by R. Appiani.

Benesch (1990—figure 36) depicted the base of a 40-cm-diameter crystal from Anjanabonoina.

PRODUCTION AND DISTRIBUTION

By 1912, the total production of colored tourmaline from Anjanabonoina was 1,675 kg (Guigues, 1954). According to Bariand and Poirot (1992), production decreased in the next 10 years, yielding a total of about 15 kg of rubellite and multicolored tourmaline. But between 1920 and 1925 the tourmaline output increased dramatically, with almost 1,700 kg mined. Production was negligible from 1950 to 1970. E. J. Petsch (pers. comm., 2002) recalled that Société Germadco recovered several thousand kilograms of red and polychrome tourmaline in the 1970s. During the 1980s and early 1990s, some tonnes of gem tourmaline were recovered, but no specific data are available. More recently, there has been small, sporadic production from local miners working with hand tools (E. J. Petsch, pers. comm., 2002).

According to statements to one of the authors (FP) from older miners and Malagasy gem and mineral dealers in Betafo and Antsirabe, major pockets were discovered at Anjanabonoina in 1972, 1978, 1984, and 1991. The 1978 pocket was probably the largest, with 2.6 tonnes of polychrome and red tourmaline crystals weighing up to 20 kg each (see



Figure 13. This duck is carved from Madagascar tourmaline and is mounted on a rutilated quartz bowl. The body, wings, and tail are carved from separate pieces. Courtesy of Herbert Klein, Idar-Oberstein; photo © Harold & Erica Van Pelt.

Pezzotta, 2001). The 1984 pocket produced about 2 tonnes of similar tourmaline, as well as several other gem materials (see Wilson, 1984). The quantity of tourmaline from the 1991 pocket is not known, although FP was told of a single sale of 600 kg of red tourmaline from this find.

Lacroix (1922a,b) reported that, besides the well-known polychrome variety, gem tourmaline from Anjanabonoina occurred in many homogeneous colors: red to violetish red (with faceted stones approaching 40 ct) grading into pink, “yellowish pink,” or colorless; “amethyst” violet to colorless; various greens, browns, and yellows; and pale blue. Facetable morganite, kunzite, spessartine, and danburite also were produced.

In the early part of the 20th century, the gem material from Anjanabonoina went first to France and later also to Germany and Switzerland (Pezzotta, 2001). Lacroix (1922b) noted that after cutting, the best-quality gems (which presumably included tourmaline) were commonly sold as Brazilian goods. During the early 1970s, the majority of the tourmalines produced by Société Germadco were exported

to the Julius Petsch Jr. Company in Idar-Oberstein (E. J. Petsch, pers. comm., 2002).

PROCESSING: SLICING AND CARVING

Lacroix (1908) and Termier (1908) first illustrated the triangular polychromatic zoning in Madagascar tourmaline (see also Wöhrmann, 1994). To reveal the beautiful zoning, most multicolored liddicoatite is fashioned as polished slices (see figure 1 and Benesch, 1990). Liddicoatite provides gem artists with a wide variety of colors and patterns, and so has been used to great advantage in carvings (figure 13) and intaglios (figure 14). More recently, partially faceted stones have gained popularity (Johnson and Koivula, 1998a; Weldon, 2000).

Gerhard Becker, who purchased much of the tourmaline from the Julius Petsch Jr. Company, reportedly first commercialized the cutting of liddicoatite into slices to display the color zoning patterns more dramatically (E. J. Petsch, pers. comm.,

Figure 14. Tourmaline from Alakamisy Itenina, Madagascar, was used in this intaglio, which was designed and carved by Ute Bernhardt with permission from Mikhail Baryshnikov to depict his representation of an older man in the ballet *Heart Beat*. Note the “aggregate-type” color zoning. Photo © GIA and Tino Hammid.





Figure 15. These study samples illustrate the color diversity found in Madagascar tourmaline. The six slices on the left (1.9 to 7.0 cm) were represented as being from Anjanabonoina; microprobe analysis of one (pink and light green, to the lower right) revealed that it was liddicoatite. The two slices on the right (3.0 and 4.4 cm) also were liddicoatite, except for two elbaite analyses in the green rim of the larger slice. Left—Courtesy of William Larson, right—courtesy of Richard T. Liddicoat (top) and GIA (bottom); photos by Maha Tannous.

2002). He described the slicing of one such tourmaline in a 1971 article tantalizingly titled “70 pound tourmaline crystal produces multicolored slabs.” GIA’s Richard T. Liddicoat happened to visit Becker’s shop shortly after he sliced the crystal, and photographed the progression of patterns that were revealed from its base toward the termination (see Becker, 1971). Because of their large size, Madagascar tourmaline slices also have industrial applications: Since World War II, they have been used for radio oscillator plates and pressure gauges (Fron del, 1946; Althaus and Glas, 1994).

MATERIALS AND METHODS

We studied a total of 27 samples of Madagascar tourmaline (figures 15–17). These included eight polished multicolored slices (figure 15), six of which have a probable provenance of Anjanabonoina (W.

Larson, pers. comm., 2001) with the other two from unspecified localities in Madagascar. All of the slices were cut perpendicular to the c-axis; they ranged from 1.5×1.9 cm to 5.0×7.0 cm. We also examined nine faceted (1.17–12.88 ct) and two freeform (1.24–1.29 ct) parti-colored samples that were purchased in Antsirabe, again with a probable Anjanabonoina provenance (T. Cushman, pers. comm., 2002; see figure 16). As a third group, we looked at five faceted purplish red tourmalines (1.05–6.20 ct) from Anjanabonoina that were originally obtained by A. Lacroix in the early 20th century and three faceted purplish red tourmalines (2.98–5.48 ct) from Anjanabonoina purchased by GIA from E. Petsch in 1981 (figure 17). These last three stones were analyzed by electron microprobe (two spots per sample) in 1982 at the California Institute of Technology in Pasadena, California, and confirmed as liddicoatite.

Figure 16. Parti-colored tourmaline from Madagascar is fashioned into dramatic step cuts and freeform polished stones, as shown in these study samples (1.17–3.56 ct on the left, and 4.00–12.88 ct on the right), which are probably from Anjanabonoina. Despite the similarities in their appearance, electron-microprobe data from the samples in the left photo revealed that two were elbaite, three were liddicoatite, and three contained zones of both species (e.g., the kite-shaped stone on the bottom right). Courtesy of Allerton Cushman & Co.; photos by Maha Tannous.





Figure 17. A range of tone and saturation is shown by these purplish red liddicoatites (1.05–6.20 ct) from Anjanabonoina. Courtesy of the National Museum of Natural History in Paris and the GIA collection (i.e., the stones on the far left and right, and the oval in the center); photo by Maha Tannous.

Standard gemological properties were obtained on all samples, to the extent possible. A GIA GEM Instruments Duplex II refractometer with a near-sodium-equivalent light source was used for refractive index readings. Specific gravity was determined by the hydrostatic method, although four of the slices could not be measured because they were too large for our immersion container. Reaction to ultraviolet radiation was viewed in a darkened room with four-watt long- and short-wave UV lamps. Because the absorption spectra for tourmalines typically do not provide much meaningful information (see, e.g., Webster, 1994), we did not perform spectroscopy on these samples. Internal features were observed with a standard gemological microscope, and a polariscope was used to view strain. Laser Raman microspectrometry, performed with a Renishaw 2000 Ramascope at GIA in Carlsbad, was used to identify mineral inclusions in several samples.

Quantitative chemical analyses were obtained by electron microprobe at the University of New Orleans, Louisiana (ARL-SEM-Q instrument), and at the University of Manitoba, Canada (Cameca SX 50 instrument). Most of the Madagascar study samples were analyzed: three slices, two freeforms (each of which had a large flat area), and 14 faceted stones. In addition, a small fragment from the tourmaline crystal that is illustrated in Appendix A was analyzed by electron microprobe. As part of an ongoing project by one of the authors (WS) to characterize

the composition of gem tourmaline, chemical data were also obtained for several samples from other localities that are known or suspected to produce liddicoatite: two faceted ovals (3.95 and 20.47 ct; the latter stone was described by Koivula and Kammerling [1990]), reportedly from Minas Gerais,

TABLE 1. Properties of liddicoatite-elbaite from Madagascar.

Property	Description
Color	Diverse color range, commonly in complex zones and patterns, arranged predominantly parallel to pyramidal faces. Homogeneous colors include red to violetish red (most common), grading into pink, pinkish yellow, and colorless; "amethyst" violet to colorless; various greens and browns; pale blue; and yellow of various hues. ^a
Pleochroism	Weak to strong, depending on color
Clarity	Transparent to translucent; an opaque black skin is present on most crystals
Morphology	Stout prismatic crystals with trigonal symmetry, bounded by faces of the prism, rhombohedron, and scalenohedron; striated parallel to the c-axis ^a
Optic character	Uniaxial negative (may contain biaxial zones); strain commonly observed with polariscope
Refractive indices	
n_{ω}	1.635–1.651 (1.637±0.003 ^b)
n_{ϵ}	1.619–1.634 (1.621±0.003 ^b)
Birefringence	0.014–0.027 (0.019 ^b)
Specific gravity	3.05–3.07 for parti-colored stones and slices; 3.06–3.11 for purplish red samples (3.052–3.092 ^a , 3.00–3.07 ^b)
Dispersion	0.017 (B to G) ^c
Hardness	7–7½ ^b
Luster	Vitreous on fracture surfaces ^d
Cleavage	Poor on {0001} or absent ^d
UV fluorescence	
Short-wave	Inert to moderate greenish yellow to golden yellow
Long-wave	Inert
Internal features	Color zoning, accompanied by growth zoning in some samples; strain patterns; interconnected network of wavy, partially healed fractures that are composed of stringers, minute lint-like particles, and irregular forms (both one- and two-phase liquid-gas), commonly with a wispy appearance; feathers; needle-like tubes; pinpoints; albite, tourmaline, xenotime, and quartz inclusions; negative crystals and cavities

Properties were obtained in this study unless otherwise noted:

^aLacroix (1922a)

^bDunn et al. (1978)

^cWebster (1994)

^dDunn et al. (1977)

Brazil; one polished slice from Vietnam; one polished crystal (from Abuja) and six polished slabs from unspecified localities in Nigeria; five polished slabs from "Congo"; and a small crystal fragment from Chita, eastern Transbaikalia, Russia. From four to 14 spots per stone were analyzed.

Since some elements in tourmaline (i.e., boron, lithium, and hydrogen) cannot be measured by electron microprobe, a series of assumptions must be made when calculating the cations in the formulas. For consistency, we calculated the cations for all of the analyses—whether obtained by us or from the literature—according to standard conventions (see Deer et al., 1992). Contents of Li_2O , B_2O_3 , and H_2O also were calculated, except for those analyses for which Li, B, and H were determined by analytical means.

RESULTS

Our results confirmed earlier statements in the literature (see, e.g., Webster, 1994) to the effect that liddicoatite and elbaite cannot be separated conclusively without chemical analysis. Both tourmaline species were found in the Madagascar study samples. Although all of the parti-colored tourmalines were represented as liddicoatite, two of the nine samples analyzed by microprobe were elbaite, three were liddicoatite, and three contained both species depending on the particular spot analyzed. All three of the slices analyzed were liddicoatite, but one contained elbaite near the rim. All eight of the purplish red gemstones were liddicoatite. Regardless of the species, the samples showed overlapping properties and therefore the results obtained for liddicoatite and elbaite are not differentiated below or in table 1.

Visual Appearance and Gemological Properties. The parti-colored samples displayed multiple closely spaced color zones with sharp to diffuse boundaries, as described by Mitchell (1984). The color zones were commonly arranged in straight, subparallel layers, although some samples had bent or swirled patterns (figures 18 and 19). The colors ranged from pink to purplish red, orangy pink to pinkish orange, yellowish green to bluish green, brownish green to brown to brownish yellow, greenish blue, black, and colorless. Most of these hues were present in a wide range of tones (i.e., light to dark) and saturations (i.e., pale to intense), resulting in considerable variations (see figures 16, 18–19).

The polished slices also showed distinct patterns of color zoning, the two most common of which



Figure 18. Oscillatory (narrow, repeating) zoning is shown by this parti-colored tourmaline that is probably from Anjanabonoina. Note the gradation in pink color intensity within each color zone, and the sharp boundaries with the green layers. Photomicrograph by John I. Koivula; magnified 10 \times .

were triangular zones around the core and concentric layers near the rim. The triangular zones are defined by straight, planar boundaries that are parallel to a pyramidal direction (i.e., a rhombohedron). In some slices, however, the boundary with the central triangle is parallel to the prism faces (i.e., the c-axis). The concentric outer zones are oriented parallel to the prism faces and are typically very narrow.

All samples (other than the slices, which were viewed parallel to the c-axis) showed moderate to strong dichroism in the darker, more saturated colors, and weak pleochroism in the lighter, less saturated areas.

The samples ranged from transparent to translucent, except for zones or layers that were black (opaque). The diaphaneity of the lighter colors was commonly reduced by the presence of abundant inclusions.

When viewed with the polariscope, most of the multicolored samples exhibited birefringence

Figure 19. Color zones in Madagascar tourmaline can display myriad shapes. Strong growth structures are also visible in this sample as a series of straight lines. Photomicrograph by John I. Koivula; magnified 5 \times .

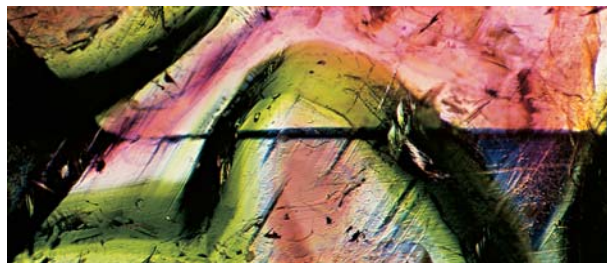




Figure 20. These images show strain patterns in a slice of liddicoatite from Madagascar cut perpendicular to the c-axis. The left view shows the color zoning, whereas the center and right photos were taken with cross-polarized light to show the anomalous birefringence; the image on the right was taken with a first-order red compensator. Although not one of the study samples, it has been confirmed as liddicoatite by electron microprobe analysis (J. Koivula, pers. comm., 2002). Photomicrographs by John I. Koivula; magnified 20×

(strain) patterns. These mottled, lamellar, cross-hatched, and irregular patterns varied in intensity from subtle to distinct. Lamellar birefringence was seen in the outer areas of the slices that showed multiple concentric color zones, but in some samples a patchy appearance was seen in the core, starting at the boundary with the triangular color zones. No strain features were visible in the three homogeneous purplish red samples, except when oriented parallel to the c-axis.

The measurement of refractive indices was problematic for most of the multicolored samples due to significant R.I. variations across the color zones. These zones were generally too narrow to permit accurate R.I. readings of individual color bands, so the shadow cutoff moved according to the viewer's eye position. In such cases the best "average" readings for the upper and lower R.I. values were recorded. Unzoned portions that were large enough to measure independently (found in a few slices and polished stones) yielded sharp R.I. readings. Although

there appeared to be no systematic differences in R.I. or birefringence according to color in these stones, in general they did show significant R.I. variations from one color zone to another (typically ± 0.004 – 0.007). The maximum variation seen in a single sample was $n_o=1.639$ – 1.650 and $n_e=1.620$ – 1.629 . The range of R.I. values measured in all of the samples was $n_o=1.635$ – 1.651 and $n_e=1.619$ – 1.634 . All of the slabs yielded two R.I. values (parallel to the c-axis) that differed by as much as 0.027. Overall, birefringence varied widely (0.014–0.027), but most values ranged from 0.015 to 0.021.

Specific gravity showed less variation than R.I. The 15 multicolored samples that could be measured with our apparatus had a fairly even distribution of values, ranging from 3.05 to 3.07. The eight purplish red samples had S.G. values of 3.06–3.11.

All of the samples were inert to long-wave UV radiation, and approximately two-thirds were inert to short-wave UV. The 10 (multicolored) samples that fluoresced to short-wave UV showed greenish

Figure 21. Partially healed fractures were ubiquitous in the tourmaline samples. They were typically composed of wavy, intersecting networks of fluid inclusions. Photomicrograph by John I. Koivula; magnified 40×

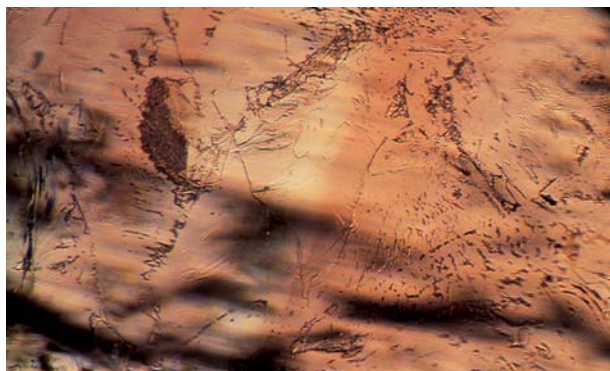
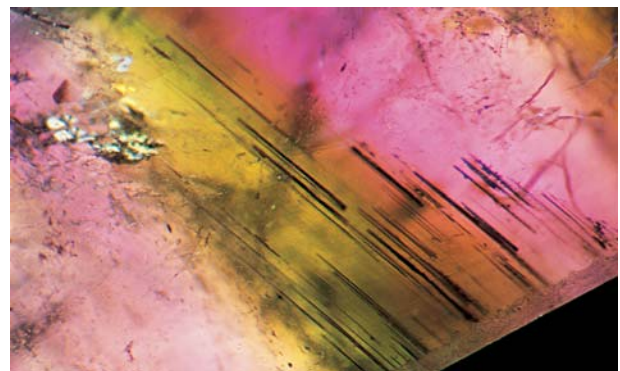


Figure 22. Many of the tourmaline samples contained needle-like tubes that were isolated or arranged in parallel arrays. They were most commonly located within green color zones. Photomicrograph by John I. Koivula; magnified 20×



yellow to “golden” yellow luminescence, of weak to moderate intensity, in specific areas corresponding to certain color zones. Most commonly, these zones were pale pink to colorless, although green, brown, and brownish green or yellow zones also fluoresced in some samples. No phosphorescence was seen.

Internal Features. When examined with the microscope, the most obvious internal feature in the multicolored samples was the pronounced color zoning, as described above. In some samples, repeating sequences of color zones had sharp boundaries between one another, and showed gradations in color within each sequence (figure 18). Growth structures were evident in a few samples, mainly along color boundaries and parallel to them; less commonly, crosscutting growth patterns were seen (figure 19).

The strain patterns observed with the polariscope in the multicolored samples were also visible with the microscope in cross-polarized light (see, e.g., figure 20); the same patterns described above were noted. The homogeneous purplish red samples showed no signs of strain except when viewed down the optic axis, revealing subtle wavy or mottled patterns.

Present in all samples were partially healed fractures containing fluid- and/or two-phase (liquid-gas) inclusions (figure 21). These commonly formed wavy, intersecting networks composed of elongate stringers, minute capillaries with a thread- or lint-like appearance (i.e., trichites), or a variety of irregularly shaped forms. Angular cavities were present along partially healed fractures in some samples. Small fractures (“feathers”) also were common. Within the slices, some of the surface-reaching feathers were filled with an opaque white substance that was tentatively identified by Raman analysis as wax or oil.

Other common inclusions were needle-like tubes that were isolated or arranged in parallel arrays. Seen in five samples, these were most commonly located within green color zones (figure 22), and in two samples they appeared to start at minute colorless mineral inclusions showing high relief. Many other mineral inclusions were noted. In eight samples, rounded, colorless crystals formed isolated inclusions and (less commonly) groups; in five of the samples, these were identified by Raman analysis as albite (see, e.g., figure 23). Colorless to pale green crystals with low relief, seen in two parti-colored liddicoatite samples, were identified by Raman analysis as tourmaline; they varied from stubby to prismatic (figure 24).

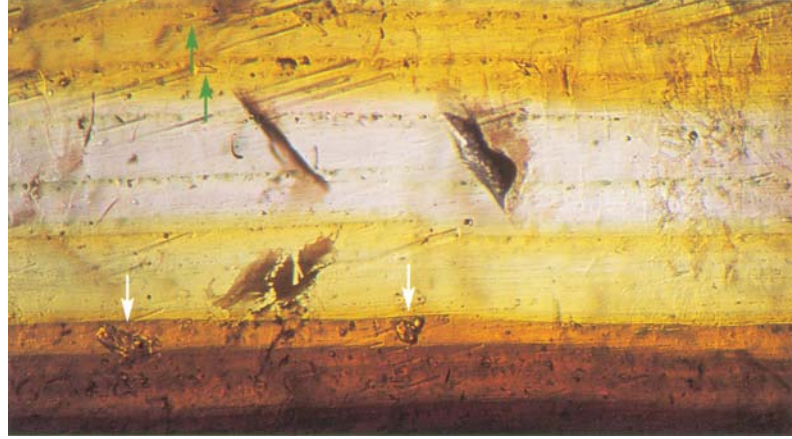


Figure 23. A light brown zone in this parti-colored elbaite-liddicoatite contains some relatively large, rounded, colorless inclusions with high relief (white arrows); these were identified as albite by Raman analysis. Several minute, colorless, blocky crystals of xenotime (identified by Raman analysis) were also present in this sample; a few of them are shown here (green arrows). Photomicrograph by John I. Koivula; magnified 15×

Near one of these tourmaline inclusions, a crystal of orangy brown xenotime was identified by Raman analysis (again, see figure 24). In the elbaite portion of another parti-colored sample, xenotime with a quite different appearance was also identified by Raman analysis: minute, colorless, blocky crystals aligned parallel to color zoning (again, see figure 23). Quartz was present in one liddicoatite sample as a relatively large, rounded, colorless inclusion. Black pinpoints (not identifiable) were seen in one parti-colored elbaite sample. Negative crystals and cavities were present in a few samples.

Figure 24. Several prismatic, birefringent inclusions are evident in this parti-colored liddicoatite; the largest one was identified as tourmaline by Raman analysis. The Raman spectrum of the adjacent dark orangy brown inclusion showed that it was xenotime. Photomicrograph by John I. Koivula; partially cross-polarized light, magnified 2.5×

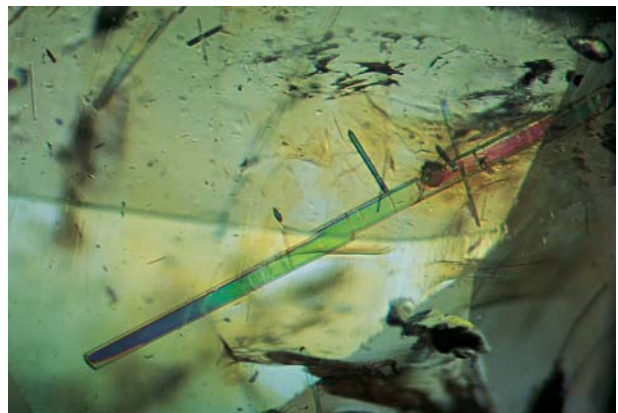


TABLE 2. Chemical composition of liddicoatite from Madagascar.^a

Chemical composition	Anjanabonoina (probable) ^{b-1}			Anjanabonoina ^{b-2}	Anjanabonoina ^{b-3}	Anjanabonoina ^{b-4,c,d}		Antsirabe area ^{b-5,c}
	1.17 ct RSC Dk. bluish green	1.85 ct RSC Colorless	2.84 ct RSC Pale pink	5.47 ct RBC Purplish red	1.05 ct hexagon Purplish red	nr Dk. red	nr Dk. greenish yellow	Holotype specimen Brown
Oxides (wt.%)								
SiO ₂	36.87	37.43	37.12	37.50	37.81	37.58	37.02	37.70
TiO ₂	nd	nd	nd	nd	nd	0.59	0.11	0.38
B ₂ O ₃	11.00	11.18	11.03	10.92	11.00	11.36	11.07	10.89
Al ₂ O ₃	40.23	41.18	40.06	37.99	38.96	40.22	39.08	37.90
FeO	0.98	0.10	0.12	0.09	nd	0.57	0.74	0.83
MnO	0.34	0.10	0.22	2.84	0.10	0.65	4.86	0.27
MgO	nd	nd	nd	nd	nd	0.07	0.07	0.11
CaO	2.78	3.46	3.84	3.03	4.05	4.00	2.86	4.21
Li ₂ O	2.36	2.57	2.63	2.35	2.75	2.85	1.88	2.48
Na ₂ O	1.35	0.92	0.79	1.27	0.59	1.72	1.01	0.88
K ₂ O	nd	nd	nd	0.04	nd	0.24	0.19	nr
H ₂ O	3.16	3.23	3.23	3.77	3.34	3.45	3.44	2.69
F	1.33	1.33	1.22	nr	0.96	0.98	0.81	1.72
Subtotal	100.62	101.54	100.48	99.80	99.72	104.28	103.13	100.06
-O=F	0.56	0.56	0.51	0.00	0.41	0.41	0.34	0.72
Total	100.06	100.98	99.97	99.80	99.32	103.87	102.79	99.34
Ions on the basis of 31 (O,OH,F)								
Si	5.826	5.818	5.846	5.970	5.971	5.750	5.811	6.015
Al	0.174	0.182	0.154	0.030	0.029	0.250	0.189	0.000
Tet. sum	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.015
B	3.000	3.000	3.000	3.000	3.000	2.999	2.999	2.999
Al (Z)	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.318	1.363	1.282	1.099	1.222	1.004	1.042	1.127
Ti	nd	nd	nd	nd	nd	0.068	0.013	0.046
Fe ²⁺	0.130	0.013	0.016	0.011	nd	0.073	0.097	0.111
Mn	0.046	0.013	0.029	0.383	0.013	0.084	0.646	0.036
Mg	nd	nd	nd	nd	nd	0.016	0.016	0.026
Li	1.497	1.609	1.663	1.507	1.765	1.755	1.185	1.591
Y sum	3.000	3.000	3.000	3.000	3.000	2.999	3.000	2.937
Ca	0.471	0.576	0.648	0.517	0.685	0.656	0.481	0.720
Na	0.414	0.277	0.241	0.393	0.179	0.510	0.307	0.272
K	nd	nd	nd	0.009	nd	0.047	0.038	nr
Vacancy	0.116	0.146	0.111	0.081	0.136	0.000	0.173	0.008
X sum	1.000	1.000	1.000	1.000	1.000	1.213	1.000	1.000
F	0.665	0.654	0.608	nr	0.481	0.474	0.402	0.868
OH	3.335	3.346	3.392	4.000	3.520	3.526	3.598	2.863
Ca/(Ca+Na)	0.53	0.68	0.73	0.57	0.79	0.56	0.61	0.73

^aAll iron reported as FeO. Except where noted, all analyses were by electron microprobe, with Li₂O, B₂O₃, and H₂O calculated by stoichiometry: B = 3 apfu (atoms per formula unit), Li = 3-SumY, and OH + F = 4 apfu. Note that some cation sums may not add up exactly as shown, due to rounding of the calculated numbers. Abbreviations: dk. = dark, lt. = light, nd = not detected, nr = not reported, RBC = round brilliant cut, and RSC = rectangular step cut. Nuber and Schmetzer (1981) reported the composition of a green Madagascar liddicoatite as (Ca_{0.65}Nb_{0.35})(Li_{1.40}Al_{1.60})Al₉(O,OH,F)₄(BO₃)₃Si₆O₁₉.

^bReference/analyst—b-1: F. C. Hawthorne (this study); b-2: Caltech sample 12961; b-3: W. B. Simmons and A. U. Falster; (this study) b-4: Lacroix (1922a); b-5: Dunn et al. (1977); b-6: Duparc et al. (1910); b-7: Akizuki et al. (2001); b-8: Aurisicchio et al. (1999); and b-9: Bloomfield (1997), see also table 5.12, analysis 57 of Shmakin and Makagon (1999). Analyses by F. C. Hawthorne used a Cameca SX 50 instrument, with minerals or synthetic compounds as standards, an accelerating voltage of 15 kV, sample current of 20–30 nA, 10 μm beam diameter, 20–30 second count time, and the data correction procedure of Pouchou and Pichoir (1985); the following elements were analyzed for but not detected: P, Sc, V, Cr, Co, Ni, Cu, Zn, Sb, and Bi. Analyses by W. B. Simmons and A. U. Falster used an ARL SEMQ instrument, with minerals or synthetic compounds as standards, an accelerating voltage of 15 kV, sample current of 15 nA, 2 μm beam diameter, 60 second count time, and the CITZAF φ(ρZ)/PRSUPR data acquisition and data reduction program; the following elements were analyzed for but not detected: V, Cr, Cu, Zn, and Bi, except in the 1.05 ct hexagon which contained up to 0.10 wt.% V₂O₅, 0.15 wt.% ZnO, and 0.09 wt.% Bi₂O₃.

Chemical Composition. Chemical analyses of Madagascar liddicoatite from this study and the literature are presented in table 2. Because of space limitations, only selected analyses are shown; the remainder

of the data (including elbaite analyses) can be viewed on the Internet at the *Gems & Gemology* data depository (www.gia.edu/gandg/ggDataDepositary.cfm). As illustrated in figure 25, a considerable portion of

Antaboaka ^{b-6,c,e}	Maroandro ^{b-6,c,f}	Jochy ^{b-7,g}	Lacamisinten ^{b-8,h}	Malakialina ⁱ				Sahatany Valley ^{b-9}
nr Red	nr Pink	Specimen A nr	Crystal section Pink-red	Pink rim	Crystal section Lt. yellow	Lt. green	Darker green	TB01 nr
37.29	37.06	38.31	37.22	37.74	37.96	37.91	37.94	37.47
nr	nr	nd	0.07	0.03	0.36	0.11	0.12	0.08
11.01	11.04	11.10	10.93	10.91	11.04	10.99	11.02	11.19
38.91	40.53	38.57	38.03	37.70	37.92	37.95	38.00	41.08
0.70	0.36	0.02	0.10	0.06	1.14	0.81	1.16	0.29
0.52	1.23	0.05	4.06	0.70	0.22	0.11	0.15	0.20
0.30	0.43	nd	0.18	0.08	0.10	0.10	0.13	nd
4.10	2.58	4.69	2.63	3.95	4.10	4.15	4.16	3.30
2.59	2.10	2.97	1.86	2.80	2.75	2.80	2.75	2.55
0.76	0.80	0.54	1.40	1.00	0.94	0.96	0.95	1.08
0.10	0.13	0.09	0.02	nd	nd	nd	nd	0.02
3.14	3.23	2.78	3.17	2.50	2.67	2.89	2.95	3.46
1.40	1.23	2.21	0.64	2.67	2.40	1.91	1.79	0.84
100.82	100.71	101.33	100.31	100.15	101.60	100.69	101.14	101.57
0.59	0.52	0.93	0.27	1.12	1.01	0.80	0.75	0.35
100.23	100.20	100.40	100.04	99.02	100.59	99.89	100.39	101.22
5.885	5.835	5.999	5.966	6.013	5.976	5.992	5.980	5.817
0.115	0.165	0.001	0.034	0.000	0.024	0.008	0.020	0.183
6.000	6.000	6.000	6.000	6.013	6.000	6.000	6.000	6.000
3.000	3.000	3.000	3.024	3.000	3.000	3.000	3.000	3.000
6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
1.122	1.357	1.118	1.152	1.078	1.013	1.062	1.040	1.333
nr	nr	nd	0.008	0.004	0.042	0.013	0.015	0.009
0.092	0.047	0.003	0.013	0.008	0.150	0.108	0.153	0.038
0.070	0.164	0.007	0.551	0.095	0.029	0.014	0.020	0.026
0.071	0.101	nd	0.043	0.018	0.024	0.025	0.031	nd
1.645	1.331	1.872	1.199	1.797	1.741	1.778	1.741	1.593
3.000	3.000	3.000	2.967	3.000	3.000	3.000	3.000	3.000
0.693	0.435	0.787	0.452	0.674	0.692	0.703	0.702	0.549
0.233	0.244	0.164	0.435	0.310	0.287	0.294	0.289	0.325
0.020	0.026	0.018	0.004	nd	nd	nd	nd	0.004
0.054	0.294	0.031	0.109	0.015	0.020	0.002	0.009	0.122
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.699	0.612	1.095	0.324	1.343	1.194	0.953	0.893	0.412
3.301	3.388	2.905	3.390	2.657	2.806	3.047	3.107	3.588
0.75	0.64	0.83	0.51	0.68	0.71	0.71	0.71	0.63

^cDetermined by wet chemistry.

^dSpectrographic analysis also revealed traces of Ga and Pb.

^eThis sample had R.I. values of $n_o = 1.6411$ and $n_e = 1.6256$, birefringence = 0.0155, and S.G. = 3.047.

^fThis sample had R.I. values of $n_w = 1.6498$ and $n_e = 1.6246$, birefringence = 0.0162, and S.G. = 2.978.

^gAnalysis of the o sector of a sector-zoned crystal.

^hAverage of three analyses; Lacamisinten is the name used by gem dealers, but the actual Malagasy name is Alakamisy Itenina. B_2O_3 was determined by SIMS, Li_2O by atomic absorption, and H_2O by GC and TGA.

ⁱUnpublished data of W. B. Simmons and A. U. Falster.

^jCalculation included traces of Pb; this element is not shown above due to possible contamination problems.

the analyses from this study correspond to elbaite compositions. As expected, there was no correlation between color and Ca/Na content.

Among the liddicoatite analyses, Ca contents

ranged from relatively constant to variable (e.g., 2.74–4.56 wt.% CaO in one slice) within single samples. An X-ray map of a small portion of one sample revealed gradational Ca contents that corre-

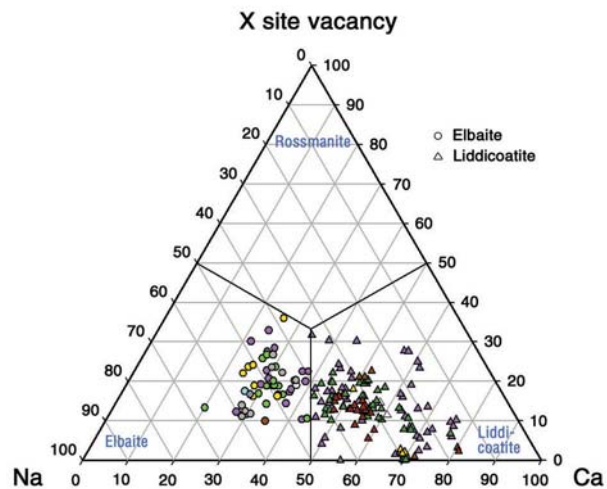


Figure 25. This compositional plot shows the X-site occupancy for the 191 liddicoatite-elbaite analyses from Madagascar obtained for this study and taken from the literature (see table 2 and depository table). The color of each data point is indicative of the color of the tourmaline; points for which no color was reported are shown in dark red. All of the data points fall into the liddicoatite and elbaite fields, and there is no correlation between X-site occupancy and color.

sponded to both liddicoatite and elbaite compositions (figure 26). The most Ca-rich and Na-poor liddicoatite that we know of was published by Akizuki et al. (2001); it contained 4.69 wt.% CaO and 0.54 wt.% Na₂O (83 mol.% liddicoatite).

The chromophoric elements Fe, Mn, and Ti were typically low in the Madagascar tourmaline. The highest contents of these elements were found in the parti-colored samples; these analyses can be viewed in the data depository. Up to 2.66 wt.% FeO was measured (in a pale gray zone), and the green and blue zones had significantly more iron than the colorless or pink bands (again, see figure 26). High Mn contents were reported for a dark greenish yellow sample analyzed by Lacroix (1922a) that contained 4.86 wt.% MnO, and for some of the purplish red stones analyzed for this study (up to 3.22 wt.% MnO). The greatest Ti content was measured in a yellow color zone: 0.82 wt.% TiO₂. Fluorine contents were typically above 1 wt.%. Traces of Mg, K, and Pb also were present, although backscatter electron imaging of some samples revealed surface contamination of pores and fractures with lead (Pb). Therefore all of the Pb analyses of our samples are considered unreliable and are not reported in the data. The Pb residue probably resulted from the polishing process used by the lapidary (J. Zang, pers. comm., 2002). This element

has not been included in analyses of liddicoatite published in the literature.

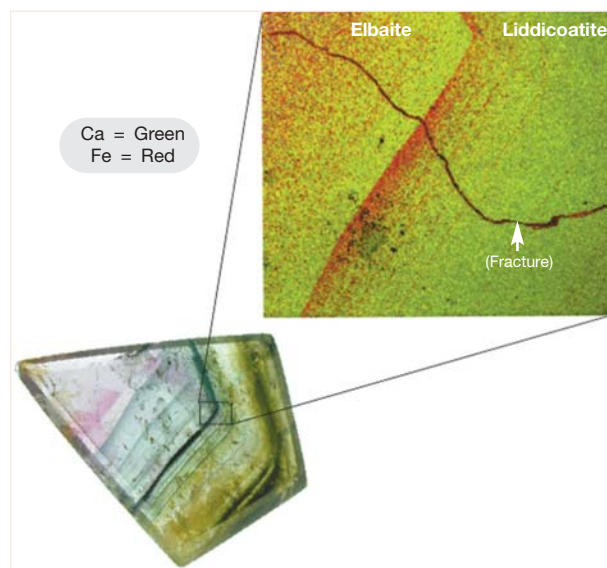
For chemical data on liddicoatite from other world localities, see Appendix A.

DISCUSSION

Color Zoning. Benesch (1990) provided a detailed description of color zoning in Madagascar tourmaline, with excellent illustrations of cross-sections cut in orientations perpendicular and parallel to the c-axis (see, e.g., figure 27). A visual journey through a succession of liddicoatite slices cut perpendicular to the c-axis is accessible on the Internet at minerals.gps.caltech.edu/mineralogy/animation.htm.

The slices we studied displayed color zoning that is consistent with the features described for liddicoatite by Dunn et al. (1977, 1978). These authors (as well as earlier researchers) indicated that, while the color zoning in elbaite is parallel to the basal pinacoid and/or prism faces, the predominant triangular color boundaries in liddicoatite are "parallel to

Figure 26. This X-ray map, generated with an electron microprobe by one of the authors (WS), shows the distribution of Ca and Fe in a portion of the 1.29 ct freeform sample. Point analyses by the microprobe showed that the darker green (i.e., Ca-rich) area on the lower right of the X-ray map is liddicoatite, and the lighter green area on the upper left is elbaite. The red bands in the X-ray map show enrichment in Fe, and correspond to the dark bluish green layers in the sample.



a pyramid." Therefore, in slices cut perpendicular to the c-axis, these boundaries will not appear sharp. In contrast, the outer concentric color zones are parallel to prism faces (and thus the c-axis), so they do appear sharp in the slices (see, e.g., figure 1). Regardless of which color zones are observed, both abrupt and gradual transitions from one color to another are seen; these reflect dynamic geochemical changes in the crystallization environment (Lacroix, 1922a; Benesch, 1990; Zang, 2000).

Although not seen in our study samples, a trigonal star pattern is a notable feature of many Madagascar tourmaline slices cut perpendicular to the c-axis (e.g., Lacroix, 1922a; Wentling, 1980; Zang, 1994c). This star is typically pink or red, and crosscuts the adjacent triangular zones before being truncated against the outer concentric color layers (see figure 3). In slices cut *parallel* to the c-axis (figure 27), this same feature may be visible as a spike-shaped color zone of variable width that follows the apex of the pyramidal faces. Trigonal stars of various colors have been seen in tourmaline from Brazil, Mozambique, and elsewhere, although these crystals are typically smaller (less than 4 cm in diameter) than those from Madagascar (Benesch, 1990); we did not chemically analyze any such samples for this study. The origin of these stars has been debated for years (Benesch, 1990). From his observations of Madagascar tourmaline, Zang (1994c) suggested that during crystallization under decreasing temperature, the red stars form as a result of the preferential incorporation of the large Mn^{2+} ion into the fast-growing pyramid $\{10\bar{1}1\}$ faces.

Another color-zoning phenomenon (not seen in our study samples but found in some tourmalines from Madagascar, Brazil, and Namibia) is the "aggregate type" zoning described by Benesch (1990). This is present in crystal portions (generally near the termination) that consist of an accumulation of tourmaline subcrystals in parallel orientation. Slices cut from such crystals often display spectacular mottled patterns (see, e.g., figure 14).

Gemological Properties. As in elbaite, the R.I. values of liddicoatite should vary with transition metal contents (e.g., Fe, Mn, and Ti): Higher contents of these elements lead to greater R.I. and birefringence values (Deer et al., 1997). Although in most cases we could not obtain R.I. measurements on the narrow individual color zones, for those few samples with wide enough color zones, the lack of systematic R.I. trends was probably due to the relatively



Figure 27. This watercolor painting of an Anjanabonoina tourmaline sliced parallel to the c-axis shows how the color zoning is oriented parallel to the prism and pyramid faces. Note also the central spike-shaped pink area that follows the apex of the pyramidal faces. Looking perpendicular to the c-axis, this pink zone would form the central part of a trigonal star. This cross-section was reconstructed from a series of slices from the same crystal oriented perpendicular to the c-axis. Reprinted with permission from Benesch (1990, p. 298), © Verlag Freies Geistesleben & Urachhaus GmbH, Stuttgart, Germany.

small variations in overall transition metal contents. From a study of several tourmalines of different colors and from different deposits in Madagascar, Lacroix (1922a) noted a general correlation between increasing R.I. and S.G. values, but no systematic relationship of either measurement to color. The R.I. values we measured (1.619–1.651) were similar to the range Lacroix reported (1.6200–1.6480) but somewhat higher than those reported by Dunn et al. (1978) for liddicoatite (1.621 and 1.637, ± 0.003). The birefringence values we obtained (0.014–0.027) are fairly similar to those of Lacroix (0.0162–0.0236).

The slabs (cut perpendicular to the c-axis) apparently contained biaxial domains, as they yielded two R.I. values with significant birefringence (i.e., up to 0.027). Lacroix (1922a) noted that Madagascar tourmaline crystals are locally biaxial; however, he observed no correlation between biaxial character and color zoning. In liddicoatite from Jochy, Madagascar, Akizuki et al. (2001) determined that biaxial domains—which have triclinic and orthorhombic symmetry—correspond to certain crystallographic sectors (and compositional zoning) that formed during crystal growth. Biaxial domains also have been found in elbaite (see Foord and Mills, 1978). The common occurrence of strain patterns in elbaite and liddicoatite may therefore be related to biaxial domains that formed during growth.

Notwithstanding the effects of inclusions, the specific gravity of tourmaline increases with greater contents of transition metals (Deer et al., 1997). Our multicolored samples showed rather small variations in specific gravity (3.05–3.07). The higher S.G. values (3.06–3.11) obtained for the eight purplish red liddicoatites may be due to the fact that they contained fewer fluid inclusions than the multicolored samples. There was no systematic relationship between transition-metal content and S.G. in our samples. The S.G. values of the multicolored samples fell within the ranges reported for tourmaline of liddicoatite composition: 3.052–3.092 (Lacroix, 1922a) and 3.00–3.07 (Dunn et al., 1978). The higher S.G. values measured for the purplish red samples are consistent with the 3.107 value reported by Lacroix (1922a) for “amethyst”-violet tourmaline from Anjanabonoina.

The partially healed fractures, feathers, tubes, and pinpoints seen in our study samples are typical of inclusions in tourmaline (see, e.g., Webster, 1994). Among the mineral inclusions, albite and tourmaline are commonly found in elbaite (see

Koivula, 1994; Webster, 1994). To our knowledge, however, xenotime and quartz had not been documented previously in elbaite or liddicoatite.

Chemical Properties. To distinguish liddicoatite from elbaite, cations in the formula are calculated from the weight-percent oxides obtained from the quantitative chemical analyses so that the X-site constituents can be compared on an “atoms per formula unit” basis. In an analysis of lithium tourmaline, if Ca is the dominant element in the X site, it is liddicoatite. Conversely, elbaite is the Na-dominant species. Besides Ca and Na, this site may contain potassium and/or vacancies. Although potassium is not important in tourmaline, vacancies may constitute a significant proportion of the X site; if they are dominant, then the lithium tourmaline species is rossmanite. (For more on distinguishing among lithium-aluminum tourmalines, see Hawthorne and Henry [1999] and Zolotarev and Bulakh [1999].)

Dunn et al. (1978) indicated that Madagascar tourmaline crystals usually are composed entirely of one species. This was not the case for several of the samples we analyzed from Madagascar and elsewhere (see depository data). Akizuki et al. (2001) studied two sector-zoned liddicoatite crystals from Jochy, Madagascar, one of which contained elbaite in the $a\{11\bar{2}0\}$ sector. Nevertheless, some liddicoatite from Madagascar is chemically homogeneous enough to be used as a reliable reference material for elemental and isotopic work (Auricchio et al., 1999). The experience of one of the authors (FP) has shown that the polychrome crystals from Anjanabonoina usually are derived from large cavities, and these tourmalines are typically liddicoatite throughout. By contrast, crystals showing simpler zonation from small cavities at this mine are predominantly elbaite or dravite, with liddicoatite being scarce or absent.

The Ca and Na contents of liddicoatite show no systematic relationship to color (Dunn et al., 1978; see also figure 25). Conversely, Fe, Mn, and Ti affect the coloration of liddicoatite in the same way that they affect elbaite (Dietrich, 1985). Analyses of colorless samples revealed very small amounts of these elements. Pink samples contained small but significant amounts of Mn and very low amounts of Fe, whereas green portions contained higher Fe; analogous trends were reported by Webber et al. (2002) in liddicoatite from Anjanabonoina and Fianarantsoa. Yellow bands generally have moderately low to low

Fe with higher Mn and Ti. The blue, greenish blue, and gray portions contained the highest Fe. The coloration of elbaite (and liddicoatite, by inference) is well documented in the literature; for useful reviews, see Althaus (1979), Dietrich (1985), Zang (1994a), Deer et al. (1997), and the Web site minerals.caltech.edu/files/visible/tourmaline/index.htm.

Geologic Origin. Selway et al. (1999) noted that liddicoatite may be found in elbaite-subtype pegmatites, but not in those of the lepidolite subtype. Selway (1999) indicated that within elbaite-subtype pegmatites, liddicoatite-elbaite is the last tourmaline to form (i.e., after the crystallization of Ca-bearing schorl and Mn-rich elbaite). Therefore, geochemically it is the most “evolved” tourmaline in these pegmatites.

Granitic pegmatites typically are not rich in Ca, and any amounts present may be consumed by the early crystallization of plagioclase and Ca-bearing tourmaline. The presence of liddicoatite in gem-bearing cavities indicates that Ca was abundant during late-stage pegmatite crystallization. Teertstra et al. (1999) postulated that the Ca needed to form liddicoatite could be mobilized from the pegmatite host rocks or the alteration of previously crystallized Ca-bearing minerals (e.g., plagioclase), or the Ca could be geochemically conserved (e.g., as fluoride complexes) during pegmatite crystallization until late stages. While all three of these mechanisms may play a role, it is important to note that in elbaite-subtype pegmatites, liddicoatite is typically found in deposits that are located in or near Ca-rich host rocks (Selway, 1999). (One exception is liddicoatite from the Malkhan district in Russian, which is not associated with Ca-rich host rocks.) Although Ca-rich minerals are common in many Madagascar pegmatites, liddicoatite is not always present and therefore its formation may be related more to paragenetic effects (i.e., pertaining to the order of mineral crystallization) than to the total amount of Ca available in the pegmatite system.

A petrogenetic model for the formation of the Anjanabonoina pegmatites is currently being developed (Dini et al., 2002; De Vito, 2002; and unpublished work of one of the authors [FP]). This model invokes significant contamination of the pegmatitic melts with components derived from the metasedimentary (including dolomitic carbonate) host rocks. Isotopic data suggest that the boron in the pegmatites is derived from metasedimentary evaporitic rocks. In this model, the pegmatitic magmas formed

by the fractional crystallization of late to post-tectonic granites—and were contaminated by fluids derived from the metasediments of the Itremo Group—during pegmatite emplacement in extensional faults. The complex color zoning of the polychrome tourmaline reflects a dynamic multistage crystallization process.

IDENTIFICATION

Dunn et al. (1977) reported that liddicoatite cannot be differentiated from elbaite by its optical and physical characteristics, or even with X-ray diffraction techniques and unit cell dimension data. In the gem trade, liddicoatite traditionally has been informally separated from elbaite by the presence of features such as triangular color zoning, a trigonal star, or parti-colored zonation. However, quantitative chemical analyses are required to confirm the tourmaline species. Since they cannot be separated by practical gemological methods, gemologists typically do not distinguish between liddicoatite and elbaite. Therefore, some tourmalines sold as elbaite may actually be liddicoatite, and more localities for this species are being recognized as chemical analyses are obtained (see, e.g., Hlava, 2001; Laurs, 2001; Appendix A).

Little is known about the treatments done to liddicoatite. We could not find any reference to the heating or irradiation of this tourmaline, although some “elbaite” treated by these methods may actually be liddicoatite, as discussed above. Reddish violet tourmaline (probably liddicoatite) from the Coronel Murta area in Minas Gerais, Brazil, has been heat-treated to a green color (H. Elawar, pers. comm., 2002). A polychrome tourmaline slice (locality not specified) was recently reported to be fracture-filled with resin (Bank et al., 1999b). Madagascar tourmaline slices containing natural fractures are commonly stabilized with resin (W. Larson, pers. comm., 2002). Fractured slices also have been stabilized by constructing doublets with glass or plastic (Koivula et al., 1992; Henn and Bank, 1993; Bank et al., 1999a).

Wax or oil was tentatively identified in some slices obtained for this study. According to W. Larson (pers. comm., 2002), prior to polishing the slices, surface irregularities are filled with paraffin wax to prevent the unsightly concentration of polishing residues in those areas. The wax is then melted away by boiling the slices in water, although it is not always completely removed from the fractures.



Figure 28. Designers enjoy incorporating the beautiful banding of liddicoatite into creative carvings. The butterfly brooch shown here is made of 18K yellow and white gold with two carved Madagascar tourmalines (84.47 ct total weight), yellow and colorless diamonds, and pearls. Courtesy of Buccellati.

CONCLUSION

Most of the liddicoatite in the gem trade has come from the Anjanabonoina pegmatites in central Madagascar. Although fine color-zoned tourmalines have been recovered elsewhere in the world, and some of these have been identified as liddicoatite by quantitative chemical analysis, the complex color zones and patterns seen in Madagascar tourmaline

are unrivaled by tourmaline from other localities (Benesch, 1990). The difficult access, mining conditions, and security problems continue to limit further production at Anjanabonoina, although previously mined material does enter the market occasionally. Dramatic and unusual, liddicoatite is revered by gem collectors and researchers, and is well-suited for one-of-a-kind jewelry designs (figure 28).

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APPENDIX A: WORLD SOURCES OF LIDDICOATITE

In addition to Anjanabonoina, liddicoatite has been identified from several locations in central and south-central Madagascar, including Antaboaka, Jochy, Lacamisinten (also called Alakamisy Itenina), Malakialina, Maroandro, and the Sahatany Valley (see table 2), as well as Vohitrakanga (preliminary data of FP). Table A-1 contains chemical analyses of liddicoatite from elsewhere in the world. All of these localities have produced gem-quality tourmaline except for those in Canada and the Czech Republic, which are included for completeness. In Canada, liddicoatite was found in the High Grade Dike of the Cat Lake–Winnipeg River pegmatite field (Teertstra et al., 1999). The tourmaline occurs at two localities in the Czech Republic. Liddicoatite-elbaite from Bližná in southern Bohemia was documented by Novák et al. (1999). At Recice, liddicoatite is very rare, forming narrow zones in crystals of Ca,Mn-rich elbaite (M. Novák, pers. comm., 1999).

Brazil has been rumored as a possible source of liddicoatite for years (see, e.g., Koivula and Kammerling, 1990; figure A-1). The large faceted stone described in that Gem News item, as well as a 3.95 ct sample from the same source, were confirmed as liddicoatite for this study. Several additional brownish purple Brazilian samples, from the same source (Mauro de Souza, Marcelo Gemas Inc., Los Angeles) were qualitatively analyzed by GIA Research in 1990, and indicated as liddicoatite and elbaite. These samples probably came from the Coronel Murta area, where significant amounts of similar-colored tourmaline have been mined and sold as liddicoatite (H. Elawar, pers. comm., 2002).

Multicolored slices of tourmaline that are reportedly from the “Congo” were analyzed for this study and found to contain liddicoatite in certain zones (without any particular trend in color or position). To our knowledge, this is the first time liddicoatite has been identified there.

An analysis of liddicoatite from Mozambique was presented by Sahama et al. (1979). Chemical data on tourmaline from this country are uncommon in the literature, and more analyses will probably reveal additional liddicoatite from the extensive pegmatite fields there.

Recently, Nigeria has emerged as a source of liddicoatite. Electron microprobe analyses of an orangy pink liddicoatite from the Ogbomosho area revealed relatively high bismuth contents (Hlava, 2001), and a purplish red crystal from the Abuja area was also confirmed as liddicoatite (Laurs, 2001, and this study). Further analyses of multicolored slices from Nigeria done for this study revealed liddicoatite in

several samples and representing many colors (see depository data).

Liddicoatite has been documented from the Malkan district in Russia (see Zagorsky et al., 1989; Zagorsky and Peretyazhko, 1992). A sample analyzed from the Transbaikalia area for this study contained zones of liddicoatite, elbaite, and schorl-elbaite.

Zang (1994b) analyzed a tourmaline from Sanga-Sanga, Tanzania, that contained attractive triangular color zones; both liddicoatite and elbaite (as well as schorl) were present in the sample.

Ngu (2001) presented an X-ray diffraction pattern and Raman spectrum for what was reportedly black liddicoatite from Luc Yen, Vietnam, but did not provide a chemical analysis of the material to confirm the identification. A multicolored slice from Vietnam analyzed for this study contained liddicoatite in a red zone. This slab displayed the trigonal star that is so commonly seen in Madagascar liddicoatite, yet it was dominantly elbaite.



Figure A-1. The purplish red color of this rough and cut tourmaline is similar, yet the crystal (elbaite-liddicoatite) is from Anjanabonoina and the oval brilliant (liddicoatite) was reportedly mined in Minas Gerais, Brazil. The crystal (6.4 × 3.7 cm) is courtesy of William Larson, and the faceted stone (20.47 ct) is from the GIA collection. Photo © Harold & Erica Van Pelt.

TABLE A-1. Chemical composition of liddicoatite from localities other than Madagascar.^a

Chemical Composition	Minas Gerais, Brazil ^{b-1}		Manitoba, Canada ^{b-2,c}	"Congo" ^{b-3,d}		Bližná, Czech Republic (Unit A) ^{b-4,c}	Muiiane, Mozambique ^{b-5}	Abuja, Nigeria ^{b-3,e}
	20.37 ct cushion Purplish red	3.95 ct cushion Purplish red	nr	Slice	Slice	nr	nr	1.39 ct crystal
			nr	Grayish pink	Yellowish green	Pink	Brown	Purplish red
Oxides (wt.%)								
SiO ₂	38.08	37.27	37.20	37.68	38.53	35.50	36.55	38.45
TiO ₂	nr	nr	nr	0.03	0.05	0.34	0.07	nd
B ₂ O ₃	11.10	10.93	10.84	11.00	11.02	10.84	10.87	11.23
Al ₂ O ₃	39.81	38.71	40.70	39.26	37.94	38.30	38.45	40.15
FeO	0.00	0.11	0.30	0.46	0.68	0.14	2.94	0.09
MnO	0.29	2.39	1.50	0.60	0.57	4.62	0.77	0.22
MgO	nr	nr	nr	nd	nd	0.05	0.16	0.05
CaO	3.25	2.79	2.50	3.53	3.13	2.58	2.88	3.02
Li ₂ O	2.62	2.28	2.03	2.51	2.79	1.66	2.13	2.69
Na ₂ O	0.97	1.30	1.20	0.57	1.09	1.39	1.42	1.48
K ₂ O	nr	nr	nr	nd	nd	nr	nd	0.02
H ₂ O	3.13	3.08	3.37	3.54	3.59	3.07	3.07	3.29
F	1.48	1.45	0.90	0.54	0.45	1.13	1.44	1.23
Subtotal	100.88	100.92	100.54	99.75	99.86	99.62	100.76	101.94
-O=F	0.62	0.61	0.38	0.23	0.19	0.48	0.61	0.52
Total	100.25	100.31	100.16	99.52	99.68	99.14	100.16	101.42
Ions on the basis of 31 (O,OH,F)								
Si	5.961	5.926	5.868	5.951	6.078	5.765	5.842	5.951
Al	0.039	0.074	0.132	0.049	0.000	0.235	0.158	0.049
Tet. sum	6.000	6.000	6.000	6.000	6.078	6.000	6.000	6.000
B	3.000	3.000	2.952	3.000	3.000	3.039	3.000	3.000
Al (Z)	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
Al	1.306	1.181	1.434	1.260	1.054	1.097	1.085	1.275
Ti	nr	nr	nr	0.004	0.005	0.042	0.008	0.000
Fe ²⁺	0.000	0.015	0.040	0.061	0.089	0.019	0.393	0.011
Mn	0.038	0.322	0.200	0.080	0.076	0.636	0.104	0.029
Mg	nr	nr	nr	nd	nd	0.012	0.038	0.011
Li	1.649	1.457	1.288	1.592	1.771	1.084	1.371	1.674
Y sum	3.000	3.000	2.962	3.000	3.000	2.890	3.000	3.000
Ca	0.545	0.475	0.423	0.597	0.529	0.449	0.493	0.500
Na	0.294	0.401	0.367	0.174	0.333	0.438	0.440	0.445
K	nr	nr	nr	nd	nd	nr	nd	0.004
Vacancy	0.160	0.124	0.210	0.229	0.138	0.113	0.065	0.051
X sum	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
F	0.733	0.729	0.449	0.270	0.222	0.580	0.728	0.603
OH	3.267	3.270	3.546	3.730	3.778	3.326	3.272	3.397
Ca/(Ca+Na)	0.65	0.54	0.54	0.77	0.61	0.51	0.53	0.53

^aAll iron reported as FeO. Except where noted, all analyses by electron microprobe, and Li₂O, B₂O₃, and H₂O calculated by stoichiometry: B = 3 apfu (atoms per formula unit), Li = 3-SumY, and OH + F = 4 apfu. Note that some cation sums may not add up exactly as shown, due to rounding of the calculated numbers. Abbreviations: lt. = light, nd = not detected, nr = not reported, xl = crystal.

^bReference/analyst—b-1: F. C. Hawthorne (this study); b-2: Teertstra et al. (1998); b-3: W. B. Simmons and A. U. Falster (this study); b-4: Novak et al. (1999); b-5: Sahama et al. (1979); b-6: Zagorsky et al. (1989); and b-7: Zang (1994b). For instrumental operating conditions used by F. C. Hawthorne, as well as by W. B. Simmons and A. U. Falster, see table 2, footnote b.

^cAverage of an unspecified number of analyses; boron, lithium, and hydrogen were determined by ion microprobe (SIMS).

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Nigeria ^{b-3,f}			Malkhan, Russia ^{b-6,g}	Transbaikalia, Russia ^{b-1}	Sanga Sanga, Tanzania ^{b-7,h}			Vietnam ^{b-3,i}
Slice			nr	Crystal fragment	Crystal section			Slice
Pinkish orange	Colorless	Lt. pink	Lt. green	Lt. pink	Blue	"Rose"	Yellow-brown	Red
37.90	38.90	38.76	37.85	37.96	37.41	37.12	38.37	36.54
nd	nd	nd	0.09	nr	0.08	0.02	0.02	0.02
10.98	10.98	10.93	11.70	11.12	10.78	10.89	11.05	10.95
39.06	37.47	37.18	38.10	40.23	37.37	39.14	38.76	41.02
0.22	0.05	0.02	0.92	0.17	0.24	0.09	0.11	0.11
0.66	0.36	0.27	1.00	0.58	2.20	1.25	1.01	1.46
nd	nd	nd	0.03	nr	nd	nd	nd	0.04
3.09	3.08	3.20	3.20	2.58	2.58	2.66	2.73	2.04
1.67	3.06	3.10	2.13	2.48	2.40	2.39	2.62	2.04
1.03	0.89	0.83	1.28	1.40	1.31	1.32	1.30	1.08
nd	nd	nd	0.09	nr	nd	0.02	nd	0.02
3.46	3.46	3.47	2.80	3.18	3.65	3.38	3.81	3.32
0.69	0.69	0.63	1.00	1.39	0.15	0.79	0.00	0.98
<u>98.78</u>	<u>98.94</u>	<u>98.43</u>	<u>100.19</u>	<u>101.16</u>	<u>98.17</u>	<u>99.07</u>	<u>99.79</u>	<u>99.61</u>
<u>0.29</u>	<u>0.29</u>	<u>0.27</u>	<u>0.42</u>	<u>0.59</u>	<u>0.06</u>	<u>0.33</u>	<u>0.00</u>	<u>0.41</u>
98.49	98.65	98.16	99.77	100.57	98.11	98.74	99.79	99.20
5.988	6.160	6.165	6.015	5.931	6.032	5.923	6.037	5.799
<u>0.012</u>	<u>0.000</u>	<u>0.000</u>	<u>0.000</u>	<u>0.069</u>	<u>0.000</u>	<u>0.077</u>	<u>0.000</u>	<u>0.201</u>
6.000	6.160	6.165	6.015	6.000	6.032	6.000	6.037	6.000
3.000	3.000	3.000	3.209	3.000	3.000	3.000	3.000	3.000
6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
1.263	0.994	0.971	1.136	1.340	1.103	1.284	1.188	1.472
nd	nd	nd	0.011	nr	0.010	0.002	0.002	0.002
0.029	0.007	0.003	0.122	0.022	0.032	0.012	0.014	0.015
0.089	0.048	0.037	0.135	0.077	0.300	0.169	0.135	0.196
nd	nd	nd	0.007	nr	nd	nd	nd	0.009
<u>1.619</u>	<u>1.951</u>	<u>1.986</u>	<u>1.361</u>	<u>1.558</u>	<u>1.555</u>	<u>1.533</u>	<u>1.660</u>	<u>1.305</u>
3.000	3.000	3.000	2.772	3.000	3.000	3.000	3.000	3.000
0.524	0.522	0.546	0.545	0.432	0.446	0.455	0.460	0.347
0.317	0.274	0.257	0.394	0.424	0.410	0.408	0.397	0.333
nd	nd	nd	0.018	nr	nd	0.004	nd	0.003
<u>0.159</u>	<u>0.205</u>	<u>0.197</u>	<u>0.043</u>	<u>0.144</u>	<u>0.143</u>	<u>0.133</u>	<u>0.141</u>	<u>0.316</u>
1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
0.346	0.346	0.317	0.503	0.687	0.076	0.399	0.000	0.489
3.654	3.654	3.683	2.968	3.313	3.924	3.601	4.000	3.511
0.62	0.66	0.68	0.58	0.50	0.52	0.53	0.54	0.51

^aAlso contained up to 0.10 V₂O₅.

^eAlso contained up to 0.09 wt.% ZnO and 0.04 wt.% Bi₂O₃; Cl, Cr, V, and Ba were not detected.

^fAlso contained up to 0.04 V₂O₅.

^gBoron and lithium were determined by wet chemistry.

^hAnalyzed by SEM-EDS.

ⁱAlso contained up to 0.19 wt.% ZnO.

^jCalculation included traces of Pb; this element is not shown above due to possible contamination problems.

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STAR OF THE SOUTH: A HISTORIC 128 CT DIAMOND

By Christopher P. Smith and George Bosshart

The Star of the South is one of the world's most famous diamonds. Discovered in 1853, it became the first Brazilian diamond to receive international acclaim. This article presents the first complete gemological characterization of this historic 128.48 ct diamond. The clarity grade was determined to be VS₂ and the color grade, Fancy Light pinkish brown. Overall, the gemological and spectroscopic characteristics of this nominal type IIa diamond—including graining and strain patterns, UV-Vis-NIR and mid- to near-infrared absorption spectra, and Raman photoluminescence—are consistent with those of other natural type IIa diamonds of similar color.

Rarely do gemological laboratories have the opportunity to perform and publish a full analytical study of historic diamonds or colored stones. However, such was the case recently when the Gübelin Gem Lab was given the chance to analyze the Star of the South diamond (figure 1). This remarkable diamond is not only of historical significance, but it is also of known provenance—cut from a piece of rough found in the state of Minas Gerais, Brazil, almost 150 years ago. In addition, the Star of the South has a natural pinkish brown color and is classified as a nominal type IIa diamond (refer to the Spectrometry section). Because of the age and previous descriptions of this diamond, which predate the growth of synthetic diamonds and modern color-enhancement techniques, we are able to guarantee that it was natural and unaltered.

A BRIEF OVERVIEW OF DIAMOND DEPOSITS IN BRAZIL

The most frequently cited date for the discovery of diamonds in Brazil is 1725 (Legrand, 1980; Lenzen, 1980; Wilson, 1982). Cassedanne (1989) indicated that the first reference to Brazilian diamonds was in 1714, although the source for this information is not provided. However, it is likely that some diamonds were recovered as a byproduct of gold panning activities during the 17th century and even earlier. What is commonly referred to as “The Brazilian Era” in the history of diamonds extended

from approximately 1730 to 1870, during which time Brazil was the world's principal source of diamond. This era ended with the discovery of more significant quantities of diamonds in South Africa.

According to Levinson (1998), it has been estimated that prior to the Brazilian finds only about 2,000–5,000 carats of diamonds arrived in Europe annually from the mines of India. In contrast, the Brazilian finds supplied an estimated 25,000 to 100,000 carats of rough diamonds per annum (for some years, such as 1850 and 1851, production reached 300,000 carats). This sudden influx of relatively large quantities of diamonds had a significant effect on the world's diamond market. As Lenzen (1980, p. 55) states, “The importance of the Brazilian discoveries is reflected in the fact that within five years, from 1730 to 1735, the world diamond market exploded. Prices dropped by three-quarters.”

Almost all of the diamonds recovered in Brazil to date have been from secondary (alluvial) deposits. The first kimberlite pipe was not even discovered until 1965 (Wilson, 1982). Since then, a large number of kimberlites have been identified, but the vast majority were found to be barren of diamonds. To date, the diamondiferous ones have not been found to contain sufficient concentrations of diamonds to

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support commercially viable mining operations. Brazil's alluvial diamond deposits have been classified into three basic types based on where they occur relative to the waterways that are associated with the deposits (Lenzen, 1980; Wilson, 1982): high-level deposits (roughly 1,200–1,500 m above sea level), low- or terrace-level deposits (in the river valleys, above the high-water level), and fluvial or river deposits (in the river sediments).

Brazil's diamond deposits are spread out over an extensive surface area. The Diamantina region alone covers approximately 10,000 km² (Cassedanne, 1989). Wilson (1982) indicated that diamonds have been discovered in 40 districts in 11 states. He added that the most significant deposits lie in the southwest portion of Minas Gerais, in an area known as the Mining Triangle.

The concentration of diamonds throughout most of these regions is very low. However, there are some exceptions to this general rule. Holes or depressions along some river tributaries occasionally have provided a rich cache of diamonds. Some holes are small and relatively shallow, whereas others have been described as being as large as caves (Lenzen, 1980).

The first large diamond discovered in Brazil, called the Regente de Portugal, reportedly was found along the Abaeté River in Minas Gerais in the mid-18th century (Reis, 1959). It is believed to have been cut into a 215 ct stone, but nothing is known of its subsequent disposition; there is even some question as to whether it ever existed, or was in fact a topaz (Reis, 1959). In 1938, the largest Brazilian diamond ever documented was found. It weighed an impressive 726.6 ct and was named the President Vargas diamond, in honor of Brazil's then president (Balfour, 2000); several stones were cut, the largest of which—originally 48.26 ct (since recut to 44.17 ct)—is known as the Vargas diamond (Krashes, 1984). Certain areas of Minas Gerais have become well known for the number of large diamonds they have yielded. The Coromandel region alone, where the President Vargas was found, produced nine diamonds that weighed more than 200 ct each, as well as another 16 that were more than 100 ct, during the period 1935–1965 (Legrand, 1980). In one five-year period, Coromandel yielded five stones that had an average weight of 320 ct (refer also to Cassedanne, 1989). Cincora, Monte Carmelo, Romaria, Cascalho Rico, Grupiara, Patos, and Estrêla do Sul are other areas that have supplied large diamonds (Wilson, 1982). It was in the area



Figure 1. The 128.48 ct Star of the South was originally discovered in Brazil in 1853 and faceted shortly thereafter (in 1856 or 1857). It was the first Brazilian diamond to achieve international acclaim for its size and quality. Photo by Phillippe Hitz.

now known as Estrêla do Sul that the Star of the South was found (e.g., Streeter, 1877; Bauer, 1896; Reis, 1959; Balfour, 2000).

For a more thorough discussion of the Brazilian diamond deposits, the authors refer readers to the following reviews: Legrand (1980), Lenzen (1980), Wilson (1982), Cassedanne (1989), and Levinson (1998). Good descriptions and historical aspects of the large diamonds found in Brazil are provided by Reis (1959).

STAR OF THE SOUTH: KNOWN HISTORY

The Star of the South has earned notoriety for a number of reasons. It was the first Brazilian diamond to become renowned worldwide. In addition, and unlike many historical diamonds, the early history of the Star of the South is well documented. According to Dufrenoy (1856), near the end of July 1853 a slave woman working in alluvial diamond deposits of the Bagagem River in Minas Gerais discovered a diamond that weighed an impressive 52.276 grams or 254¹/₄₂ "old" carats (calculated to 261.38 metric carats). The rough measured 42 × 35 × 27mm (Dufrenoy, 1856). As a result of this fortu-

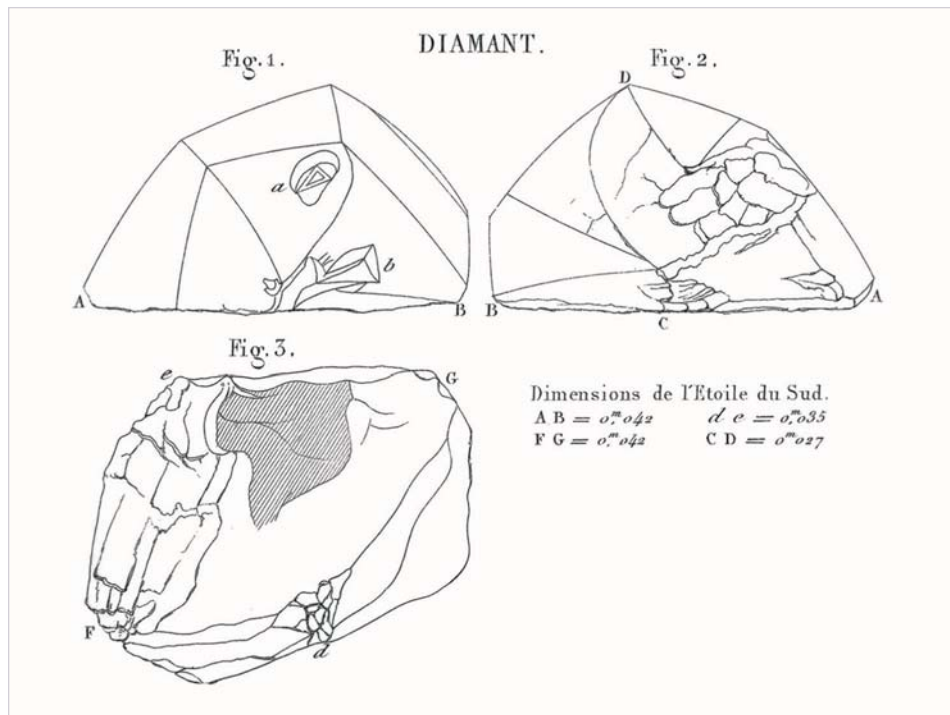
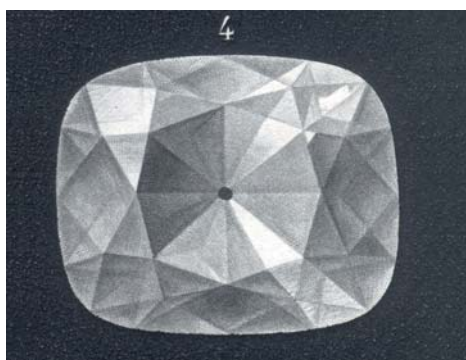


Figure 2. According to the authors' research, noted French mineralogist A. Dufrénoy provided the only firsthand description of the original crystal from which the Star of the South was cut. (It is unclear if Barbot actually examined the rough.) These three crystal drawings (Figs. 1, 2, and 3—drafted by M. Lemaitre, an associate of A. Dufrénoy) represent different views of the crystal, as described in the text. Emanuel (1867) made a more realistic rendering of this crystal seemingly from Dufrénoy's originals. The resulting 128.48 ct cushion-shape faceted stone was illustrated by Simonin (1869).



itous discovery—and as a reward for turning the stone over to the mine owners—the slave woman was given her freedom and, reportedly, a pension for the remainder of her life (see, e.g., Streeter, 1882). For more than a century, the Star of the South held the distinction as the largest diamond ever found by a woman. In 1967, the Lesotho diamond, weighing an astounding 601.26 ct, was discovered by Ernestine Ramaboa (Balfour, 2000).

Noted French mineralogist A. Dufrénoy, while a professor at the Natural History Museum of Paris, provided a first-hand description of the original crystal from which the Star of the South was fashioned (Dufrénoy, 1856, pp. 93–95). He wrote (as translated by GB; all figure references refer to the three line drawings of the crystal reproduced in figure 2 here):

One observes on one of the faces of the diamond a rather deep octahedral cavity, situated in *a* (fig. 1, pl. 225); it represents the impression left by a diamond

crystal that earlier was implanted on the surface of the Star of the South. The interior of this cavity, examined with a loupe, shows pronounced octahedral striae. One also sees, in *b*, the trace of three other diamonds, which were grouped on the main diamond. The rear face of the Star of the South still bears traces of two diamonds, which have been detached The kind of base on which one naturally places this diamond, and which we have represented [in] fig. 3, still offers, in *d*, marks of the adherence of several other small diamond crystals. On this side, one notes in *f* a flat part where the cleavage appears. I am very inclined to consider it as a breakage, maybe the point of attachment of this diamond to the matrix; . . . I have already noted that this beautiful diamond is not symmetrical [refers to figs. 1, 2, and 3]. . . .

Prof. Dufrénoy mistakenly proposed that this diamond grew as part of a larger cluster of diamonds, with this crystal attached to the matrix wall. He suggests that diamonds coated the walls of

a geode-like formation, similar to quartz geodes. This explains why he interpreted the cavities and flat area of the crystal as he did. Barbot (1858, pp. 161–162) further described the piece of rough and clarified certain statements made by Dufrénoy:

. . . the “Étoile du Sud” [Star of the South], was a rhombic dodecahedron, bearing along each of its faces a curved junction [where adjoining faces meet] so that it became a solid of 24 faces. The natural faces were matte and striated. . . . this incomparable diamond exhibited, on one of its faces, a cavity so deep that some have believed it to be due to the implantation of an octahedral crystal of the same nature; we are certain, after further consideration, that this cavity was only an interruption of one of the [crystal] growth layers; the other, shallower cavities were certainly due to the same cause. The flat part that appeared cleaved is probably an accident of nature. . . .

The . . . late Mr. Dufrénoy thought that this diamond had to be part of a group of diamondiferous crystals; in this, he was mistaken: diamonds grow isolated in diverse sections of their matrix, and never agglomerate, or are superimposed, or graft on one another like pyrites and crystals of spar [calcite] and quartz. . . .”

All subsequent mineralogical descriptions and illustrations of this crystal seem to be derived from these two original descriptions and crystal drawings (see, e.g., Kurr, 1859, plate I, figure 5; Emmanuel, 1867; Streeter, 1882; Bauer, 1896; as well as all modern references).

The first owner of the diamond, Casimiro de Tal, sold it shortly after its discovery for a reported £3,000, apparently well below its international market value (Streeter, 1882). In the two years that followed, the diamond remained in its rough state and was again sold, this time for £35,000 (Streeter, 1882). In 1855, the rough diamond was showcased at the Paris Industrial Exhibition (Kurr, 1859). At that time, it was owned by Messrs. Halfen (two brothers who were diamond dealers in Paris) and christened Star of the South (Dufrénoy, 1856). Barbot (1858) stated that the Halfen brothers chose this name. In 1856 or 1857, the diamond was taken to Amsterdam, where it was cut by a Mr. Voorzanger of the firm Coster. We are able to establish this date of cutting because Dufrénoy (1856) reports that the diamond was still in the rough state when he examined it after the 1855 Paris Exhibition, whereas Barbot (1858) indicates that he examined the faceted diamond.

The fashioning of the diamond took three months; the cut stone was illustrated by Simonin

(1869; again, see figure 2). Barbot (1858, p. 162) described the cut gem as follows: “Its oval form is rather charming and permits it to refract light well. It is, by the way, a very spread stone, for it is 35 millimeters long by 29 millimeters wide, but only 19 millimeters thick.” Various weights and descriptions have been given for the cut stone: Streeter (1882) describes it as an “elegant oval” of 125 “old” carats. In more modern references, some (e.g., Balfour, 2000) describe it as a 129 ct elongated cushion, whereas others (e.g., *Notable Diamonds of the World*, 1990; Liddicoat, 1993) refer to it as a 128.80 ct oval brilliant. Shipley (1935) gives a weight of 128.5 ct. Its color was described in early publications as having a “rather pronounced pink tint” (Barbot, 1858, p. 162) or “decided rose tint” (Streeter, 1882, p. 81), as well as “not perfectly white and pure” (Emanuel, 1867, p. 85). No modern first-hand observations of the faceted diamond’s color were found. All contemporary publications seem merely to be repeating these comments.

Subsequently, the small town of Bagagem, near the place where the diamond was discovered in the Bagagem River, was renamed Estrêla do Sul (in Portuguese) in honor of the large gem (see, e.g., Balfour, 2000). According to Simonin (1869), a replica of the faceted diamond along with replicas of several other famous diamonds was put on display during the 1862 London Exhibition and the 1867 Paris World Exhibition. However, most modern references state incorrectly that the actual diamond was put on display (see, e.g., Bruton, 1978; Liddicoat, 1993; Balfour, 2000).

According to Balfour (2000), during the 1860s the Star of the South ranked as the sixth largest faceted diamond in the world. Sometime between 1867 and 1870, Khande Rao, then Gaekwar (official sovereign ruler) of the Indian kingdom of Baroda, purchased the stone for a reported £80,000 (approximately \$400,000; Shipley, 1935; Balfour, 2000). Prior and Adamson (2000) incorrectly state that the diamond was acquired in 1865. This was not possible, since the diamond was only offered for sale to the Gaekwar of Baroda after the 1867 exhibition (Streeter, 1882). The diamond remained in the collection of the Gaekwars of Baroda for at least 80 years. In 1934, the grand nephew of Khande Rao, Sayaji Rao III Gaekwar of Baroda, informed Robert M. Shipley (founder of the Gemological Institute of America) that the Star of the South had been set in a necklace along with the English Dresden diamond (figure 3; “Owner of famous jewels. . . ,” 1934; Shipley, 1935; Prior and



Figure 3. Khande Rao, Gaekwar of Baroda, had this fabulous necklace created to display both the Star of the South and the 78.5 ct English Dresden below it. The date of this photograph is approximately 1880. Photo courtesy of the British Library, Oriental and India Office.

Adamson, 2000). Also from the Bagagem River, the English Dresden (119¹/₂ ct in the rough, cut as a 78.53 ct pear shape; see, e.g., Balfour, 2000) had been found in 1857, not far from the discovery site for the Star of the South.

The English Dresden reportedly was sold by the rulers of Baroda to Cursetjee Fardoonji of Bombay, India in 1934 (Balfour, 2000), and Bruton (1978) reported that the Star of the South also came into the possession of Rustomjee Jamsetjee sometime around 1939. However, this latter claim is not correct. It is now known that the original necklace containing both the Star of the South and the English Dresden was still intact and in the possession of Sita Devi, Maharani of Baroda, as of 1948 (figure 4). The whereabouts of these two diamonds could not be verified after about 1950, and the Star of the South's location for the next 50 years is not clear. In 2001, however, it was purchased through a broker by owners who wish to remain anonymous. In December 2001, the Star of the South was sub-

mitted to the Gübelin Gem Lab for a diamond grading report, thus enabling us to assemble the following detailed information.

ANALYTICAL METHODS

Clarity assessments and the study of internal characteristics such as inclusions and graining were carried out with a binocular microscope and various lighting techniques. We used crossed polarizing filters to observe the internal strain patterns and interference colors. Weight determination was made using a Mettler AE 1000 C electronic scale, calibrat-

Figure 4. In the town of Baroda, India, at the celebration of her husband's birthday in 1948, Sita Devi, Maharani of Baroda, was photographed wearing a slightly modified version of the necklace shown in figure 3, where more diamonds had been added around the bottom portion of the English Dresden. Photo and information by Henri Cartier-Bresson, © Henri Cartier-Bresson/Magnum Photos.



ed to ± 0.001 ct. Color observations were made in the neutral viewing environment of a MacBeth Judge II light box. Reaction to long- and short-wave ultraviolet radiation was observed in a darkened room with a dual 365 nm and 254 nm lamp.

We recorded the diamond's ultraviolet-visible-near infrared (UV-Vis-NIR) absorption spectrum at liquid nitrogen temperatures in the region from 200 to 2500 nm using a Perkin Elmer Lambda 19 dual beam spectrometer, equipped with a beam condenser. The spectrum was run at a speed of 1 nm/sec and with a spectral slit width of 0.2 nm.

The near- to mid-infrared spectrum was taken at room temperature in the region $7000\text{--}400\text{ cm}^{-1}$, recording 200 scans at the standard 4 cm^{-1} resolution of a Pye-Unicam PU9624 Fourier Transform infrared (FTIR) spectrometer. Both a SpectraTech diffuse reflectance unit and a Specac $5\times$ beam condenser were used.

Raman photoluminescence spectrometry was conducted at liquid nitrogen temperatures with a Renishaw 2000 Raman microspectrometer equipped with a helium/cadmium laser (He/Cd–excitation 324.98 nm) and an argon-ion laser (Ar-ion–excitation 514.5 nm). Five areas were analyzed: two in the center of the table, two on bezel facets on either side of the diamond, and the culet.

GEMOLOGICAL CHARACTERISTICS

General Description. The Star of the South diamond weighs 128.480 ct. Its antique cushion shape has a slightly asymmetric outline. It is faceted in the brilliant-cut style, with eight bezel facets and eight large pavilion mains (again, see figure 1). Its dimensions are: $34.21 \times 28.10 \times 18.72$ mm. The table facet measures 21.10 mm parallel to the length of the stone and 18.80 mm parallel to the width. The octagonal culet facet measures 3.10 and 2.65 mm in the corresponding directions. The total depth percentage is 66.6%. The average percentage for crown height is 15% and for pavilion depth is 52%. The majority of the circumference of the diamond, where the crown meets the pavilion, forms a knife-edge girdle. However, several small girdle facets have been polished, and in some areas a number of extra facets have been placed, primarily around the girdle area.

Color. We color graded the Star of the South as Fancy Light pinkish brown. In the face-up position, the color appeared slightly more concentrated at both ends of the diamond, as a result of its shape

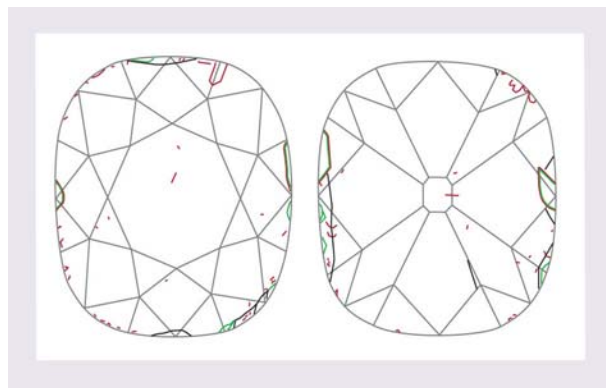


Figure 5. The Star of the South received a clarity grade of VS₂, with inclusions consisting of two indented naturals (one on each side) and a number of shallow chips and small bruises. In addition, a small remnant of a cleavage was present in the table and a pinpoint inclusion can be seen under a bezel facet at one side. Red outside of green = indented naturals, green = naturals, black = extra facets, and red = chips, bruises, cleavage, and pinpoint.

and cut. Face-down, subtle lamellar bands of a light brown hue could be seen traversing the width of the stone.

Internal Features. Considering the large size and long history of this diamond, one might expect it to have more inclusions and surface blemishes than it does. The clarity grade of the Star of the South is VS₂ (figure 5). The most prominent inclusion features consist of one indented natural on each side of the diamond. The larger of the two indented naturals contained deep triangular depressions, whereas the other displayed a series of parallel striations. Both of these features revealed the orientation of these natural surfaces, along octahedral crystal faces. We also saw several other essentially planar naturals on various areas around the girdle. A pinpoint inclusion in one side of the diamond was visible through either a lower girdle facet or a bezel facet. A small remnant of a cleavage plane was present in the table, as were several small circular feathers in the areas surrounding the naturals. As a result of wear and tear over the years, there were also several, mostly minor, chips around the girdle, as well as numerous other small bruises and tiny feathers on the surface of various other facets. Since the majority of the clarity-affecting inclusions were at or just beneath the surface of the gem, recutting the diamond could improve its clarity to VVS (although the authors strongly recommend against recutting any historic diamond).

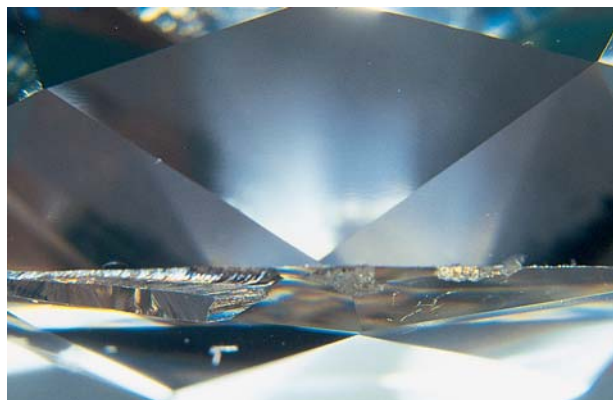


Figure 6. Whitish graining was evident in certain areas and viewing directions of the Star of the South. This optical effect imparted a sheen-like cast to these areas, as seen here through a bezel facet. Photomicrograph by Christopher P. Smith; magnified 7 \times .

Graining and Strain Patterns. An optical phenomenon that relates to structural disturbances, described by gemologists as whitish “graining,” was visible in specific areas of the gem when viewed at certain angles (figure 6). Internal strain patterns—banded and “tatami,” with blue and gray interference colors—also were prominent when the diamond was viewed between crossed polarizing filters. Depending on the crystallographic viewing direction, distinct, irregular or cellular strain patterns with strong interference colors of purple-pink, orange, yellow, green, and blue also were seen (figure 7).

Fluorescence. The Star of the South fluoresces a uniformly distributed blue of moderate intensity to long-

Figure 8. A homogeneous blue fluorescence of moderate intensity was emitted by the Star of the South when it was exposed to a long-wave UV lamp. Photo by Franzisca Imfeld and Christopher P. Smith.

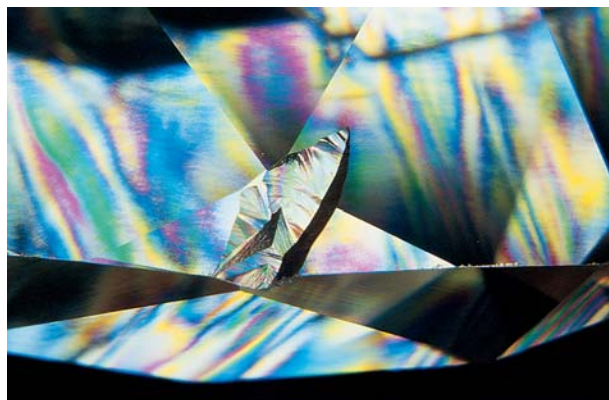
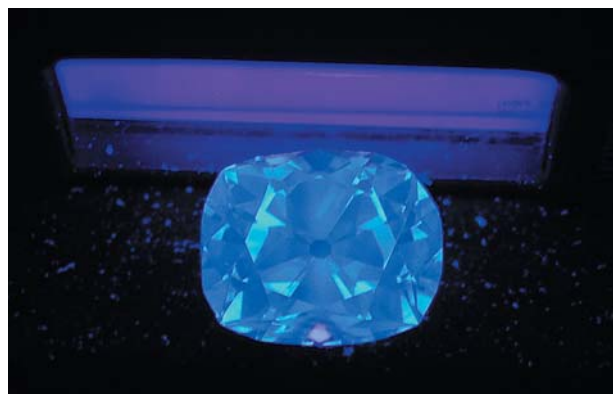


Figure 7. One distinctive feature of the Star of the South is the prominent irregular strain patterns, which exhibited purple-pink, orange, yellow, green, and blue interference colors. Such strain patterns more typically are associated with type Ia natural-color brown or pink diamonds, although they are encountered in some type IIa diamonds. Also seen here is the larger of two indented naturals. The triangular patterns reveal the octahedral orientation of this remnant of the original crystal surface. Photomicrograph by Christopher P. Smith; magnified 7 \times .

wave UV radiation (figure 8), and a similar but weaker blue to short-wave UV. No phosphorescence to either long- or short-wave UV was observed.

SPECTROMETRY

UV-Vis-NIR. The UV-Vis-NIR absorption spectrum recorded at cryogenic temperature is featureless down to about 600 nm, at which point the absorption starts to increase gradually and becomes steeper until it reaches the fundamental absorption edge at 225 nm in the ultraviolet region (figure 9). Superimposed on this general absorption are five very weak to weak absorption bands in the yellow-green to violet regions: a very weak, broad band centered at approximately 560 nm; a weak, sharp peak at 503.2 nm (H3); a more distinct, sharp peak at 415.2 nm (N3); and two weak, broad bands at 390 and 375 nm. At the foot of the fundamental absorption edge of the diamond, there are two additional small but distinct peaks situated at 236.0 (N9) and 229.5 nm.

Mid-IR and Near-IR. The mid-infrared spectrum of the Star of the South diamond reveals the two-phonon and three-phonon absorption bands intrinsic to diamond (2650–1500 and 4000–2650 cm^{-1} , respectively; see figure 10). No absorption was apparent in the one-phonon region of the spectrum (1500–1000 cm^{-1}). We classified this diamond as a

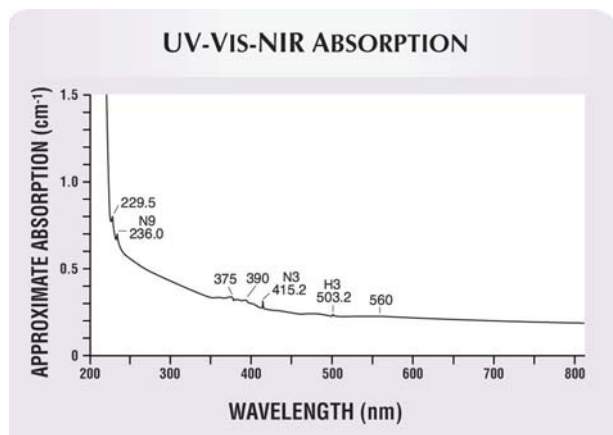
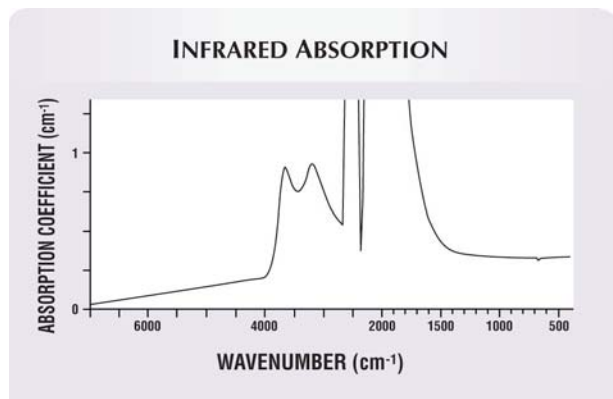


Figure 9. This representative UV-Vis-NIR absorption spectrum of the Star of the South, recorded at liquid nitrogen temperature and high resolution, displays increasing general absorption starting at approximately 600 nm, which is responsible for the primary brown coloration, as well as a faint broad band at approximately 560 nm, which causes the pinkish color modifier. Other characteristics are peaks at 229.5, 236.0 (N9), and 415.2 (N3) nm, a very weak peak at 503.2 (H3) nm, and weak, broad bands centered at approximately 375 and 390 nm.

type IIa as a result of the relative absence of IR features in the one-phonon region of the infrared spectrum. However, by expanding the spectrum in this region, a minute, broad absorption band was observed, located at 1174 cm^{-1} , which relates to minute traces of nitrogen in the form of B-aggre-

Figure 10. The FTIR absorption spectrum of the Star of the South reveals the two- and three-phonon absorption bands, which are intrinsic to diamond (i.e., at $2650\text{--}1500$ and $4000\text{--}2650\text{ cm}^{-1}$, respectively), but no distinct absorption features related to nitrogen impurities. Hydrogen or boron impurities were not detected either.



gates. Therefore, we further qualified this diamond as a *nominal* type IIa. No other traces of nitrogen, or of hydrogen or boron, were detected in the infrared region.

Raman Photoluminescence. Overall, the spectra recorded on various facets of the diamond did not reveal significant variations (table 1).

He/Cd laser (325 nm). Two dominant photoluminescence systems were apparent (figure 11A): the 415.2 nm (N3), with a series of broad and progressively weaker bands between 420 and 480 nm; and the 503.1 nm (H3), also with a series of broad and progressively weaker bands between 510 and 530 nm. A weak, sharp band located at 437.9 nm was superimposed on a phonon replica of the N3 system. In addition to

TABLE 1. Raman photoluminescence of the Star of the South diamond recorded at cryogenic temperatures.^a

Band (nm)	Band allocation	Description
He/Cd laser, 325 nm excitation		
350		Faint, broad
380		Weak, broad
406.0		Faint, sharp
415.2	N3	Strong, sharp
437.9		Weak, sharp
503.1	H3	Moderate, sharp
535.9		Weak, sharp
537.4		Weak, sharp
574.8	(N-V) ⁰	Faint, sharp
575.8		Weak, sharp
Ar-ion laser, 514.5 nm excitation^b		
535.9		Moderate-strong, sharp
564.3		Faint, sharp
565.8		Faint, sharp
566.1		Weak, sharp
566.5		Weak, sharp
567.5		Weak, sharp
569.2		Weak, sharp
570.4		Faint, sharp
574.8	(N-V) ⁰	Moderate-strong, sharp
575.8		Moderate-strong, sharp
600–620		Weak, broad
630.5		Weak, sharp
637.0	(N-V) ⁻	Moderate-strong, sharp

^aFor an explanation of the N3, H3, (N-V)⁰, and (N-V)⁻ defects, see box A of Smith et al. (2000).

^bDepending on the facet analyzed, the following peak ratios and FWHM (full width at half maximum) values were obtained:

575.8/574.8 nm peak ratio = 0.64 to 2.89

574.8/637.0 nm peak ratio = 0.92 to 2.88

574.8 nm peak FWHM = 0.37 to 0.58 nm

575.8 nm peak FWHM = 0.21 to 0.29 nm

637.0 nm peak FWHM = 0.47 to 0.56 nm.

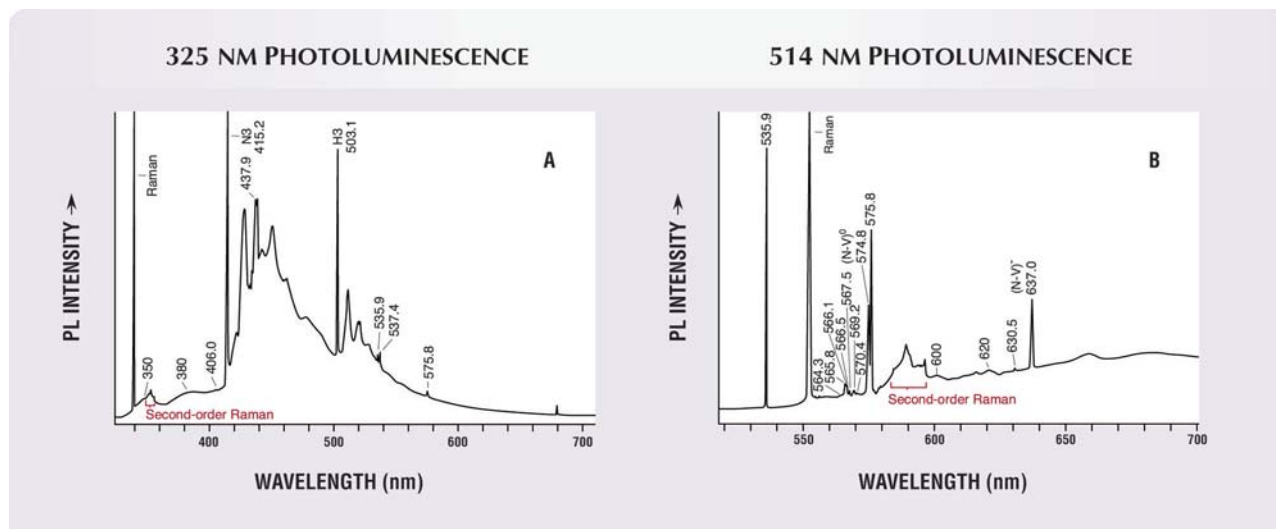


Figure 11. Raman photoluminescence spectra of the Star of the South were taken at liquid nitrogen temperature for significantly improved sensitivity and spectral resolution. Spectrum A, taken with the helium/cadmium laser (325 nm excitation), shows two dominant photoluminescence systems, resulting from N3 and H3 defects, in addition to several other peaks that were also present. Spectrum B, taken with an argon-ion laser (514 nm excitation), recorded strong PL bands at 535.9, 574.8 (N-V)⁰, 575.8, and 637.0 (N-V)⁻ nm. Another series of weak to moderate PL bands were resolved between 564 and 571 nm.

these, several other more subordinate PL spectral features were present (see figure 11A and table 1).

Ar-ion laser (514 nm). With this excitation, several additional PL features above 530 nm were recorded (figure 11B). The 535.9 nm peak and two closely spaced, but unrelated PL bands at 574.8 (N-V)⁰ and 575.8 nm were the most dominant spectral features present with this laser. The ratio of the 575.8 nm to the 574.8 nm (N-V)⁰ peaks was variable for the five measurements taken on different facets. The (N-V)⁻ center at 637.0 nm was present in all the spectra. In all but one of the spectra, the intensity of the (N-V)⁻ was weaker than the (N-V)⁰ (also refer to Chalain et al., 2000; Fisher and Spits, 2000; Smith et al., 2000). The full width at half maximum (FWHM) of the (N-V)⁻, (N-V)⁰, and 575.8 nm peaks was also variable. Several other weaker PL bands were also recorded (see figure 11B and table 1).

DISCUSSION

When diamonds were discovered during the 1860s in South Africa, these hugely prolific finds signaled the inevitable end to the Brazilian Era and Brazil's status as the world's primary source of gem-quality diamonds. Although today several countries surpass Brazil in the quantity and value of diamonds mined, Brazil still produces an annual average of approximately 1 million carats, which includes occasional pieces of rough that yield large, high-quality faceted diamonds.

A number of discrepancies were discovered during our search for historical references to the Star of the South diamond, notably the weights indicated for both the rough gem and the faceted stone. The discrepancies in the weight of the original rough are easier to explain, in that it has been reported as either 254^{1/42} or just 254 "old" carats, or as 261.24 to 261.88 when converted to metric carats. In part, this is due to differences in "old" carats before this unit of measurement was standardized in 1914 as 0.2 gram [Liddicoat [1993, p. 275] provides a list for local variances for "old" carats from different trading areas.] However, if previous researchers had accessed Dufrénoy (1856, p. 93), they would have seen the accurate weight in grams (52.276), which he calculated to 254^{1/42} "old" carats. The conversion to modern metric carats would have been straightforward (261.38 ct). For the faceted gem, Streeter (1882) indicates a weight of 125 "old" carats and Bauer (1896) gives the weight as 125^{1/42} "old" carats; however, most modern references indicate 128.80 metric carats (the 128.8[0] ct figure appears to be a calculated weight, as opposed to one that was measured). It is interesting that Shipley (1935) came closest to the actual weight when he stated 128.5 ct. Considering the measurements indicated by Barbot (1858) compared to those taken for this study, as well as the "antique" quality of the polish and the weight indicated by Shipley (1935), there is no evidence to suggest that the diamond has been repolished. The description of the diamond as an oval by some and a cushion shape by others is understand-

able, since gemstones with this general shape commonly have an outline that is intermediate between an oval and a cushion.

Other discrepancies were encountered in regard to the name "Star of the South." For both the English and Portuguese derivations, we found more than one diamond with this name (see, e.g., Reis, 1959; Liddicoat, 1993; Balfour, 2000). In English, the other Star of the South is a 14.37 ct kite shape that was purchased in 1928 by Evalyn Walsh McLean (who at the time also owned the Hope diamond) and sold by her estate to Harry Winston (Krashes, 1984). In Portuguese, a 179.36 ct rough diamond found during 1910 or 1911, also in the Bagagem River, was called *Estrêla do Sul* or *Estrêla do Minas*, but nothing is known of its ultimate disposition (Reis, 1959). A 140 ct green piece of rough discovered in Minas Gerais in 1937 was christened "New Star of the South" (Cassedanne, 1989); again, though, nothing is known about the current location of this diamond (Reis, 1959). It is not uncommon to encounter such potentially confusing information when attempting to trace the history of famous gems. However, the provenance of the present diamond as the original "Star of the South" is well established.

Diamonds are classified as type IIa based on the relative absence of nitrogen-related features in the infrared region of the spectrum (1500–1000 cm^{-1}) when recorded at room temperature (for a general discussion of diamond type, see, e.g., Fritsch and Scarratt, 1992, pp. 38–39). However, it is not uncommon for such diamonds to reveal minute traces of nitrogen-related (and even hydrogen-related) absorption in the ultraviolet and visible regions when the spectrum is taken at liquid nitrogen temperature with a high-quality UV-Vis-NIR or Raman spectrometer (see, e.g., Fisher and Spits, 2000; Smith et al., 2000). The spectral analyses of the Star of the South identified that it is such a nominal type IIa diamond. It revealed traces of nitrogen-related point defects in very low concentrations when analyzed at cryogenic temperatures with UV-Vis-NIR and Raman. These included very weak to weak absorption bands of H3, N3, and N9 recorded in the UV-visible range, as well as very weak to strong photoluminescence excitation of the (N-V)⁻, (N-V)⁰, H3, and N3 systems with a Raman spectrometer. In addition, we recorded several other PL bands that we are unable to assign to specific point defects in diamond.

As a nominal type IIa, most of the properties and characteristics of the Star of the South were consis-

tent with those of other type IIa diamonds of similar color. This includes its large size and the relative lack of inclusions, the banded and tatami strain patterns, and the essentially featureless spectral trace throughout most of the visible and near-infrared region of the spectrum, as well as the gradual absorption edge of diamond at 225 nm, and the He/Cd and Ar-ion Raman PL spectral features. One rather less common trait was the strong irregular or cellular strain pattern with distinct purple-pink, orange, yellow, green, and blue interference colors. This type of strain pattern is observed more often in type Ia pink or brown diamonds. However, the authors have noted similar strain on occasion in other brown to colorless type IIa diamonds. Also, the blue UV fluorescence seen in the Star of the South is more intense than the faint to weak blue luminescence evident in some type IIa diamonds (others typically are inert or have a weak yellow—or, rarely, distinct orange—reaction). In addition, the pinkish brown color is not a common hue in the family of brown type IIa diamonds.

The primary brown coloration of the Star of the South is due to the increase in general absorption that begins at about 600 nm and continues into the ultraviolet region of the spectrum, whereas the weak, broad band centered at approximately 560 nm is responsible for the pink modifying color.

Brown type IIa diamonds have received a lot of attention recently because it is now known that the color of such diamonds may be modified using high-pressure/high-temperature annealing (for a review, see Smith et al., 2000). Recording spectral data on diamonds with a known history that confirms the natural, unaltered origin of their color is crucial for building a database of natural-color diamonds against which diamonds of a questionable origin of color can be compared. This helps better establish identification criteria for both natural- and treated-color type IIa diamonds.

CONCLUDING REMARKS

The 128.48 ct Fancy Light pinkish brown Star of the South now enters an elite circle of historic diamonds for which a full gemological characterization has been published. Other diamonds in this group include the Hope (Crowningshield, 1989), the Dresden Green (Bosshart, 1989; Kane et al., 1990), and the Tavernier (Lu et al., 1998). We identified the earliest references to this 149-year-old diamond in both its rough and cut forms, which clarified several

details of its early history, and provided significant new information about its more-recent history. In addition, we were able to characterize this diamond with advanced analytical techniques, such as Raman photoluminescence using He/Cd and Ar-ion lasers,

which were not routinely available to those other researchers. The spectral data obtained on this historic diamond will help future researchers better understand the properties of—and establish identification criteria for—natural-color type IIa diamonds.

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IDENTIFICATION OF YELLOW CULTURED PEARLS FROM THE BLACK-LIPPED OYSTER *PINCTADA MARGARITIFERA*

By Shane Elen

Although the *Pinctada margaritifera* oyster usually is associated with the black pearls cultured in French Polynesia, it also can produce attractive large yellow cultured pearls, among other colors. An absorption feature at 700 nm can be used to separate these yellow cultured pearls from their more common counterparts produced in the South Seas by the *Pinctada maxima*. This absorption feature previously has been attributed to the presence of black pigments, and has been reported as an identifying characteristic of black cultured pearls from the *P. margaritifera*. An additional absorption feature in the UV region, between 330 and 385 nm, is indicative of natural yellow color in cultured pearls from the *P. margaritifera*.

Until the late 1990s, strands of large cultured pearls typically were marketed in single colors of white, yellow, gray, or black (Federman, 1999). The white and yellow colors originated from the *Pinctada maxima* oyster, while the gray and black came from the *Pinctada margaritifera*. However, the *P. margaritifera* can produce cultured pearls of many other colors (see, e.g., figure 1). The introduction and growing popularity of strands of multi-colored cultured pearls was a bonus for cultivators of pearls from the *P. margaritifera* oyster, as many of the pastel colors previously had been considered unusable (Federman, 1998a). Multi-

colored strands marketed today may include a mix of cultured pearls from the *P. maxima* and *P. margaritifera* (Federman, 1998b) or consist only of cultured pearls that originate from the *P. margaritifera*. The latter may include several in the following yellow hue range: yellow, greenish yellow, brownish yellow, or grayish yellow. This makes some of them difficult to distinguish from similar-color cultured pearls from the *P. maxima*.

Identification of the mollusk species in which a pearl was cultured is becoming an important issue in the industry. Until recently, it was relatively easy to identify freshwater, South Sea, "Tahitian," or Akoya cultured pearls just by size, shape, and color. Today, however, there is considerable overlap in these once distinctive characteristics from one type of cultured pearl to another. Yet guidelines for quality grading cultured pearls often vary with the mollusk species. For example, the acceptable nacre thickness for the export of black cultured pearls from Tahiti is 0.6 mm (scheduled to change to 0.8 mm on July 31, 2002; "Pearl thickness controls...", 2001). This would be exceptional for an Akoya cultured pearl (grown in the *Pinctada fucata martenisii*), as it would require a culturing period of about

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Figure 1. As multi-colored cultured pearls have become increasingly popular, a broad range of colors from the *P. margaritifera*—including various yellow hues—have arrived in the marketplace. The strand on the left, ranging from 12 to 15 mm in diameter, is courtesy of Pacific Pebbles, Beverly Hills, California. The *P. margaritifera* strand on the right, 8 to 11 mm, and the 15 × 17.82 mm loose cultured pearl on the right are courtesy of King’s Ransom, Sausalito, California. The 14 mm loose cultured pearl on the left is courtesy of Assael International. Photo © Harold & Erica Van Pelt.



four years based on the average annual deposition rate of the nacre for this species. Identification of the mother oyster is also important for the detection of treatments, such as the separation of a dyed black Akoya cultured pearl from a natural-color black *Pteria sterna* cultured pearl. Both may be similar in size, shape, and color, but this author has observed that only the latter exhibits a strong fluorescence emission at 620 nm.

The present study investigates the importance of specific absorption features in yellow cultured pearls from the *P. margaritifera* for confirming both the origin of the mother oyster and whether the coloration is natural. It also demonstrates the need for additional testing to verify natural origin of the black coloration when examining gray or black cultured pearls from the *P. margaritifera*.

BACKGROUND

A striking characteristic of the *P. margaritifera* shell is the presence of white nacre surrounded by black to dark green nacre on the interior periphery of the shell. This “black lip” enables the oyster to produce beautiful black and gray cultured pearls. In some *P. margaritifera* oysters, a layer of yellow nacre can occur and may be visible between the central white and peripheral black nacre (figure 2). When yellow coloration is present, it may not always be visible on the interior of the shell but is only revealed when the exterior surface is polished. Other *P. margaritifera* do not display the characteristic dark

green or black peripheral nacre but exhibit yellow nacre in their place (N. Sims, pers. comm., 2001), or (rarely) they exhibit only white nacre (S. Akamatsu, pers. comm., 2001).

The various combinations of nacre color and strong overtones exhibited by the *P. margaritifera* result in a wide variety of cultured pearl colors, many of them subdued or pastel in nature. Whether natural or cultured, natural-color gray and black

Figure 2. Although the nacre in most *P. margaritifera* shells is black or dark green on the periphery and white in the center, some exhibit the unusual combination of nacre coloration shown here, which progresses from white to yellow to black. Photo courtesy of Shigeru Akamatsu.





Figure 3. This group of 11.5–12.0 mm cultured pearls, all from the *P. margaritifera*, illustrates some of the colors tested in this study. Photo by Maha Tannous.

pearls from this oyster exhibit a characteristic absorption at 700 nm (Komatsu and Akamatsu, 1978). This feature, which has been observed only in the *P. margaritifera* (Miyoshi et al., 1987), is often accompanied by two other absorption features, at 405 and 495 nm; however, the 700 nm feature is typically the most prominent of the three. The feature at 405 nm, also known as the Soret band (Britton, 1983), is characteristic of porphyrins (Iwahashi and Akamatsu, 1993). Porphyrins are naturally occurring tetrapyrrole pigments, commonly referred to as the “pigments of life”; they are among the most highly fluorescent compounds in nature (Guilbault, 1990; Milgrom, 1997).

The feature at 700 nm has been attributed to black pigmentation present in the *P. margaritifera* (Coeroli, 1993). Several attempts have been made to identify the origin of the 700 nm absorption and the black pigmentation in this mollusk (Miyoshi et al., 1987; Blanc and Jabbour, 1988), but none has been conclusive. Efforts to consistently identify the presence of melanin in *P. margaritifera* have not been successful (Blanc and Jabbour, 1988), because melanin (a term used to describe naturally occurring insoluble polymeric materials that can result in red, yellow, brown, or black coloration) does not define a specific chemical structure (Britton, 1983). It has been suggested that a combination of eumelanin and pheomelanin (certain classes of melanins) might be present (Caseiro, 1993), or that an “unusual” type of melanin might be the cause (F. Blanc, pers. comm., 2001).

Due to the demand for gray and black pearls, some cultured pearls are treated with black dye or silver salts, or they are irradiated to produce similar colors (Goebel and Dirlam, 1989). These treatments

do not produce an absorption feature at 700 nm, so its presence is used frequently to verify natural black coloration (Kennedy et al., 1994). However, this test is unreliable, because it assumes that the treatment was not applied to an off-color cultured pearl originating from the *P. margaritifera*. Although the Tahitian government has strict controls on the quality of exported cultured pearls, there are other sources of *P. margaritifera* cultured pearls outside of French Polynesia that are not necessarily subject to the same rigorous standards (“Fiji’s 1st harvest . . .,” 2001).

A recent study of yellow cultured pearls from the gold-lipped *P. maxima* demonstrated that an absorption feature in the ultraviolet region between 330 and 385 nm could be used as evidence of natural color (Elen, 2001). This characteristic also may apply to similar-color cultured pearls originating from the *P. margaritifera*. Currently there are no reports of treatments used to improve yellow colors from off-colored white and yellow *P. margaritifera* cultured pearls. However, treatments used for the cultured pearls from the gold-lipped *P. maxima* (Elen, 2001) could also be applied to cultured pearls from the *P. margaritifera*.

MATERIALS AND METHODS

A total of 29 yellow cultured pearls, ranging from 10.1 to 14.8 mm in diameter, were characterized for this study. All were represented as natural color, from the *P. margaritifera*. The colors included light and medium yellow as well as light to dark yellow modified by green, brown, or gray (see, e.g., figure 3). Ten undrilled samples were obtained directly from sources in French Polynesia, and the remaining 19 drilled samples were provided by reputable suppliers of cultured *P. margaritifera* pearls (see “Acknowledgments”). Only two shell samples of *P. margaritifera* exhibiting yellow nacre on their interior surface were available for the study. Light and medium yellow nacre samples from these two shells were tested *in situ*.

Two white and two black *P. margaritifera* cultured pearls, as well as two *in situ* white nacre samples from a *P. margaritifera* shell, were studied for comparison with the two yellow *P. margaritifera* nacre samples.

Inspection of all the *P. margaritifera* cultured pearls using a binocular gemological microscope revealed no visual evidence of color treatment.

For each sample, reflectance spectra were collected from 250 to 800 nm using a Hitachi 4001

UV-Vis spectrophotometer, and fluorescence observations were made using a UVP model B100 AP long-wave ultraviolet lamp. The reflectance spectra were compared with data for similarly colored samples of nacre and cultured pearls obtained from *P. maxima* oysters for a previous study, as reported by Elen (2001).

RESULTS: UV-Vis REFLECTANCE SPECTRA AND ULTRAVIOLET FLUORESCENCE

Both yellow *P. margaritifera* nacre samples exhibited a broad absorption from 330 to 460 nm that was composed of two features: one in the UV region between 330 and 385 nm, and the other in the visible from 385 to 460 nm. Only the medium-yellow nacre sample exhibited an additional weak absorption at 700 nm (figure 4 and table 1). This sample fluoresced a moderate greenish brown, and the very light yellow shell nacre fluoresced a light yellow. The white *P. margaritifera* shell samples had no absorption features in the 330–460 nm region or at 495 or 700 nm; they fluoresced a strong very light yellow.

As indicated in table 1, the vast majority of the *P. margaritifera* cultured pearls tested exhibited a medium to strong absorption feature at 700 nm (figures 5 and 6); the exceptions were the two white samples and three very light yellow ones. Two of the very light yellow samples exhibited a weak absorption shoulder at 700 nm, and one did not

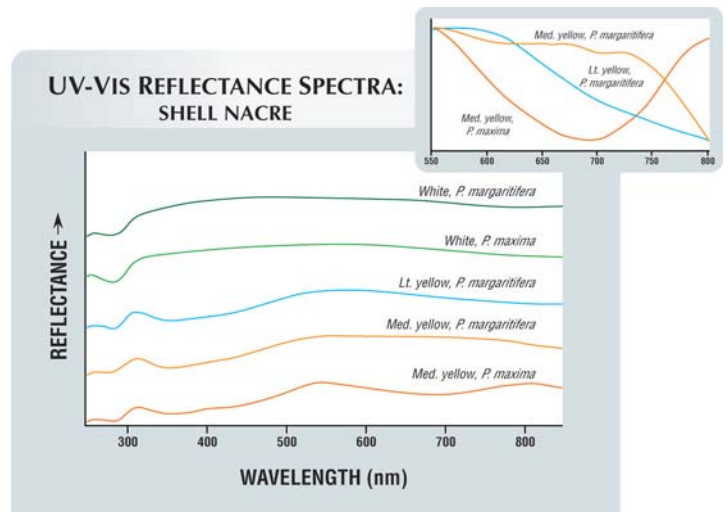


Figure 4. These reflectance spectra are for white and yellow nacre samples taken from the shells of *P. margaritifera* and *P. maxima*. The spectra for respective colors are similar in the 330 to 550 nm region, but often differ from 550 to 800 nm. The inset vertically expands this region to illustrate how the weak absorption feature at 700 nm exhibited by the darker *P. margaritifera* sample is distinctly different from the broad absorption often seen in the *P. maxima* samples.

show the feature at all. Sixteen of the 29 yellow samples also revealed a medium to strong 495 nm absorption feature, and another eight showed a weak feature at 495 nm. The fluorescence of all these samples ranged from light yellow or light brown to greenish yellow, greenish brown, or reddish brown.

TABLE 1. Comparison of color, fluorescence, and absorption features in yellow, white, and black *P. margaritifera* cultured pearls and nacre.

<i>P. margaritifera</i> samples ^a	Long-wave UV fluorescence	Total no. of samples	Absorption features (nm) ¼ no. of samples					
			330–385	385–460	330–430 or 330–460	405	495	700
Light to medium yellow and greenish yellow	Moderate to strong greenish brown, greenish yellow, light brown, and light yellow	16	16	16	0	0	12	16
Light to dark grayish and brownish yellow	Weak to strong yellow, brown, greenish brown, and reddish brown	9	0	0	9	9	9	9
Very light yellow	Moderate to strong yellow	4	4	1	0	0	3	3
White	Strong light yellow	2	0	0	0	0	0	0
Black	Moderate reddish brown	2	0	0	2	2	2	2
White shell nacre	Strong very light yellow	2	0	0	0	0	0	0
Yellow shell nacre	Light yellow and moderate green-brown	2	2	2	0	0	0	1

^a All samples are cultured pearls unless designated “nacre.”

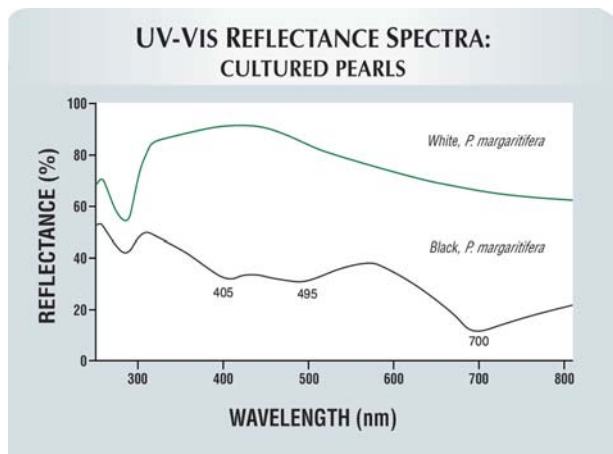


Figure 5. Reflectance spectra are shown here for white and black cultured pearls from the *P. margaritifera*. The absorption features measured for the black sample at 405, 495, and 700 nm are characteristic of black cultured pearls from this species.

Of 20 yellow and greenish yellow *P. margaritifera* cultured pearl samples, 17 exhibited a broad absorption from 330 to 460 nm that comprised two features (figure 6), similar to those observed in the yellow nacre samples (figure 4). The other three in this group, which were very light yellow, only exhibited a weak absorption in the 330–385 nm region. The nine remaining samples, which were brownish or grayish yellow, exhibited a single broad absorption feature from 330 to 430 nm, or 330 to 460 nm, with a maximum centered at 405 nm (figure 6).

The two black *P. margaritifera* cultured pearls used as reference samples exhibited strong absorptions at 405, 495, and 700 nm, as well as the broad absorption from 330 to 430 nm. These features are similar to those observed in some of the grayish and brownish yellow samples; however, the black coloration results in a much stronger overall absorption (figure 5). The spectra of the two white cultured pearls were similar to those of the two white nacre samples, in that no absorption features were

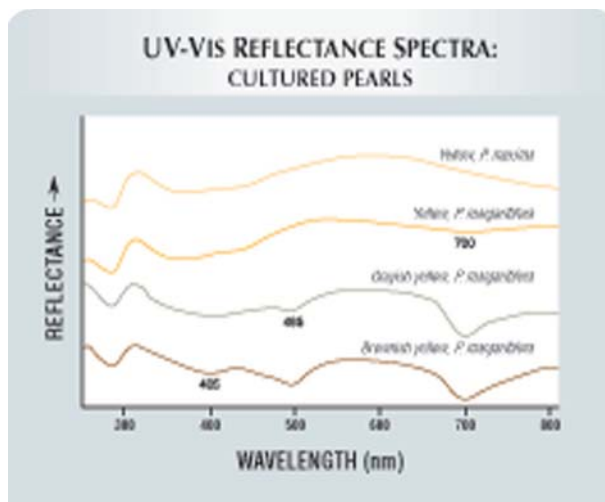


Figure 6. Reflectance spectra for yellow, grayish yellow, and brownish yellow cultured pearls from *P. margaritifera* are compared here with the spectrum for a yellow cultured pearl from *P. maxima*. Note the similarity in absorption features in the UV region between 330 and 460 nm for the “pure” yellow samples, as compared to the grayish and brownish yellow samples. All three *P. margaritifera* samples exhibit the absorption feature at 700 nm, which is absent from the yellow *P. maxima* sample and also the white *P. margaritifera* sample shown in figure 5.

noted between 330 and 700 nm (figures 4 and 5). The black cultured pearls exhibited a characteristic reddish brown fluorescence, and the white samples fluoresced a strong very light yellow.

DISCUSSION

Two distinct reflectance curve patterns were observed for the yellow *P. margaritifera* cultured pearls tested in this study. They are defined by different reflectance characteristics in the ultraviolet-to-blue region of the spectrum (figure 6). The first was typical for the yellow and greenish yellow samples: a broad absorption between 330 and 460 nm that consisted of two absorption features—from 330 to 385 nm and from 385 to 460 nm. The

TABLE 2. Summary of color and absorption features for cultured pearls from the *P. margaritifera* and *P. maxima*.

Species	Color	Presence of absorption features (nm)					
		330–385	385–460	330–430 or 330–460	405	495	700
<i>P. margaritifera</i>	White	No	No	No	No	No	No
<i>P. margaritifera</i>	Yellow and greenish yellow	Yes	Yes	No	No	Frequent	Common
<i>P. margaritifera</i>	Brownish and grayish yellow	No	No	Yes	Yes	Yes	Yes
<i>P. maxima</i>	White	No	No	No	No	No	No
<i>P. maxima</i>	Yellow	Yes	Yes	No	No	No	No

second distinct pattern was exhibited by samples with a grayish or brownish yellow color: a single broad absorption feature from 330 to 430 nm, with a maximum centered at 405 nm. A third pattern showed a single broad absorption from 330 to 460 nm, also with a maximum centered at 405 nm, but it appears to be an intermediate pattern between the other two (figure 6).

The two features between 330 and 460 nm observed in 17 of the *P. margaritifera* yellow cultured pearls and yellow shell material are consistent with similar absorption features observed in *P. maxima* natural-color yellow cultured pearls and yellow nacre (figures 4 and 6) as part of a previous study (Elen, 2001). Specifically, the 330–385 nm feature was found in natural-color yellow—but not treated-color yellow—cultured pearls from the *P. maxima*. It appears likely that the same zochrome (a naturally occurring pigment molecule found in the animal kingdom; Needham, 1974) may be responsible for the yellow coloration in both the *P. margaritifera* and *P. maxima*. Therefore, the presence of this UV absorption feature in the spectra of yellow pearls from the *P. margaritifera* should indicate natural yellow coloration. Approximately one-third of the yellow *P. margaritifera* cultured pearls tested did not exhibit this feature; however, these samples tended to be brownish or grayish yellow rather than “pure” yellow or greenish yellow (figure 6).

The fact that two very light yellow *P. margaritifera* samples—one nacre and one cultured pearl—did not exhibit an absorption feature at 700 nm indicates that some yellow cultured pearls from this oyster do not show this feature. If this absorption is due to black pigmentation, as claimed in the literature, then its appearance in the (darker) medium yellow shell sample is not entirely unexpected. In the nacre samples tested, the yellow coloration lies between the white and black nacre layers, but is not defined by a distinct boundary. The light yellow region occurs closer to the white layer, and the medium yellow region is closer to the black layer. It is, therefore, very likely that the medium yellow nacre sample incorporated some black pigmentation, which may be responsible for the 700 nm absorption. This is contradicted somewhat by the fact that some of the light yellow cultured pearls tested exhibited quite strong 700 nm absorption features. Further work is required to determine the pigments responsible for the yellow and black coloration and, especially, whether the absorption at

700 nm is directly or indirectly associated with either of these pigments.

The combination of yellow and black nacre also may be responsible for producing a dark greenish black—rather than black—nacre at the periphery of the shell in some *P. margaritifera*.

A review of the data collected for yellow *P. maxima* cultured pearls in a previous study (Elen, 2001) shows that about 20% of those samples exhibited a very broad absorption feature with a maximum occurring either at 695 or 720 nm (figure 4). This absorption is extremely broad, unlike the 700 nm feature observed in the *P. margaritifera* samples (figure 4 inset and 6). The fluorescence observed for the yellow, orangy yellow, and greenish yellow *P. maxima* samples in that same study is similar to the reaction seen in the present study for *P. margaritifera* samples of similar color. It would appear that fluorescence criteria used in the previous study for separating natural- from treated-color *P. maxima* cultured pearls also might be applicable to *P. margaritifera* samples in this hue range.

CONCLUSIONS

The UV-Vis reflectance spectrum of a yellow cultured pearl can establish that it was produced by a *P. margaritifera* oyster and, in conjunction with fluorescence reactions, indicate whether the color is natural or was produced by treatment. Specifically, those yellow cultured pearls that exhibit an absorption feature at 700 nm, often accompanied by one at 495 nm, can be positively identified as originating from the *P. margaritifera* (see table 2, for a comparison to cultured pearls from *P. maxima*). However, the absence of these features does not necessarily exclude *P. margaritifera* as the source. Another absorption feature in the UV region, between 330 and 385 nm—when accompanied by light yellow, greenish yellow, greenish brown, or light brown long-wave UV fluorescence—is also indicative of natural yellow coloration.

The feature at 700 nm has been reported previously as evidence of natural color in natural or cultured gray to black pearls from the *P. margaritifera*. However, there is always the possibility that an off-color gray or yellow *P. margaritifera* cultured pearl might be treated to produce a black color. Therefore, in the absence of other tests, the presence of an absorption at 700 nm should be used only to provide proof of origin from the *P. margaritifera*, and not as proof of natural black color.

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SERENDIBITE FROM SRI LANKA

By Karl Schmetzer, George Bosshart, Heinz-Jürgen Bernhardt,
Edward J. Gübelin, and Christopher P. Smith

Two samples of faceted serendibite, a boron-bearing mineral that is only rarely found in gem quality, are described. These samples reportedly were cut from rough discovered in secondary deposits of the Ratnapura area in Sri Lanka. The bluish green to green-blue gems are similar in color, physical and optical properties, and chemical composition to low-iron-bearing non-gem-quality serendibite from various occurrences. These gems may be confused with sapphirine and zoisite, but can be identified as serendibite on the basis of refractive indices, twinning, and spectroscopic features.

Sri Lanka, which for centuries has supplied the gem market with a large number and wide variety of gemstones, has in recent years been overshadowed by the discovery of comparably propitious gem deposits in East Africa and Madagascar. Nevertheless, during the second half of the 20th century, Sri Lanka yielded rare gem varieties of minerals such as dumortierite, ekanite, sinhalite, and taaffeite. In the 1990s, yet another new gem variety was recovered in Sri Lanka, of the mineral serendibite. Although the mineral serendibite was first described in 1903, also from Sri Lanka, not until 1997 was the first report of a gem-quality sample published (Reinitz and Johnson, 1997).

Serendibite derives from the old Arab name for Sri Lanka—Serendib—in recognition of this country as the type locality for this mineral. The first description of the mineral serendibite was published in 1903 by Prior and Coomaraswamy for the boron-bearing Ca-Mg-Al-silicate that was discovered in a contact zone between granulite and limestone at Gangapitiya, near Ambakotte, about 20 km (12 miles) east of Kandy. This first description, however, was the only publication about this mineral from a primary (as opposed to secondary) deposit in Sri Lanka. The discovery of gem-quality serendibite

from secondary deposits in the Ratnapura area in the second half of the 1990s increases the number of gems containing essential boron from this island (tourmaline, dumortierite, boron-rich korerupine [or prismaticine, according to recent mineralogical studies], and sinhalite).

To date, serendibite has been reported from 11 localities: Sri Lanka (type locality near Kandy), United States (three occurrences), Russia (two occurrences), Ukraine, Tanzania, Canada, and Madagascar (two localities). At all of these localities, serendibite occurs in metasomatic high-temperature calc-silicate rocks (skarns), mostly of granulite facies (Grew et al., 1990, 1991a,b; Grew, 1996). The occurrence of gem-quality serendibite crystals in secondary deposits near Ratnapura, Sri Lanka, is consistent with the derivation of these gem gravels from granulite-facies metamorphic rocks. According to modern mineralogical examination (see, e.g., Kunzman, 1999), serendibite is a triclinic Ca-Mg-Al-B-silicate which can also contain distinct amounts of Fe^{2+} and Fe^{3+} .

Since 1997, gemologist and gem dealer D. Palitha Gunasekera of Ratnapura has reported encountering three gem-quality samples of serendibite, weighing 0.35, 0.55, and 0.56 ct as faceted stones (pers. comm., 1997–2001). A merchant in Kolonne showed him the first (smallest) sample as a 1.25 ct pebble. This rough sample was said to originate from Ginigalgoda, near Kolonne in the Ratnapura district. Mr. Gunasekera submitted the 0.35 ct stone faceted from this piece of rough (figure 1) to the GIA Gem Trade Laboratory for identification in autumn of 1996 (Reinitz and Johnson, 1997). It was subsequently purchased by one of the present authors (EG) and identified independently as serendibite by KS in 1997, also using X-ray powder diffraction. A review

See end of article for About the Authors and Acknowledgments.
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Figure 1. These two stones, both from Sri Lanka, are the first faceted serendibites recorded in the gemological literature. The sample on the left weighs 0.35 ct and the one on the right weighs 0.55 ct.

of the literature did not turn up any other references to gem-quality serendibite.

Subsequent to the identification of the 0.35 ct sample, Mr. Gunasekera found what he believed to be a second—0.55 ct—sample in a mixed parcel of unidentified faceted stones in his possession. This stone (again, see figure 1) was purchased by the same author (EG) and identified as serendibite on the basis of the properties gathered for the 0.35 ct sample. Mr. Gunasekera reported that a third serendibite recently was found at Mudunkotuwa in the Ratnapura district. The 1.24 ct pebble was sold to another gem merchant, who cut a 0.56 ct. faceted stone from it (D. P. Gunasekera, pers. comm., 2001). We were not able to obtain this stone for identification or examination as part of this study.

In view of this gemstone's rarity, the authors took the opportunity to perform a detailed gemological, chemical, and spectroscopic study of the first two available faceted samples.

MATERIALS AND METHODS

In addition to the 0.35 ct and 0.55 ct faceted gemstones from Sri Lanka (see again figure 1), we obtained four polycrystalline, non-gem-quality serendibite samples in rock matrix from Johnsbury, Warren County, New York, for comparison (we were not able to obtain any nongem samples from Sri Lanka). This second reported serendibite locality was described in 1932 by Larsen and Schaller and studied later by various authors (e.g., Schaller and Hildebrand, 1955; Grew et al., 1991a, 1992). Subsequent to visual inspection, we obtained the X-ray powder diffraction patterns of two small powdered

Johnsbury samples using a Gandolfi camera. These X-ray data were compared with the diffraction pattern of the 0.35 ct sample obtained by the same technique.

The two faceted serendibites were tested by standard gemological methods for refractive indices, fluorescence to long- and short-wave ultraviolet radiation, and specific gravity. The optic character was determined by observation of the optic axis figure with and without the addition of a gypsum plate. We used standard microscopic techniques to examine the internal features under different lighting conditions, both with and without immersion liquids. Both stones also were examined with a desk-model spectroscope.

Qualitative chemical data were obtained by energy-dispersive X-ray fluorescence (EDXRF) spectroscopy using a Tracor Northern Spectrace 5000 system. To determine the quantitative chemical composition, we used a Cameca Camebax SX 50 electron microprobe with traverses of 9 point analyses each, measured across the tables of the faceted stones.

Polarized ultraviolet-visible-near infrared (UV-Vis-NIR, 300–2500 nm) absorption spectra were recorded using a Perkin Elmer Lambda 19 dual-beam spectrophotometer. Because of the small size and twinning of the faceted serendibites, as well as the unknown orientation of their optic axes, we were unable to obtain exactly oriented, polarized spectra in all three axial directions. Thus, two polarized spectra for each sample were taken with the incident beam traversing the stones through a crown facet and opposite pavilion facet, selected so that rotating the polarizer yielded maximum pleochroism. A third spectrum was obtained perpendicular to the direction of maximum pleochroism. In addition, colorimetric data were collected on the basis of non-polarized spectra taken in the 380–760 nm range with a Zeiss MCS 311 multi-channel color spectrometer.

Infrared spectroscopy in the 7000–2000 cm^{-1} range was performed in transmission mode using a Pye Unicam 9624 Fourier Transform infrared (FTIR) spectrometer and a DRIFTS (beam collector) unit, with different orientations of the faceted samples. Furthermore, minute amounts of powder were scraped off the girdle of both gem-quality serendibite specimens. These microsamples were used to prepare 3-mm-diameter KBr pellets (approximately 0.3 wt.% serendibite powder) for infrared spectroscopy in the mid-infrared range (2000–400 cm^{-1}).

Raman and photoluminescence spectra were

obtained with a Renishaw 2000 Raman microspectrometer equipped with a He/Cd laser (excitation in the ultraviolet region at 324.98 nm) and an Ar-ion laser (excitation in the green region at 514.5 nm). Since we were not able to obtain oriented Raman and photoluminescence spectra, we did take measurements on several facets to examine the orientation dependency of the Raman and photoluminescence signals. To obtain any Raman bands, we had to use high integration times per scan sequence.

RESULTS

The X-ray diffraction pattern of the 0.35 ct faceted Sri Lankan stone was identical to those of the Johnsbury nongem serendibites. The gemological properties of the two cut stones are listed in table 1 and discussed below.

Gemological Properties. The 0.35 ct serendibite was bluish green and the 0.55 ct specimen was green-blue (figure 1). Both samples were transparent and only slightly included. The dominant wavelengths derived with the Zeiss color spectrometer were 494.8 nm and 489.6 nm, respectively.

Although we were unable to determine the exact orientation of the optic axes relative to the table facets, it was evident from the color and the strong pleochroism of both specimens that their cuts were

TABLE 1. Gemological properties of two gem-quality serendibites from Sri Lanka.

Property	0.35 ct	0.55 ct
Size	4.42 × 3.80 × 2.80 mm	4.98 × 4.95 × 2.72 mm
Color	Bluish green	Green-blue
Pleochroism	Strong: Light yellowish green Bluish green Violetish blue	Strong: Light yellowish green Bluish green Violetish blue
Clarity	Transparent	Transparent
Refractive indices		
n_x	1.696	1.697
n_y	1.699	1.700
n_z	1.701	1.702
Birefringence	0.005	0.005
Optic character	Biaxial negative	Biaxial negative
Specific gravity	3.43	3.44
UV fluorescence		
Long-wave	Inert	Inert
Short-wave	Inert	Inert
Microscopic features	Isolated twin lamellae, partially healed fissure, fracture, tiny mineral inclusions	Polysynthetic twinning

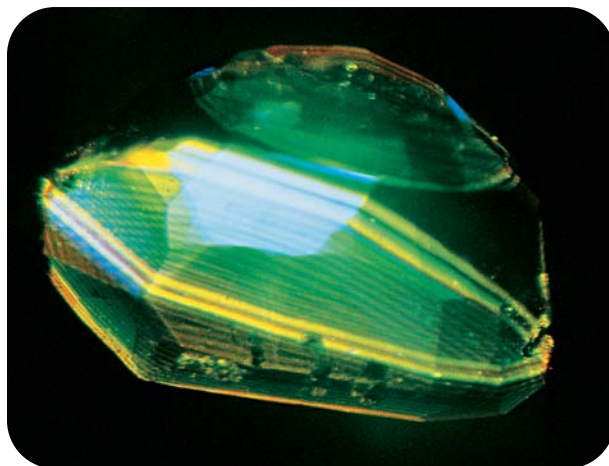


Figure 2. Both faceted serendibites showed evidence of twinning. At 20× magnification, the 0.55 ct sample reveals two polysynthetically twinned areas within untwinned regions. Immersion, crossed polarizers.

oriented differently. In the 0.35 ct sample, the strongest pleochroism—light yellowish green to violetish blue—was evident in the direction parallel to the table facet. In the 0.55 ct sample, the strongest pleochroism—also light yellowish green to violetish blue—was evident in a direction perpendicular to the table facet. The third pleochroic color, observed perpendicular to the directions of the strongest pleochroism, was bluish green for both samples. Refractive indices and specific gravities are summarized in table 1. The samples were inert to both long- and short-wave UV radiation.

Features Observed with the Microscope. Both samples showed various forms of twinning. The smaller stone contained several isolated small parallel twin lamellae; the larger had two areas with polysynthetic twinning as well as areas free of twinning (figure 2). In the 0.35 ct sample, both a partially healed fissure and a nonhealed fracture were encountered. Small colorless mineral inclusions also were detected in this sample. These inclusions, however, were too small for identification with Raman analysis.

Chemical Composition. EDXRF analysis revealed the main components of serendibite (Mg, Ca, Al, and Si), minor amounts of Na and Fe, and traces of P, K, Ti, V, Cr, Mn, and Ga. The electron microprobe results are given in table 2; no obvious chemical zoning was observed in either sample. The chemical composition of these gem-quality serendibites is similar to the composition of sodium-bearing, low-iron serendibite from Johnsbury, New York (see table 2).

Spectroscopic Properties. *UV-Vis-NIR Spectroscopy.* Both samples revealed a broad, distinctly polarized absorption band in the 600–800 nm range (figure 3). This band was centered at about 720 or 700 nm for the directions of the violetish blue and bluish green pleochroic colors. A weaker band in the 800–900 nm range with a maximum at about 850 nm (not shown on figure 3) was measured for the direction of the yellowish-green coloration. The

TABLE 2. Chemical composition of gem-quality serendibite from Sri Lanka, compared to non-gem-quality serendibite from Johnsburg, New York.

Composition	Sample		
	0.35 ct ^a	0.55 ct ^a	Johnsburg ^b
Oxides (wt.%)			
SiO ₂	27.18	26.56	25.95
TiO ₂	0.02	0.03	0.08
Al ₂ O ₃	34.82	34.24	35.31
B ₂ O ₃	7.63 ^c	7.55 ^c	7.64
Fe ₂ O ₃ ^d	0.84	1.07	nd
Cr ₂ O ₃	0.01	0.02	nd
V ₂ O ₃	0.02	0.02	nd
MnO	0.02	0.03	0.03
MgO	15.43	15.57	15.78
CaO	13.68	13.79	12.95
Na ₂ O	1.20	1.23	1.25
K ₂ O	0.10	0.01	nd
P ₂ O ₅	0.03	0.02	nd
Total	100.98	100.14	99.98
Cations per 20 oxygens			
Si	3.096	3.058	2.989
B	1.500 ^e	1.500 ^e	1.520
Al	1.401	1.440	1.491
P	0.003	0.002	nd
Sum Z	6.000	6.000	6.000
Al	3.272	3.205	3.302
Fe	0.072	0.093	0.081
Cr	0.001	0.002	nd
V	0.002	0.002	nd
Ti	0.002	0.003	0.007
Mg	2.620	2.672	2.709
Mn	0.002	0.003	0.003
Sum Y	5.971	5.980	6.117 ^f
Ca	1.669	1.701	1.598
Na	0.265	0.275	0.279
K	0.015	0.002	nd
Sum X	1.949	1.978	1.877

^aElectron microprobe analyses, average of 9 analyses each.

^bElectron microprobe analyses (and ion microprobe analyses for B₂O₃) from Grew et al. (1991a). The sample also contained traces of Li, Be, and F; nd = not determined.

^cCalculated from B = 1.500.

^dTotal iron calculated to Fe₂O₃.

^eAccording to the theoretical formula, Ca₂(Mg₃Al₃)(Al_{1.5}Si₃B_{1.5})O₂₀.

^fAlso contains traces of Li and Be.

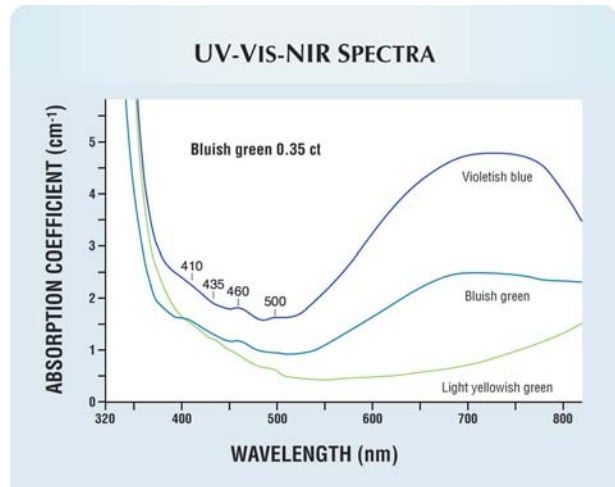


Figure 3. These polarized UV-Vis-NIR absorption spectra for the 0.35 ct serendibite show strongly polarized absorption bands in the 600–800 nm range that are responsible for the pleochroism. Weak absorption bands also are present between 400 and 600 nm. The absorption coefficient is approximate.

strong polarization of this band is almost exclusively responsible for the distinct pleochroism of the serendibites. In one specific orientation of the polarizer, the strong band in the 600–800 nm range split into two maxima at about 660 and 740 nm, possibly due to interference with twin plane reflections. A number of weak to very weak bands also were found in the 400–600 nm range in both samples, with maxima at approximately 410, 435, 460, and 500 nm. The 460 and 500 nm lines were visible with the desk-model spectroscope.

Infrared Spectroscopy. Both faceted samples showed several absorption bands in the 3700–3200 cm⁻¹ and 2800–2500 cm⁻¹ areas and an absorption edge at about 2200 cm⁻¹, as indicated on figure 4A. The strengths and positions of these absorption bands in our nonpolarized spectra varied only slightly for different IR beam traverses through the samples. The weak bands at 3695 and 3620 cm⁻¹ in the spectrum of the 0.35 ct sample were not observed in the 0.55 ct sample. Thus, they might be caused by the minute inclusions observed only in that sample.

The mid-infrared spectra for the powder microsamples of both specimens (figure 4B) revealed virtually identical absorption spectra. The 0.35 ct sample exhibited major bands at 975, 811, 608, 537, and 489 cm⁻¹. The 0.55 ct sample yielded a set of slightly shifted major bands at 965, 807, 608, 537, and 484 cm⁻¹. Other, minor bands would require reconfirmation by spectra of additional microsamples.

INFRARED SPECTRA

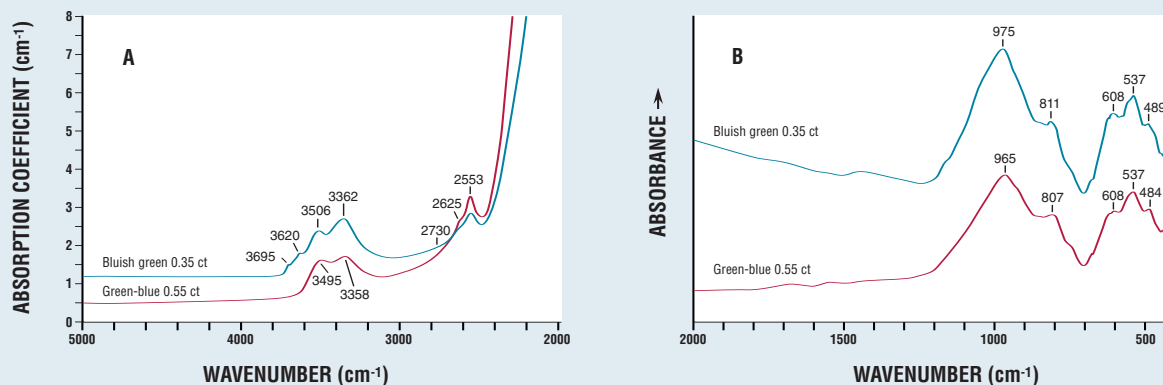


Figure 4. In part A, the infrared spectra of the two gem serendibite samples are shown in the $5000\text{--}2000\text{ cm}^{-1}$ range. The major bands are found in the $3700\text{--}3200$ as well as in the $2800\text{--}2500\text{ cm}^{-1}$ range. The weak bands of the 0.35 ct sample at 3695 and 3620 cm^{-1} are probably due to minute mineral inclusions. The absorption coefficient is approximate. Part B shows the mid-infrared spectra of KBr pellets containing minute amounts of serendibite powder, with the KBr absorption subtracted. The main serendibite absorption bands are in the $1200\text{--}700\text{ cm}^{-1}$ and $700\text{--}400\text{ cm}^{-1}$ ranges.

Raman and Photoluminescence Spectroscopy. We noted no significant differences in the intensities of the weak Raman bands, and only small differences in the intensities of photoluminescence bands (which actually is not typical for anisotropic minerals), when we tested the samples in different orientations. A series of faint, broad Raman bands recorded at ambient temperature with the Ar-ion laser are illustrated in figure 5. As a result of the low intensity of these bands, it is not appropriate to discuss them in further detail.

Although the Raman signals were of low intensity, a series of dominant photoluminescence (PL) bands were present in the spectra taken with both lasers. With the He/Cd laser, we recorded a series of PL bands positioned at approximately 1500 , 2770 , and 3870 cm^{-1} Raman shift (calculated to about 340 , 357 , and 370 nm ; figure 6A). The Ar-ion laser exhibited an even more intense series of PL bands positioned at 4970 , 5005 , and 5435 cm^{-1} Raman shift (calculated to 690 , 693 , and 715 nm accordingly; figure 6B).

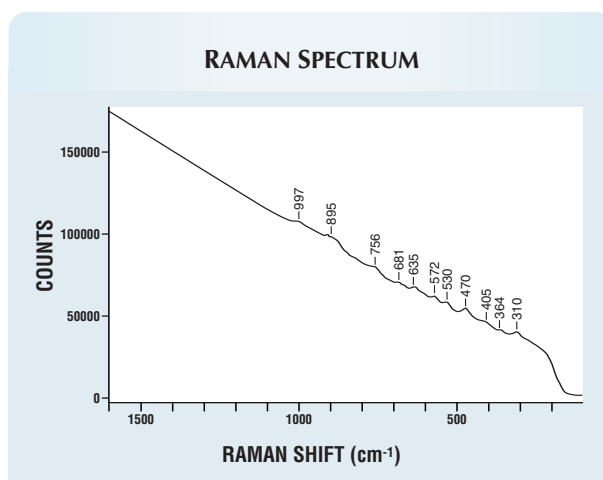
DISCUSSION

Gem-quality serendibite from Sri Lanka is similar in composition to low-iron-bearing serendibite from Johnsbury, New York, which also contains small but distinct amounts of sodium replacing part of the calcium in the idealized formula (table 2). The color

of our Johnsbury serendibite samples resembles that of the gem material as well.

The physical and optical properties of these two gem serendibites from the Ratnapura area (table 1) are in the range of those of low-iron-bearing serendibites, such as from Johnsbury and Russell, New York (Larsen and Schaller, 1932; Grew et al., 1990, 1991a) or from Melville Peninsula, District of Franklin, Canada (Hutcheon et al., 1977). In detail, the refractive indices of the gemstones are somewhat lower

Figure 5. The Raman spectrum of the 0.55 ct serendibite reveals several weak bands in the 1000 to 300 cm^{-1} range.



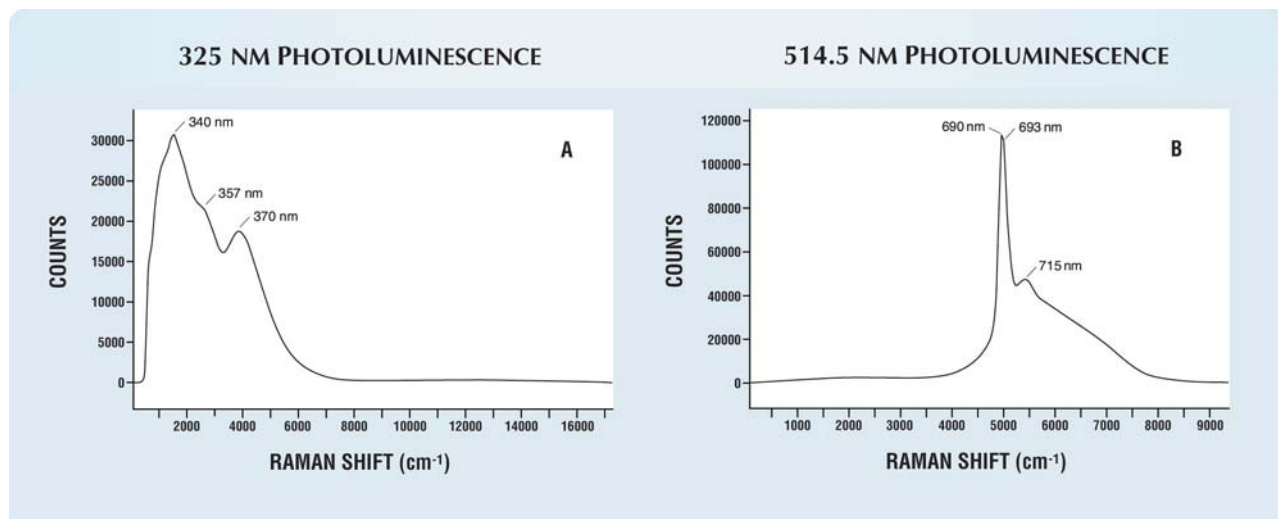


Figure 6. (A) This 325 nm photoluminescence spectrum of the 0.55 ct serendibite reveals a series of PL bands at 340, 357, and 370 nm. (B) The 514.5 nm photoluminescence spectrum of this sample shows PL features at 690, 693, and 715 nm.

than the optical properties of low iron-bearing serendibites, such as from Johnsbury, New York (2.76 wt.% FeO, $n_x = 1.701$, $n_y = 1.703$, $n_z = 1.706$; Larsen and Schaller, 1932) or from Melville Peninsula, Canada (3.48 wt.% FeO, $n_x = 1.700$, $n_y = 1.703$, $n_z = 1.706$, Hutcheon et al., 1977). This undoubtedly is due to the somewhat lower iron contents of the Sri Lankan material. We believe these are the lowest refractive indices reported thus far for any serendibite. Small discrepancies in the properties reported by Reinitz and Johnson (1997) on the 0.35 ct sample are most probably due to differences in the instrumentation used.

Serendibite is triclinic and belongs to the aenigmatite-rhönite group, which has a general formula of $X_2Y_6Z_6O_{20}$. Kunzmann (1999) provides the structural formula of serendibite as $Ca_2(Mg_3Al_3)(Al_{1.5}Si_3B_{1.5})O_{20}$, with (Mg_3Al_3) in octahedral sites and $(Al_{1.5}Si_3B_{1.5})$ in tetrahedral sites. In general, some Fe^{2+} substitutes for part of the Mg and some Fe^{3+} replaces part of the Al. An isomorphous replacement between sodium and calcium, coupled with replacement of magnesium by aluminum and aluminum by silicon, is also observed (see also Machin and Süsse, 1974; Grew et al., 1991a,b; Van Derveer et al., 1993; Burt, 1994). Calculating the cations of our analyses according to the chemical formula of serendibite, that is, with 20 oxygen and 1.5 boron atoms per formula unit, shows that our data are consistent with this formula (table 2).

The absorption bands measured in the visible and near-infrared are probably caused by Fe^{2+} and/or Fe^{3+} replacing Mg or Al in octahedral sites of the serendibite structure. A detailed assignment of all

absorption bands, however, is not possible without further research, such as with Mössbauer spectroscopy. The strong photoluminescence in the red region observed with the Ar-ion laser is found in the range typical for spin-forbidden Cr^{3+} absorption and emission lines. Thus, the small chromium contents found by X-ray fluorescence and microprobe analysis might be responsible for these lines.

Two gem minerals that are found occasionally with similar color and almost identical properties—such as refractive indices, birefringence, and specific gravity—might be mistaken as serendibite, namely, sapphire and zoisite. The distinction from sapphire—at least for the low-iron-bearing serendibites known to date in gem quality—can be made by careful measurement of refractive indices. Although the birefringence may be identical for sapphire and serendibite, the refractive indices for sapphire are always slightly above 1.700 (Fryer, 1985; Kane, 1987). Note, though, that higher iron contents in serendibite may cause misleading R.I. values. In such a case, identification would require additional examination with microscopy or spectroscopy.

The optical properties and specific gravity of serendibite and zoisite, on the other hand, show a complete overlap. The color of the rare chromium- and even rarer vanadium-and-chromium-bearing varieties of zoisite from Tanzania (Schmetzer and Bank, 1979; Barot and Boehm, 1992) may also be quite similar to that of serendibite. Again, a distinction may be made on the basis of the lamellar or polysynthetic twinning of serendibite, which was

also reported as a typical property of non-gem-quality serendibite samples from various localities. However, spectroscopic features as described for the UV-Vis-NIR and infrared ranges, as well as Raman and photoluminescence data, are considerably more reliable for the identification of suspected serendibite gems than the standard gemological properties cited above.

CONCLUSION

The rare gem material serendibite is characterized with regard to gemological, chemical, and spectroscopic properties. Gemological properties, such as refractive indices, are related to the very low iron contents of the samples, as shown by microprobe analysis. Serendibite might be confused with sapphirine or zoisite, but refractive indices, twinning, and spectra can be used to separate these gem materials

ABOUT THE AUTHORS

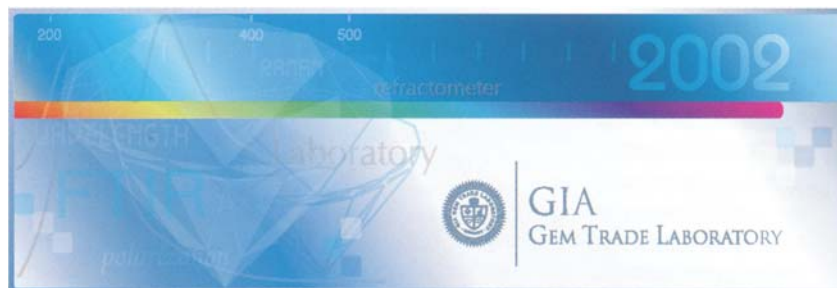
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Gem Trade LAB NOTES



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DIAMOND

Color Grade vs. Value for Fancy Colors

When determining the value of a polished diamond, the standard practice is to place the various factors (i.e., the four Cs) on a scale. In most instances, one thinks of a scale as progressing linearly from one point to another. While subtle variations from this concept exist in grading diamonds in the D–Z range, GIA's color-grading scale for fancy-color diamonds is actually three-dimensional: It places the diamond within a range of combined tones and saturations so as to provide a general understanding of its appearance in relationship to that of other fancy-color diamonds. Typically, such

diamonds placed in ranges representing stronger color are more highly valued in the trade. However, since there is more than one grading category for fancy-color diamonds with substantial color, questions have been raised as to which of these grades is most "valuable."

In 1995, GIA introduced enhancements to its system for color grading colored diamonds (see J. King et al., "Color grading of colored diamonds in the GIA Gem Trade Laboratory," Winter 1994 *Gems & Gemology*, pp. 220–242). Since then, clients frequently have asked whether a Fancy Intense (a bright, strong color) is "better" than a Fancy Deep (a deep, rich color) or vice versa. The two blue diamonds in figure 1 illustrate the complexity of

this issue. The diamond on the left is in the range described as Fancy Intense, whereas the one on the right is described as Fancy Deep. In our system, we describe these two grades as having similar strength of color and varying only in tone (lightness to darkness). *Fancy Intense* describes colors that are moderate to light in tone and moderate to strong in saturation, whereas *Fancy Deep* describes colors that are moderate to dark in tone and moderate to strong in saturation. To say one is "better" or "worse" is a matter of personal preference. Such an example supports the importance of judging each colored diamond on its visual merits and not solely on its color grade.

John M. King

Figure 1. Fancy-color grades describe ranges of tone and saturation associated with the overall face-up appearance of the diamond. The 2.18 ct emerald cut on the left was graded Fancy Intense blue, whereas the 2.47 ct diamond on the right was graded Fancy Deep blue. The saturated color appearance of both diamonds makes it difficult to justify objectively valuing one of these grades more than the other.



With Eclogitic Inclusions

While examining a 1.55 ct oval diamond, we noticed an unusual inclusion that appeared to be a bicolored, rounded, euhedral crystal. One half of the inclusion was bluish green, and the other half was brownish yellow (figure 2). The two color portions were each analyzed with a laser Raman microspectrometer. The results

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Figure 2. The “bicolored” inclusion in this diamond actually consists of a bluish green omphacitic pyroxene (left) and a brownish yellow almandine-pyrope garnet (right) that are in direct contact. Stress fractures and graphitization developed around the pyroxene, but not the garnet. Magnified 45×.

showed that the bicolored crystal was actually two different minerals: omphacitic pyroxene (bluish green) and almandine-pyrope garnet (brownish yellow). The two minerals evidently grew in close contact, so they had the appearance of a single bicolored crystal.

Raman analyses of additional inclusions in the diamond identified more omphacitic pyroxenes, some in the form of triangular platelets (figure 3). This morphology is rare in diamond, and could be due to xenomorphism in the crystallization process. Additional almandine-pyrope garnet inclusions also were identified. Pyroxene and garnet are the main mineral constituents of eclogite, a rock type that is sometimes diamond bearing and is commonly thought to form during subduction of the earth’s crust into the deep mantle. Also identified was a rutile crystal that was in direct contact with a pyroxene inclusion. Rutile is also common in eclogite, and the occurrence of all three minerals in a single diamond is very uncommon. Further studies of these inclusions could reveal useful infor-

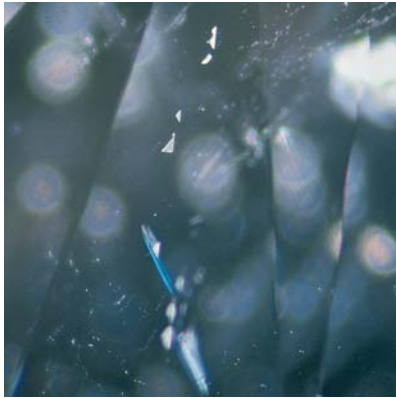
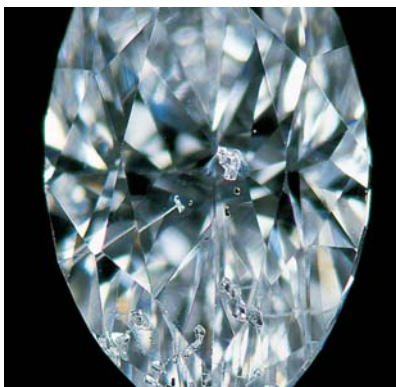


Figure 3. Some of the pyroxene inclusions in the diamond formed triangular platelets, which is unusual. Magnified 63×.

mation about the environment in which the diamond crystallized.

Another interesting feature of this diamond is the fracturing and/or graphitization that developed around the largest pyroxenes. When a diamond forms in the earth’s mantle, the volume of a particular inclusion is the same as the space that it occupies in the diamond. However, during transport of the diamond to the surface, differential expansion between the inclusions and the host diamond occurs in response to decreasing pressure and temperature. Due to this expansion, the volume of the inclu-

Figure 4. This 0.48 ct diamond revealed numerous large, white-appearing inclusions—three with laser drill holes—together with a number of smaller reddish brown crystals.



sions could increase more than the host diamond. If the stress exceeds the tensile strength of diamond, then a fracture/cleavage, and sometimes graphitization, occurs around the inclusion. Pyroxene expands more than garnet as pressure decreases; this explains why the pyroxene inclusions have stress fractures and the garnets do not, even when they are in direct contact (again, see figure 2). The Raman peaks of the garnets were shifted to slightly higher wavelengths compared to garnet at ambient pressure, which indicates that the garnet inclusions were under pressure. However, there was evidently not enough stress exerted on the host diamond to cause it to fracture.

Wuyi Wang and Vincent Cracco

With a Large Void

In March of this year, a 0.48 ct marquise brilliant (figure 4) was submitted to the East Coast lab for a full grading report. With magnification, we observed four large, white-appearing inclusions, three of which had laser drill holes connecting them to the surface. The fourth inclusion (figure 5)

Figure 5. Although initially this large white feature appeared to be a crystal with feathers, it is actually a void that was created when a mineral inclusion was dissolved away. The reddish brown crystals near it were identified as chrome spinel by Raman analysis. Magnified 63×.



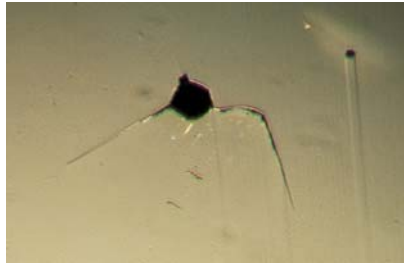


Figure 6. The opening of the void is apparent in reflected light as a dark circular area. Note that the opening is too small for the crystal to have simply fallen out of the diamond. Magnified 63×.

appeared to be surface reaching, with a small portion touching the table facet. In the vicinity of this fourth inclusion were a number of small reddish brown crystals, similar in shape to the much larger inclusions.

What was unusual about this diamond was that the large inclusion touching the surface, after closer scrutiny, turned out to be a void. The apparent contact point at the surface was actually a small opening (figure 6), which enabled us to examine the inside of the larger void. Growth markings on the inside walls suggested that at one time a crystal filled this space. The walls also appeared very clean, with no foreign material present.

Since voids do not occur naturally in diamond, and the opening was too small for a larger crystal to have fallen out, the most logical reason for the unusual feature is that a mineral inclusion was totally dissolved when the diamond was immersed in acid following laser drilling. Vaporization with a laser, another possibility, would have left some residue on the walls, which we did not see. Because the void was of similar shape, and in close proximity, to the smaller reddish brown crystals, one could assume that the original crystal was of the same composition. Laser Raman microspectrometry identified the reddish brown crystals as chrome spinel.

In the trade, hydrochloric and sulfuric acids typically are used on lasered stones. However, these acids

would not be sufficient to dissolve spinel crystals. Perchloric acid could dissolve such inclusions, but it is rarely used because it is extremely dangerous. Aqua regia is another acid used by the trade (Ivan Pearlman, S & I Drilling, pers. comm., 2002); it is composed of one part nitric and three parts hydrochloric acid. This acid mixture would also readily dissolve chrome spinel and, therefore, accomplish the task that the laser operator set out to do: make the dark-appearing inclusions less obvious to improve the apparent clarity of the diamond.

Vincent Cracco and Wuyi Wang

GENTHELVITE: A Second Occurrence

In the Fall 1995 issue of *Gems & Gemology* (pp. 206–207), we reported on what was, to the best of our knowledge, the first example of a faceted, gem-quality genthelvite. The 0.33 ct stone, illustrated in that Gem News entry, was described as purplish red-brown. Genthelvite, $Zn_4Be_3(SiO_4)_3S$, forms a solid-solution series with both danalite and helvite.

It was therefore of great interest when Luciana Barbosa, of the Gemological Center in Belo Horizonte, Brazil, submitted an 8.16 ct emerald cut for identification that she believed

to be genthelvite. Not only would this be significantly larger than the first stone we saw, but it was also an attractive orange-red (figure 7). This gem material is very difficult to identify, because its gemological properties are indistinguishable from those of pyrope-almandine garnet. Accurate identification requires chemical and X-ray diffraction analyses.

The gemological properties of the 8.16 ct stone were almost exactly the same as those obtained on the genthelvite examined in 1995: singly refractive, R.I.—1.742, S.G.—3.67, inert to both long- and short-wave UV radiation, and a visible absorption spectrum matching that of pyrope-almandine garnet. With the microscope, several fractures could be seen along with some angular growth features.

Chemical analysis using energy-dispersive X-ray fluorescence (EDXRF) spectroscopy showed a significant concentration of zinc along with silicon and sulfur, as expected for genthelvite. Also detected were small amounts of iron and manganese. Beryllium and oxygen cannot be detected by this instrument.

This chemical composition, coupled with the X-ray diffraction pattern, proved that this 8.16 ct stone was indeed another genthelvite. *SFM*

Figure 7. This 8.16 ct orange-red emerald cut is only the second example of gem-quality genthelvite that the laboratory has seen.



JADEITE Carving: Assembled, Dyed, and Impregnated

Because of its high desirability in fine qualities, jadeite jade historically has been subjected to many different procedures to improve its appearance. Dyeing has been carried out for centuries. An ingenious method seen in the 1960s involved hollowed-out cabochons that had been “jelly filled” (see M. L. Ehrmann, “A new look in jade,” Spring 1958 *Gems & Gemology*, pp. 134–135, 158). Today, “bleaching” of surface-reaching fractures followed by impregnation, sometimes using a colored substance, is the jadeite treatment seen most frequently in the GIA laboratory.

The carved pendant shown in figure 8 provides a recent example of the



Figure 8. This attractive jadeite carving (37.48 × 15.19 × 11.85 mm) was dyed, impregnated, and assembled.

resourcefulness that goes into enhancing the appearance of jadeite. At first glance, this carving was not particularly suspicious. However, when it was observed with 10× magnification, color concentrations could be seen in very fine surface-reaching fractures. Examination with a desk-model spectroscope revealed the 437 nm band that is indicative of jadeite, as well as a broader band from 630 to 670 nm, which confirmed the presence of dye. When, as has now become routine for jadeite, we checked for impregnation using an infrared spectrometer, the spectrum revealed a band centered at 2900 cm^{-1} , which indicates the presence of a polymer (see E. Fritsch et al., "Identification of bleached and polymer-impregnated jadeite," Fall 1992 *Gems & Gemology*, pp. 176–187). The dye was probably mixed with the polymer before the piece was impregnated.

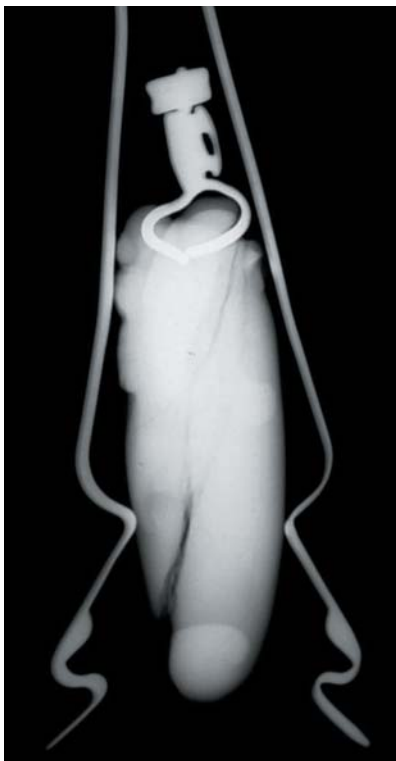


Figure 9. The X-radiograph confirmed that the jadeite carving in figure 8 was assembled, with the joint showing up as a dark diagonal line.

The most notable feature, though, was seen with further microscopic examination: a "seam" following the length of the carving that appeared to be some type of adhesive. When this seam was exposed to long-wave UV radiation, it fluoresced blue, as is characteristic of many epoxies. An X-radiograph (figure 9) revealed a dark line that diagonally traversed the carving, proving that it actually was composed of two pieces. It did not appear to be a repair, but rather a well-executed assemblage.

To confirm that the peaks we observed in the infrared spectra were indeed from the polymer impregnation and not from the "glue" holding the two pieces together, we obtained another spectrum from a carefully isolated area on the bottom of the carving. The result was similar to the first infrared spectrum, thus confirming that the jadeite was impregnated

as well as assembled. Although undoubtedly done to deceive an unwary buyer, this assemblage was very convincing. TM

Coated Natural PEARLS

In March, the West Coast laboratory received an elaborate pair of white metal ear clips that featured what appeared to be brilliant-cut diamonds and two partially drilled oval "pearls" (figure 10) for a pearl identification report. The pearls, which measured approximately 11.5 × 10.5 mm, appeared to be very well matched in size and luster. However, we noticed a few small areas on the backs of both that were slightly rough to the touch.

Closer examination of these areas with strong overhead illumination and 10× magnification revealed a slightly "pitted" surface. Focusing on the most prominent area at higher magnification, we noticed that parts of the top and underlying layers were missing, which was responsible for the pitted—almost cratered—appearance (figure 11). The exposed underlying layers appeared to be semi-translucent and showed the densely packed suture lines that are characteristic of nacre formation. We also noticed a few polishing lines as well as polishing drag lines originating from the rims of the "craters." The top layer was transparent and also showed a few polishing lines. However, we could not resolve any structural characteristics in that layer. This indicated that it was not nacre, but rather a transparent foreign material that had been applied to the surface of the pearls. To determine the stability of this layer, we checked the surface with the tip of a needle. Only after some pressure had been applied did the needle leave a small indentation similar to that typically left on plastic-coated materials.

Previous experience with similar types of coatings has shown that they were stable during routine testing. Therefore, we continued with X-radiography to determine the origin of the pearls. The X-radiographs showed the structural characteristics of natural pearls. On the basis of our exami-



Figure 10. The 11.5 × 10.5 mm pearls in these ear clips proved to be natural, but they had been coated with a transparent plastic-like substance.

nation with magnification and the X-radiographs, we concluded that these were natural pearls that had been coated and subsequently polished. In addition, we were able to measure the thickness of the surface coating with a special table gauge: It averaged approximately 0.1 mm. KNH

Figure 11. At 15× magnification, the pits on the pearls had an almost crater-like appearance. Note the polishing lines extending from the rim of the crater and the apparent transparency of the coating.



Spinel in Heat-Treated Blue SAPPHIRE

The West Coast laboratory recently studied a most unusual heat-treated

Figure 12. Numerous dendritic inclusions of varying size—identified as spinel by Raman analysis—have formed along a parting plane in this blue heat-treated sapphire. Such inclusion patterns could easily be mistaken as evidence of a natural, unheated stone, although they are undoubtedly a result of the treatment process. Magnified 20×.



sapphire. Examination of the 1.04 ct stone with a gemological microscope and a fiber-optic illuminator not only showed evidence typical of heat treatment—such as diffused color zoning, ruptured inclusions, and pits with heat-damaged surfaces—but it also revealed parting planes that were decorated with numerous dendrites of an unknown light-to-dark green material (see figure 12). The grayish green color and transparency were observed only in the larger dendrites. The dendrites showed no pleochroism or birefringence, which suggested that they were singly refractive.

Some of the dendrites had been polished on edge and exposed on the surface during faceting. Laser Raman microspectrometry of one of these very small exposed surfaces revealed that the dendrites were spinel.

This immediately brought to mind the discovery and subsequent analysis in 1989 by Dr. Henry Hänni, director of the SSEF Swiss Gemmological Institute (Basel, Switzerland), of dendritic spinel inclusions in association with a glass component in a heat-treated ruby (“Behandelte Korunde mit glasartigen Füllungen,” *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 35, No. 3/4, 1986, pp. 87–96). Dr. Hänni concluded that these inclusions had resulted from the treatment process. On the basis of that work and our recent discovery of dendritic spinel inclusions in a heat-treated blue sapphire, it appears that we can expect to see these features occasionally in both rubies and sapphires. Since such spinel dendrites are rarely encountered, however, it is important to know of their existence and especially to be able to recognize them as products of heat treatment. They should not be mistaken for, or interpreted as, natural inclusions.

John I. Koivula and Maha Tannous

PHOTO CREDITS

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Vincent Cracco—figures 2, 3, 4, 5, and 6;
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SPECIAL REPORT

A New Corundum Treatment from Thailand. In December 2001, these authors learned of a new type of heat treatment being done in Thailand that purportedly could change the abundant light pink sapphire from Madagascar to a beautiful “padparadscha” color. At the time, treaters said only that the stones were being heated in an oxygen atmosphere and they believed the process was new and revolutionary.

Subsequently, we were told by Ken Scarratt, of the AGTA Gemological Testing Center (AGTA-GTC), and

other colleagues that in addition to the pink Madagascar material, green sapphire from Songea (Tanzania), and even old stocks of Thai ruby were involved. When, in early January, we had our first opportunity to examine some of these stones, it was clear that more than one type of corundum was being treated by this process. By that time, gemologists had noted that many of these stones were different from the heat-treated corundum we typically examine, which gave rise to the belief that there was more to the “heat” treatment than was being disclosed.

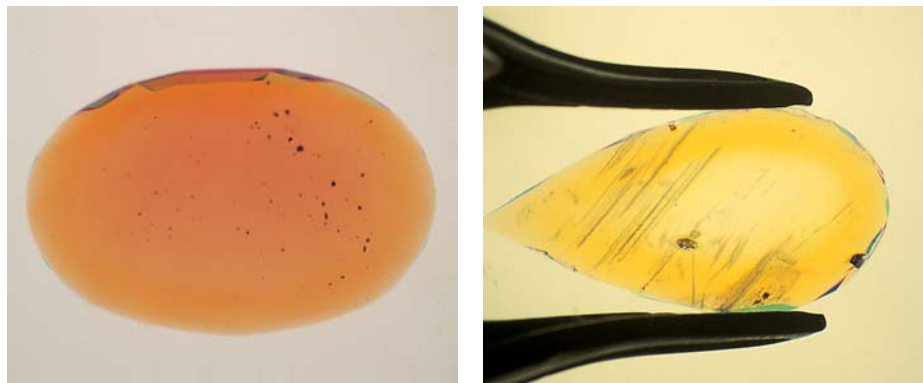
Figure 1. A new corundum treatment is being done in Thailand to produce the colors seen here (0.43–1.09 ct). Although the earliest colors seen from this process were orangy pink to orange and orangy red, more recently we have also seen yellow sapphires. The starting material consists of various colors, including pink, colorless, light green, and dark purple-red. Photo by Maha Tannous.



Examination of Treated Samples. Our initial research involved the examination of 48 stones treated by this purportedly new process. Pala International of Fallbrook, California, kindly loaned GIA 27 of the treated sapphires, all faceted, which they had recently obtained in Thailand. Shortly afterward, we received from D. Swarovski and Co. of Austria an additional 16 treated sapphires—10 faceted and six preforms. They reported that the 10 faceted samples were provided by Metee Jungsangsangsih of World Sapphire in Chanthaburi, Thailand, who (according to Swarovski) is one of the key people involved in this process. At the same time, five corundums that appeared to have been treated in a similar manner were submitted to our New York laboratory for identification. Of these 48 samples, six were orange, 35 were pinkish orange to orangy pink, and seven were orangy red to red-orange (see, e.g., figure 1). The samples ranged from 0.34 to 3.53 ct, with most 1–2 ct. Four of the six orange stones were purported to originate from Songea, while the origin of the orangy red to red-orange stones is unclear at this time. All the other samples were reportedly from Madagascar.

The gemological properties of these stones were, for the most part, typical for corundums of these colors. There were only minor variances from the norm. For example, the orangy red stones had slightly elevated refractive indices (1.766–1.774) and an abnormally strong iron absorp-

Figure 2. Many of the sapphires treated by this new process have surface-related color zoning that is visible when they are immersed in methylene iodide. The 1.55 ct stone on the left shows an orange layer over a pink core. The 1.80 ct stone on the right shows a yellow layer over a near-colorless core. Photomicrographs by Shane F. McClure; magnified 10x.



tion in the desk-model spectroscope. The R.I. measurements were consistent when taken on several facets of the same stone. With magnification, most of the stones showed evidence of high-temperature heat treatment in the form of altered and heat-damaged inclusions. In fact, there was evidence that the temperatures being used were even higher than normal; for example, zircon inclusions, which usually survive the heat treatment process, were destroyed in these samples.

Soon after reports of this new treatment appeared, it was noted that the orange color did not go all the way through many of these stones (see, e.g., Web sites www.agta.org/consumer/gtclab/orangesapphirealert.htm, www.palagems.com/gem_news.htm). Most of our samples also revealed evidence of a surface-related color when they were immersed in methylene iodide and examined over diffused light with a microscope. In fact, 36 of the stones showed a distinct orange color layer following the faceted shape of the stone over a pink central core (see, e.g., figure 2). In many of these, the layer was only near the surface, penetrating just 10%–20% of the stone, with an appearance similar to that produced by diffusion treatment in blue sapphires (see, e.g., R. E. Kane et al., "The identification of blue diffusion-treated sapphires," *Gems & Gemology*, Summer 1990, p. 117—figure 2). In several of the stones, however, the color layer extended deeper than any diffusion treatment we had seen in the past. In fact, in a few samples the layer penetrated more than 50% of the distance to the center of the stone, with one extending approximately 80%. Immersion also showed the presence of small spotty blue zones in the cores of the orangy red to red-orange stones.

Five of the pinkish orange to orangy pink samples displayed uneven coloration, but either did not have a surface-related color zone or the zone was very indistinct. One showed alternating bands of orange and pink in a hexagonal pattern. Another was mostly orange with small areas of yellow.

Only four of the 48 stones, all orange, had the same color throughout. These four were represented as being Songea sapphires that were originally green.

Although the near-surface, facet-related orange layer evident in many of these stones was very similar to the color zoning seen previously in diffusion-treated stones, we

observed none of the other identifying characteristics of diffusion: There was no higher relief in immersion, patchy surface color, or concentration of color at facet junctions.

We performed a quick color stability test on one pinkish orange sample by heating the stone in the flame of an alcohol lamp and then comparing it to a control sample of the same color. We observed no change in the color appearance of the test sample.

Advanced Testing. All the surface diffusion-treated stones we have studied to date have shown an abnormal concentration of the color-producing metallic ion used in the diffusion process, such as titanium or chromium, at or near the surface. With this in mind, we performed energy-dispersive X-ray fluorescence (EDXRF) qualitative chemical analysis on the surface of five of the above samples. Three were preforms that were sawn in half (with the sawn surfaces then polished) and also analyzed by electron microprobe at Rutgers University in New Brunswick, New Jersey. Neither of these techniques revealed the abnormal chemistry that we would expect from diffusion-treated material.

Dr. John Emmett, president of Crystal Chemistry in Brush Prairie, Washington, suggested that very low concentrations of some light elements, such as magnesium, could diffuse easily into corundum at high temperatures and produce this kind of color change. These elements are below the detection limits of the instruments mentioned above, so we turned to two more-sensitive techniques: laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) and secondary ion mass spectrometry (SIMS). For both of these procedures, we started with the three sawn preforms that were used for the microprobe analysis.

LA-ICP-MS, performed at Boston University, revealed

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trace amounts of Mg, Ti, V, Cr, Ni, and Ga that in almost all cases gradually decreased in concentration from the outside rim of the stones to the center. However, none of these elements showed a direct, consistent relationship to the surface-related color zones.

LA-ICP-MS is one of the most sensitive analytical techniques in chemistry, particularly for “heavy” elements (i.e., those with high atomic weights) such as platinum, gold, and uranium. However, it is not always accurate for “light” elements such as lithium, beryllium, and boron.

SIMS analysis is very sensitive to both light *and* heavy trace elements, because the “background” (interference from other charged particles of the same or similar masses) is close to zero. We therefore had SIMS analysis performed at Evans East Analytical Laboratory in East Windsor, New Jersey.

The SIMS results proved quite interesting (table 1). Although some chemical variation from the rim to the center was detected for all the elements analyzed, the most pronounced variation was seen in beryllium. In fact, SIMS consistently recorded 20 to 30 times more Be near the surface than in the center of each of the three samples.

The SIMS results strongly suggest that Be was diffused into the crystal structure of the corundum from the surface. These data also indicate that other elements are enter-

ing the corundum to a lesser degree. The diffusion may be occurring as a collateral effect of the heating process and the “packing chemicals” used, or it may be the result of directly adding a Be feed source during the heating process. Beryllium atoms are relatively light in atomic weight and small in size. Furthermore, although Be can combine with oxygen, it does not do so by forming an anion species—such as $(\text{SiO}_4)^{2-}$ or $(\text{BO}_3)^{3-}$ —which would significantly limit the diffusion speed and thus the diffusion distance within a given time. For these reasons, it is possible for beryllium to migrate readily into the corundum at high temperatures. It should be noted, however, that we do not know of any instance where Be is a chromophore in corundum or any other gem material. The presence of Be may simply be an indication of a more complex chemical reaction that is taking place to cause the change in color.

Recent Developments. These results, most of which were published in the January 28 and February 15, 2002, issues of the biweekly *GIA Insider* (see www.gia.edu/news/ViewIssue.cfm?volume=4&issue=5#2), prompted two of the authors (SFM and TM) and Ken Scarratt of the AGTA-GTC to travel to Bangkok in early March. With the cooperation of the Thai Gem & Jewellery Traders Association, we held several discussions with dealers and

TABLE 1. Summary of trace-element composition analyzed using SIMS (in ppm weight).^a

Material	Sample no.	Color	Position	Na	Mg	K	Ca	Cr	Ga	Be
Corundum	39402	Orange	Rim	0.04	132	0.05	1.55	975	89.8	276
		Pink	Midpoint	0.06	128	0.04	1.26	797	59.7	26.4
		Pink	Center	0.04	92.0	0.02	0.81	664	49.9	26.9
	39403	Orange	Rim	0.63	154	0.66	8.36	373	144	462
		Pink-orange	Midpoint	0.39	96.5	0.32	1.38	242	77.0	107
		Pink	Center	0.28	83.7	0.26	2.09	206	59.0	27.8
	39404	Orange	Rim	3.46	146	4.24	7.98	697	137	452
		Pink	Midpoint	0.84	97.8	1.35	1.90	473	95.1	26.2
		Pink	Center	0.59	72.3	0.74	1.18	333	57.2	26.8
	45002	Orange	Rim	0.60	151	0.91	1.86	1122	125	229
	45031	Pink (untreated half)	Rim	0.04	125	0.04	1.22	744	77.4	22.8
			Center	0.75	215	0.40	2.71	2136	143	479
	45082	Pink	Rim	8.79	181	5.78	2.30	1814	93.8	31.5
			Center	0.58	106	1.18	2.18	1705	123	291
	45032	Orange	Rim	1.80	96.6	4.75	1.50	1363	82.9	466
Center			0.24	93.3	0.27	1.10	1798	66.5	36	
45033	Orangy red	Rim	0.31	90.9	0.35	0.95	1809	64.6	313	
		Center	4.20	28.6	6.07	0.96	14.4	181	402	
45035	Yellow	Rim	1.05	36.6	1.66	0.69	13.2	197	458	
		Center	66.9	944	3.33	675	289	83.8	4610	
Crucible	45100	—	Inner surface	117	2217	9.71	702	138	75.9	3875
		—	Outer surface							

^a The elements Na, Mg, K, Ca, Cr, and Ga were quantified using ion-implanted reference materials and their concentrations should be accurate within $\pm 25\%$ (1σ). Beryllium was quantified using calculated relative sensitivity factors, and its concentration should be accurate within $\pm 200\%$ (1σ). An ion-implanted Be standard has recently been created to increase the accuracy of these data.

treaters from Bangkok and Chanthaburi, and obtained dozens of additional samples.

As of mid-April, we had performed SIMS analyses on seven additional samples (see, e.g., table 1). (For details on the characteristics of these samples, see the *GIA Insider*, April 19: www.gia.edu/news/ViewIssue.cfm?volume=4&issue=9.) With one exception, all of the treated corundums had elevated Be levels. The one exception was a blue stone with no surface-related color zoning. We had this blue stone tested because it was represented as having been heated in the same crucible as stones that developed a surface-related color zone. SIMS revealed very little Be in either the rim or the core. Most significant were the analyses of two halves of a single stone, only one of which was treated by this new method (figure 3). The SIMS results showed approximately 10 times more Be in the treated half than in the untreated half. Greater amounts of Na, Mg, K, Ca, Cr, and Ga were also present in the treated portion, although the increases over the concentrations recorded in the untreated half were not as significant.

In an attempt to track down the source of the beryllium, we obtained SIMS analyses on a fragment of a ceramic crucible that was used to hold stones that were treated by this new method. Compared to the sapphires, the crucible showed much higher concentrations of Na, Mg, K, Ca, and in particular, Be (~4,000 ppm). In fact, the Be concentration of the crucible was approximately 10 times higher than the highest concentration detected in the treated sapphires. We are currently trying to acquire an unused crucible to see if the Be is inherent to the crucible.

In Bangkok, we learned that many different colors of sapphire, including blue, can be treated by this new method in the same crucible at the same time, and a variety of different colors will be produced. Some of these stones will develop surface-related color zones, others will develop a new color throughout the entire stone, and still others will not change at all. Although we do not fully understand the reason for this, we suspect it is related to the variable chemistry of the individual stones. The fact that many colors can be produced in the same crucible seems to be the underlying reason why those performing this treatment feel it cannot be a diffusion treatment as they know it: When they intentionally do "diffusion treatment," all of the stones in one crucible would emerge as basically the same color.

Discussion and Conclusion. Although we do know that high temperatures are involved, currently we do not know the exact treatment method(s) being used. However, the fact that the coloration may not extend through the entire stone is a significant issue for the gem trade. When a component of a stone's color is confined to a relatively shallow surface layer, there is always a danger that the color of the stone may change if it has to be recut. For example, according to William Larson of Pala International, a 2.69 ct emerald cut examined for this study originally had a large "window." When the stone was recut in an attempt to

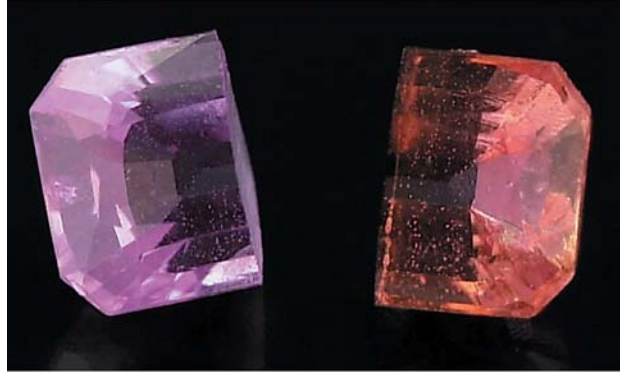


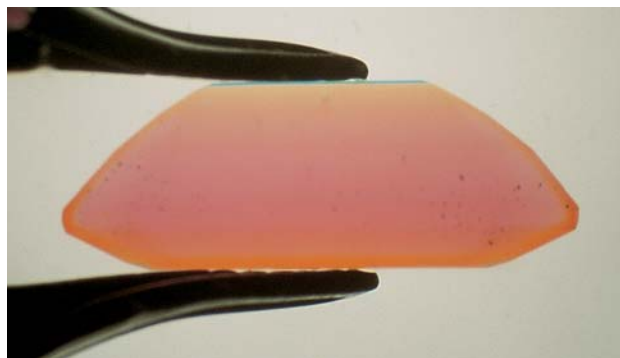
Figure 3. The right half (0.87) of this pink sapphire from Madagascar was treated by the new process. The surface-related orange zone that was developed in the treated half significantly changed the sapphire's color appearance as compared to the untreated 0.86 ct half on the left. Photo by Elizabeth Schrader.

reduce the window, the color became more pink than orange: Most of the orange color layer was removed from the pavilion during recutting (figure 4).

According to the *Academic Press Dictionary of Science and Technology* (C. G. Morris, Ed., Academic Press, San Diego, CA, 1992), one definition of diffusion is simply "the movement of individual atoms through a crystal lattice." We cannot dispute that some kind of diffusion is taking place in these stones, since we know of no other mechanism that can create these distinct, surface-related color layers in faceted corundum. At this time, however, we question whether this new treatment should be classified in the same category as the surface diffusion-treated stones we reported on in the past. If only because of the distinct differences between the two, it may be necessary to separate them in some manner. However, we do not believe we have enough information at this time to make that judgment.

What we do know is that the mechanism behind the color change in these stones appears to be extremely com-

Figure 4. This 2.69 ct treated sapphire was recut in an attempt to improve its appearance. As seen here in immersion, much of the surface-related color zone on the pavilion was removed, which resulted in a significant change in the face-up color of this emerald-cut sapphire. Photomicrograph by Shane F. McClure; magnified 10x.



plex. It is not simply heat treatment or diffusion treatment as either has been described in the past. There are definitely elements entering the corundum during the treatment process, but it is not clear what effect these elements are having on the color of the sapphires. It is not even clear what the source of these elements is: the crucible, the local environment (such as the oven), a chemical flux, or perhaps even other materials such as beryl or chrysoberyl heated together with the corundum.

It is likely that the extreme temperatures being used are causing reactions that are not well documented in the scientific literature or have not been documented at all. We will continue to research the process with different techniques and greater numbers of samples so that the industry can fairly and accurately disclose the nature of the treatment to consumers.

Terminology of Laboratory Reports. The AGTA-GTC, GIA Gem Trade Laboratory, Gübelin Gem Lab, and SSEF Swiss Gemmological Institute agreed that it was imperative to devise a unified disclosure policy to address this matter. The four labs formulated a terminology and disclosure policy for those color varieties of corundum that reveal evidence of heat treatment and have a surface-related orange color layer, as described above. There are two parts to the agreed-upon declaration policy. The first concerns the use of the name *padparadscha*, and the second concerns the actual wording given on the laboratory report.

1. Those labs that typically apply the variety name *padparadscha* to sapphires that display an orangy pink to pinkish orange face-up appearance will not apply the name to these treated stones.
2. All reports for these treated sapphires will include the following statements:

Species: Natural Corundum

Variety: Treated (Orange) Sapphire

Comments/Treatments: Indications of heating.

The orange coloration of this stone is confined to a surface-related layer.

If new information becomes available concerning the nature of the treatment, it may be necessary to amend this policy.

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AUTHORS' NOTE: At press time, we were informed by Yianni Melas of Swarovski and Co. that they have been trying to recreate this new treatment in an effort to understand the process and help alleviate the confusion surrounding it. Swarovski scientists Arno Recheis and Thomas Rauch, under the leadership of Dr. Wolfgang Porcham, have succeeded in reproducing yellow-to-orange colors in sapphire by adding chrysoberyl to the crucible during high-temperature heat-treatment experiments.

Mr. Melas explained that the parcels of yellow sapphire rough he purchases for Swarovski in Madagascar may contain as much as 30%–40% chrysoberyl. He added that since all the stones in these lots are waterworn pebbles, and some of the chrysoberyls are virtually the same color as the sapphires, it is difficult to readily separate the two materials. It is possible, therefore, that the process was discovered originally by the accidental inclusion of chrysoberyl in a crucible of yellow sapphire during heat treatment.

To date, Swarovski scientists have run five experiments with five stones treated in each experiment. Blue, yellow-green, and dark red corundum from Songea was used, as well as pink sapphire from Madagascar. Mr. Recheis reported that the blue material turned yellow but varied in tone from light to dark. He also said that the yellow-green turned yellow, the dark red turned orangy red, and the pink turned orange. They intentionally treated these stones so that the colors extended all the way through. As a result, they did not produce any with the pinkish orange color associated with surface coloration.

TUCSON 2002

The 2002 gem shows in Tucson, Arizona, provided an amazing diversity of gem materials—some from new localities—and included several interesting conferences and symposia. Both public and private meetings were held to discuss hot topics such as the new Thai heat-treated orange and “padparadscha”-like sapphires (see Special Report above) and the controversy over alleged links between tanzanite and the al Qaeda terrorist network. Reports on some of the gem materials seen at Tucson are presented here, along with a selection of conferences. Additional items seen at the Tucson shows will appear in the Summer 2002 GNI section.

CONFERENCE REPORTS

Highlights of the Tucson Diamond Symposium. The Tucson Diamond Show sponsored three panel discussions on synthetic and HPHT-treated diamonds (February 7), diamond cut (February 8), and changes in the diamond pipeline (February 10).

The seminar on **synthetic and HPHT-treated diamonds** featured Dr. James Shigley of GIA Research, Christopher Smith of the Gübelin Gem Lab, Alex Grizenko of Lucent Diamonds, Charles Meyer of Lazare Kaplan International, Martin Haske of Adamas Laboratories, and Jewelers Vigilance Committee general counsel Cecelia Gardner. Mr.

Grizenko said that producers of synthetic diamonds would continue to improve and change their processes, making identification more difficult. These products will have their place in the market, he added, so the industry should not fear them. Mr. Smith reviewed various detection procedures for HPHT-treated and synthetic diamonds, and Mr. Haske maintained that some of the detection work could be accomplished by instruments specially built for the process. Dr. Shigley reviewed GIA research on synthetics, much of which has been published in *Gems & Gemology* over the past 15 years, and said that work on HPHT-treated diamonds was ongoing, as GIA continues to build a database. Ms. Gardner told the audience that, regardless of the material, the burden of disclosure ultimately falls on the retail jeweler, so it is the retailer's responsibility to learn and understand about treatments and synthetics.

The **diamond cut** panel included Charles Meyer, Peter Yantzer of the AGS Diamond Grading Laboratory, Dr. Ilene Reinitz of GIA Research, Leon Cohen of Codiam, and David Federman representing Eight Star Diamond. Mr. Meyer led off the discussion with the comment that a quantifiable cut standard is required to protect the consumer and help hold diamond value. He acknowledged that there may never be a "definitive opinion on what makes a beautiful diamond, but we do need a recognized standard." Dr. Reinitz and Mr. Cohen stressed that specific facets, often overlooked in proportion analyses, were extremely important. "Every facet matters," said Dr. Reinitz, although GIA research has found that the lower girdle facets are particularly important: "Light coming into the crown is three times more likely to hit a lower girdle facet than a pavilion main." Mr. Cohen also argued that facets must be aligned as perfectly as possible because they act as mirrors.

Noting that interest in diamond cut has grown tremendously, Mr. Yantzer indicated that 8,000 Web sites address the subject. He said recent studies have validated the expertise of diamond cutters in deriving the most beauty from a round brilliant diamond, and noted that "Ideal" proportions have evolved over the years to yield greater fire and brilliance. Mr. Federman told how devices such as the Fire Scope and Hearts and Arrows viewers in Japan provided an easily understood, observable way to determine that a diamond was well cut. All the panelists agreed that cut evaluation was progressing to a system based more on actual "performance"—especially with regard to fire and brilliance—than on a single set of proportions.

The discussion on **changes in the supply pipeline** featured Youri Steverlinck of the Diamond High Council in Antwerp, Joe Landau of Joseph Landau Inc., Phoenix gem dealer Gary Wright, Ben Janowski of Janos Consultants, and this contributor. According to Mr. Janowski, diamond prices will become more volatile and retailers will be faced with slimmer inventories, which means fewer choices for consumers. De Beers Diamond Trading Company (DTC) sightholders will continue to ally themselves with large retailers, resulting in the disappearance of some mid-sized

chains. Synthetics could be a "major problem" to the industry, he noted, even with detection measures in place, because they could destroy the mystique of diamonds.

The contributor of this GNI entry said that a world without DTC domination would not bring massive diamond sell-offs and cataclysmic price declines as predicted by some writers. The major producers will keep a certain order to the market even without old-style De Beers custodianship. Mr. Steverlinck predicted that new manufacturing centers, particularly in China and Eastern Europe, will bring an excess of production capacity that will increase competition among diamond centers. De Beers will probably reduce its \$200 million generic diamond advertising campaigns, because its market share has declined to about 60%.

Noting that diamond margins continue to fall, Mr. Landau told the audience that "respect" has to be rebuilt in diamonds through quality initiatives, branding, and creative packaging so consumers feel they are getting something special. Mr. Wright, however, countered that the biggest problem in the industry was "Conflict of Interest" diamonds, those that diamond companies sell direct to Internet dealers or even to consumers on their own Web sites, thus undermining margins.

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8th Symposium on the Gems and Minerals of Afghanistan.

On February 9, this symposium provided a comprehensive look at the current status of the gem and mineral industry of Afghanistan. The goal was to formulate plans for research, mining, and marketing these commodities in a way that would provide employment, foreign currency, and tax revenue to the people and government of Afghanistan. About 20 participants and observers were present; this report provides a summary of the formal presentations. The symposium was organized by Gary Bowersox (GeoVision Inc., Honolulu, Hawaii); for more information, visit www.gems-afghan.com/8-symposium.

In his introduction, Mr. Bowersox emphasized that mining gems and minerals can offer immediate benefits to Afghanistan by providing jobs and foreign currency, while promoting peace. *Gems & Gemology* editor Alice Keller then reviewed the importance of this country as a source of fine emerald, tourmaline, aquamarine, and other gem minerals. Engineer Mohammed Es'Haq (Panjshir, Afghanistan) provided an informative assessment of the political and military situation. Although optimistic about the future, he is concerned that foreign and domestic rivalries could undermine peace efforts. Mir Waees Khan (Jegdalek Ruby Corp., Peshawar, Pakistan) outlined the status of the ruby and sapphire mines at Jegdalek, where most work has been suspended until the political and military situation improves.

After showing a new film called "The Gem Hunter in Afghanistan" (see review in this issue), Mr. Bowersox described how his exploration in 2002 will focus on the

central Asian region—concentrating on Tajikistan if conditions do not allow access to Afghanistan. Dr. Larry Snee of the U.S. Geological Survey (Denver, Colorado) described the resources available from his organization for training geologists and performing a mineral resource assessment of Afghanistan and neighboring countries. High-resolution satellite-based mapping can now be used to identify minerals on the surface and delineate geologic terranes that are promising for mineral exploration. Derrold Holcomb (ERDAS Inc., Atlanta, Georgia) provided further details on the capabilities of these remote-sensing techniques, with case studies illustrating how minerals, rock types, and tectonic features are mapped from satellites (figure 5). Gary Clifton, a geologist from Coleville, California, discussed ways of funding gem exploration activities in Afghanistan.

Figure 5. This image map of Afghanistan's Panjshir Valley region (northwest of the emerald mines) was made with imagery from the United States's new U.S. ASTER satellite. The sensor captures 14 wavelength ranges (or bands) in the visible, near-infrared, short-wave infrared, and thermal spectral regions. Selected specifically to aid in mineral exploration, these bands can reveal mineral signatures at a resolution of 15 m per pixel. The green areas are vegetation along the rivers. The white areas in the center of the image are clouds. Courtesy of Derrold Holcomb.

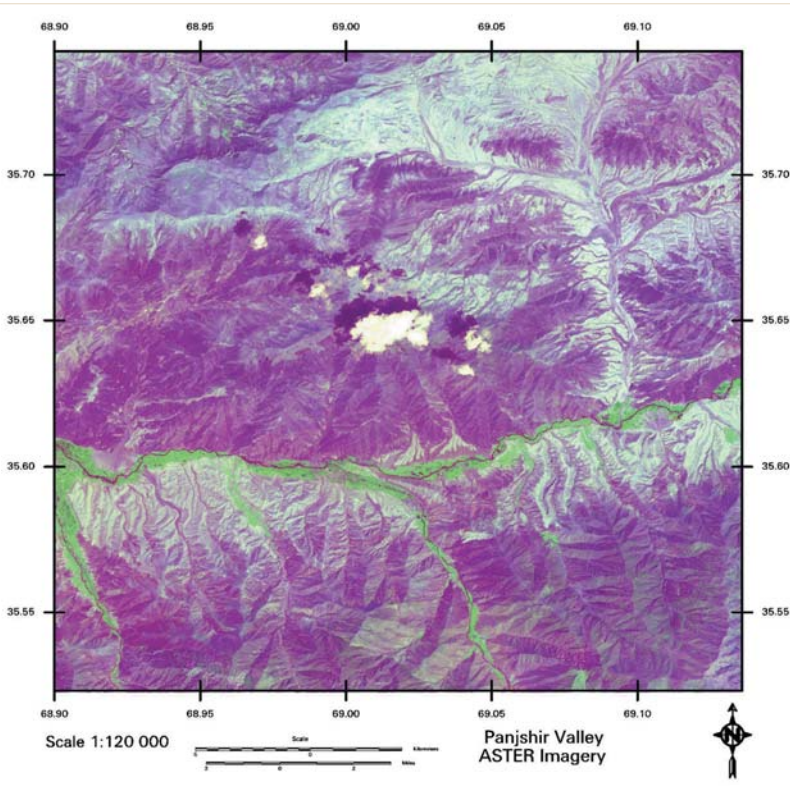


Figure 6. This amethyst crystal cluster and gemstone (12.96 ct) come from eastern Afghanistan. Courtesy of Jack Lowell; photo by Maha Tannous.

Gemological presentations at the 23rd Annual FM-TGMS-MSA symposium. "Minerals of Africa" was the theme of this year's symposium organized by the Friends of Mineralogy, Tucson Gem & Mineral Society, and the Mineralogical Society of America. Abstracts of the talks were published in the *Mineralogical Record* (Vol. 33, No. 1, pp. 75–82). Four presentations included gem minerals.

Chris Johnston (Omaruru, Namibia) reviewed the recent discoveries of aquamarine, jermesjevite, and other minerals in the Erongo Mountains of central Namibia. He warned of realistic fakes that are difficult to detect and well executed by gluing crystals to matrix. Alexander Falster (University of New Orleans, Louisiana) explored the composition of gem-quality yellow, green, and colorless "orthoclase" feldspar from Itrongay, Madagascar. X-ray diffraction analysis of several samples obtained in Madagascar in 2001 showed they were sanidine, rather than orthoclase. Dr. Karen Webber (University of New Orleans) discussed the composition of gem tourmaline from three pegmatite areas in Madagascar. Samples studied from the Antandrokomby mine were elbaite, whereas those obtained from the Anjanabonoina mine and the Fianarantsoa district were liddicoatite. Dr. William "Skip" Simmons (University of New Orleans) and Dr. Federico Pezzotta (Museo Civico di Storia Naturale, Milan, Italy) described the occurrence and composition of rhodizite-londonite from Madagascar; gem-quality material is known from the Antsongombato and Tetezantsio pegmatites.

COLORED STONES AND ORGANIC MATERIALS

Amethyst from Afghanistan. Jack Lowell (Colorado Gem & Mineral Co., Tempe, Arizona) showed GNI editor Brendan Laurs some attractive amethyst that was mined recently in southeastern Afghanistan (figure 6). The material was being sold in Tucson by Haleem Khan (Hindu Kush Malala Gems

& Minerals) and Farman Ullah (Rocks & Minerals Co.), both of Peshawar, Pakistan. They reported that the Afghani deposits were discovered in mid-1999 at two localities, Makur (or Maquar) and Zarkishan (or Zarkashen), in the Koh-I-Suleman range. The local people drill and blast for the amethyst, but there is little systematic mining or modern equipment. The rough is sold to local distributors in the village of Ali Khail near Makur, and then is taken to Peshawar for international distribution. Mr. Khan said that crystals weighing up to 8 kg have been found, and he estimated that the total production from both deposits is 25,000 kg, with 5% being gem-quality. As of April 2002, Mr. Lowell had obtained 750 carats of the faceted amethyst, in sizes ranging from approximately 3 to 21 ct.

Fossilized “Stingray” coral. Mark Castagnoli of Placer Gold Design, Vancouver, Canada, had some interesting fossilized coral at the King’s Ransom booth in the AGTA show. The material debuted at the JCK show in 2001. According to Mr. Castagnoli, this extinct coral of the genus *Favosites* is from the Silurian period (i.e., 408–438 million years ago). So far, a few kilograms have been recovered from just one area of an ancient reef that is exposed in the intertidal zone of a remote island off the coast of Alaska’s Prince of Wales Island. Fossilized *Favosites* from the Prince of Wales area have been documented by S. M. Karl et al. (“Reconnaissance geologic map of the Duncan Canal/Zarembo Island area, southeastern Alaska,” U.S. Geological Survey Open-File Report 99-168, 1999; see <http://wrgis.wr.usgs.gov/openfile/of99-168/PDF/of99-168-pamphlet.pdf>).

Mr. Castagnoli chose this trade name because the material (figure 7) reportedly resembles the patterns shown by the skin of a stingray. The distinctive cellular structure consists of white to gray or blue-gray cells that are outlined in black (see figure 7, inset). Each cell originally contained a coral polyp, which was separated from neighboring polyps by a thin wall. Similar fossil corals that have been used in jewelry contain larger cells (see, e.g., R. V. Dietrich, *Gemrocks: Ornamental & Curio Stones*, <http://www.cst.cmich.edu/users/dietr1rv/gemrx.htm>, accessed March 28, 2002). “Stingray” coral is being used principally as inlay in men’s accessories such as rings, tie tacks, and cufflinks.

Canadian emerald discovery in the Yukon. In September 1998, emeralds were discovered at Regal Ridge (also known as the “Crown showing”) in the Finlayson Lake area of southeastern Yukon Territory (61°17’N, 130°35’W). The deposit was found by geologists working for Expatriate Resources, who were exploring for base metals in the area along the Tintina fault. Preliminary reconnaissance of the deposit was encouraging, and in summer 2001 the first mechanized prospecting was performed by True North Gems Inc., Vancouver, Canada. True North has an option with Expatriate for 50% ownership of the property in exchange for a US\$1.1 million work commitment over five years. This contributor, a consultant for True North,



Figure 7. “Stingray” coral is a new gem material from Alaska. Distinctive patterns are created by its cellular structure (see inset). The polished slab in the center measures 6.1 × 3.6 cm; photo by Maha Tannous. Inset photomicrograph by John I. Koivula; magnified 10×.

showed rough and cut emeralds from the exploration work to *G&G* editors in Tucson. Representatives of True North—Bernard Gaboury and Brad Wilson—also provided information for this report.

The Regal Ridge emerald occurrence encompasses a surface area of approximately 900 × 400 m, with a depth down to 100 m. The emeralds occur in sulfate-tourmaline zones in altered chlorite-mica schist adjacent to quartz veins, and rarely within the veins (see L. A. Groat et al., “Canadian emeralds: Geology, mineralogy, and origin of the Crown showing, southeastern Yukon,” *Canadian Mineralogist*, manuscript accepted 2002). At least eight such veins, up to 1 m thick, have been identified. The best emeralds are a saturated bluish green with high clarity (figure 8); Groat et al. report average values of 3,208 ppm Cr and 171 ppm V from

Figure 8. This emerald (0.11 ct) was cut from material recovered in the course of near-surface exploration activities at Regal Ridge in the Yukon Territory, Canada. Courtesy of True North Gems Inc.; photo by Brad Wilson.



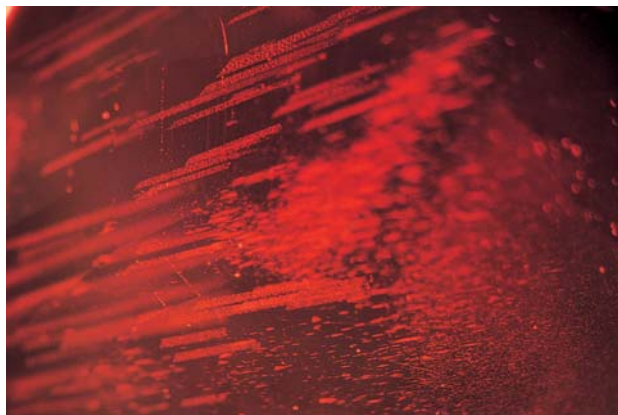


Figure 9. These three andesines (1.04 to 8.95 ct) are reportedly from a new find in the Democratic Republic of Congo. Courtesy of Laurent Sikirdji; photo by A. Cossard.

electron microprobe analyses of 25 samples. Most of the stones faceted so far are small (i.e., less than 0.25 ct); the largest faceted stone is 0.50 ct, and the largest cabochon weighs 2.08 ct. The small stone sizes are thought to result from the breakage of the near-surface material during seasonal freeze-thaw cycles in the arctic environment. Intact crystals of significant size are anticipated in the permafrost zone, below about 10 m depth.

Five faceted emeralds (0.09–0.14 ct) from Regal Ridge were loaned to GNI by True North. Standard gemological properties were obtained by GIA's Elizabeth Quinn: R.I.— $n_o=1.587-1.591$, $n_e=1.579-1.584$; birefringence—0.007–0.008; S.G.—2.70–2.76; and inert to long- and short-wave UV radiation. Cr absorption lines were seen

Figure 10. Several parallel, lath-like groups of minute reflective inclusions are responsible for the schiller-like effect in andesine from the Democratic Republic of Congo. Photomicrograph by E. Fritsch; magnified 30 \times .



with a desk-model spectroscope. These properties are consistent with emeralds from other localities, although the R.I. values are relatively high (i.e., comparable to emeralds from Zimbabwe, Zambia, and Madagascar; see R. Webster, *Gems*, 5th ed., Butterworth-Heinemann, Oxford, England, 1994).

Microscopic examination of these samples by John I. Koivula revealed minute black crystals (possibly chromite); slightly rounded, brassy yellow crystals (possibly pyrite); near-colorless crystals with the appearance of a carbonate; two- and three-phase inclusions (some with birefringent solid phases); and color and growth zoning that formed a partial hexagonal pattern when viewed parallel to the optic axis. Groat et al. identified the following mineral inclusions in their samples: calcite, chalcopyrite, molybdenite, phlogopite, pyrite, quartz, tourmaline, and zircon; also chromite, scheelite, and other minerals were identified within tiny cavities in their samples.

Regal Ridge is Canada's first potentially commercial emerald deposit. True North is continuing its evaluation program with surface and bulk samples in summer 2002.

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Red andesine feldspar from Congo. In Tucson, Dr. Laurent Sikirdji of Saint-Ismier, France, had some attractive red feldspar from Africa that resembled red labradorite from Oregon (see, e.g., C. L. Johnston et al., "Sunstone labradorite from the Ponderosa mine, Oregon," Winter 1991 *Gems & Gemology*, pp. 220–233). He was told by his contact (who wishes to remain anonymous) that the source is actually a new find in the Democratic Republic of Congo. This contributor examined three stones (figure 9), ranging from 1.04 to 8.95 ct.

The red color is irregularly distributed, and some areas are almost colorless. There was no hint of green, as is sometimes seen in Oregon labradorite. R.I. values were 1.551 and 1.560, with a birefringence of 0.009. According to these values, the composition of these plagioclase samples falls in the range of andesine (slightly less than 50% anorthite component), rather than labradorite. The optic sign was biaxial negative, and the specific gravity was 2.67. The stones were very weakly pleochroic, with one of the red colors being slightly more orange than the other.

The stones fluoresced a weak to medium orange to long-wave UV, which was strongest in the zones with the least color. When they were exposed to short-wave UV, there was a weak red emission with an even weaker blue surface-related luminescence.

All three stones contained the same inclusion scene: many parallel, lath-like groups of very small, reflective inclusions (figure 10), causing a schiller-like effect. These are presumably copper platelets, by analogy with the Oregon material. Some twin planes also were seen.

A visible-range spectrum of the 1.04 ct sample in ran-

dom orientation revealed increasing absorption from about 700 nm toward the ultraviolet, which is probably due to light scattering by copper platelets causing the schiller. On this was superimposed a moderately broad band with an apparent maximum at about 565 nm; this has been attributed to absorption by copper particles that are too small to scatter light, as is observed in “ruby” glass and red labradorite from Oregon (see A. N. Hofmeister and G. R. Rossman, “Exsolution of metallic copper from Lake County labradorite,” *Geology*, Vol. 13, 1985, pp. 644–647). EF

Fluorite from Afghanistan. A new source of attractive gem-quality green-to-blue fluorite has been found near Kandahar, Afghanistan. One of the dealers selling the material in Tucson was Mohammad Khan of M. K. Gems & Minerals, Stanton, California. He reported that the deposit was discovered in 2001, and estimated that more than 100,000 carats have been faceted so far from about 200 kg of gem-quality material produced.

Mr. Khan loaned two emerald-cut fluorites (19.05 and 27.91 ct; figure 11) to GNI editor Brendan Laurs for examination. Standard gemological properties were recorded by GIA’s Elizabeth Quinn: color—bluish green and green-blue; R.I.—1.436 or 1.437; S.G.—3.19; optic character—singly refractive with moderate cross-hatched anomalous double refraction; fluorescence—weak blue to long-wave UV, and very weak greenish blue to short-wave UV; Chelsea filter reaction—pink; and no absorption features seen with a desk-model spectroscope. Microscopic examination revealed “fingerprints,” two-phase (fluid-gas) inclusions, clouds, pinpoints concentrated in parallel layers, and cleavage fractures.

The attractive natural colors and transparency in relatively large sizes are notable characteristics of fluorite from this locality.

Green fluorite from the Rogerley mine, England. Recent activities at the Rogerley mine, located in the historic

Figure 11. The war-torn area near Kandahar, Afghanistan, is the source of these attractive fluorites (19.05 and 27.91 ct). Photo by Maha Tannous.



Figure 12. Green fluorite from the Rogerley mine in northern England has been fashioned into attractive faceted stones (here, 5.8–9.4 ct) and cabochons. Courtesy of UK Mining Ventures; photo by Jeff Scovil.

Weardale mining district in County Durham, northern England, have produced numerous specimens of “emerald” green fluorite. A moderate amount of gem-grade fluorite also has been recovered (figure 12). To date, gemstones up to approximately 15 ct have been faceted by Terra (David and Maria Atkinson) of Sedona, Arizona, as well as by Jonté Berlon Gems (Buzz Gray and Bernadine Johnson) of Fallbrook, California; they were being sold by Terra at the GJX show. Byron Weege of Pala, California, has fashioned cabochons up to approximately 25 ct and set them into gold jewelry appropriate to this soft material (e.g., brooches and pendants); these were being sold by UK Mining Ventures (UKMV) in Tucson. This contributor is a partner in UKMV and has assisted with recent mining activities for the material.

Aside from its deep green color, one of the most interesting aspects of Rogerley mine fluorite is its strong bluish purple-white fluorescence to long-wave UV radiation, which produces bluish purple overtones in sunlight. Such intense fluorescence in fluorite has been attributed to elevated contents of rare-earth elements (see H. Bill et al., “Origin of coloration in some fluorites,” *American Mineralogist*, Vol. 52, 1967, pp. 1003–1008); recent analyses have confirmed relatively large amounts of Y, Ce, La, Sm, and Nd in the Rogerley mine material (A. U. Falster et al., “REE-content and fluorescence in fluorite from the Rogerley mine, Weardale, County Durham, England,” *Rocks & Minerals*, Vol. 76, No. 4, 2000, pp. 253–254).

The Rogerley deposit was discovered in the early 1970s by local mineral collectors Lindsay Greenbank and Mick Sutcliffe, who worked the mine part-time through the early 1990s and produced a limited but steady supply of high-quality specimens. Fluorite has been recovered intermittently from other deposits in the area as well. In May 1999 a new partnership (UKMV) began mining full-

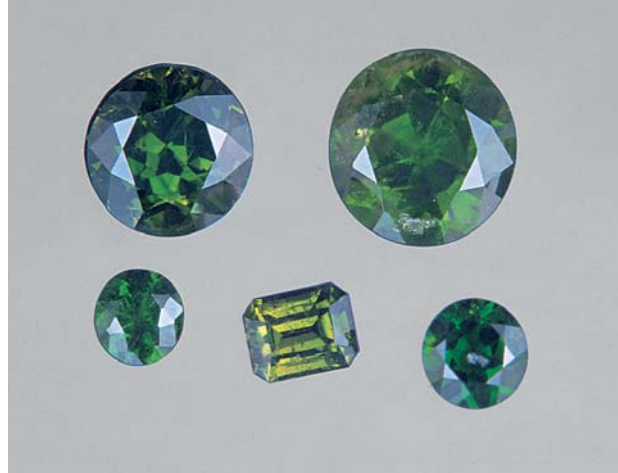


Figure 13. Iran is a new source for demantoid garnet. These stones (0.12–1.13 ct) were selected to show the range of color and size that is available from this deposit. Courtesy of Syed Iftikhar Hussain and Dudley Blauwet; photo by Maha Tannous.

time during the summer months. Working primarily underground, a crew of two to four miners uses a hydraulic diamond chainsaw to recover large specimens without damaging them (see J. Fisher and L. Greenbank, "The Rogerley mine, Weardale, County Durham, England," *Rocks & Minerals*, Vol. 75, No. 1, 2000, pp. 54–61). The mineralized cavities are hosted by a vertical vein and by metasomatic zones or "flats" that extend laterally from the vein. To date, the most attractive material has been produced from the flats. These crystals typically are penetration twinned on {111}. Individual crystals attain sizes up to 8 cm, and sometimes contain purple cores or narrow pale yellow zones near the surface.

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Demantoid garnet from Iran. Since mid-2001, attractive crystals of demantoid have been mined from a tribal area in southeastern Iran. At the 2002 Tucson show, rough and cut material was shown to GNI editor Brendan Laurs by Syed Iftikhar Hussain (Syed Trading Co., Peshawar, Pakistan) and Dudley Blauwet (Dudley Blauwet Gems, Louisville, Colorado). According to both dealers, the deposit is located in Kerman Province, near Jiroft; Mr. Blauwet further specified that it is situated near the village of Soghan.

Yellowish green to green single crystals and crystal clusters as large as 2–3 cm have been produced, although most range from 2 to 10 mm in diameter. The clusters form rounded translucent aggregates, whereas the single crystals are typically transparent in smaller sizes (i.e., 2–3 mm) and semitransparent to translucent in larger sizes. Mr. Hussain had obtained about 150 kg of rough in several parcels, with just 5 kg suitable for cutting mixed grades and 2–3 kg of top-end material. He estimated that about 2,000 carats have been faceted, in sizes ranging from 1 to 8 mm in diameter. Faceted stones over 0.70 ct are uncommon, and also tend to become too dark.

Mr. Hussain and Mr. Blauwet supplied several rough

and cut samples to GNI for examination. Standard gemological properties were obtained by GIA's Elizabeth Quinn on six faceted stones (0.12–1.13 ct; figure 13): color—yellowish green to green, medium to dark; R.I.—greater than 1.810; S.G.—3.86–3.89; optic character—singly refractive with moderate to strong anomalous double refraction; inert to long- and short-wave UV radiation; pink reaction to the Chelsea filter; and Cr doublet (620 and 640 nm) seen with the desk-model spectroscope. Microscopic examination revealed "fingerprints" in all samples, as well as feathers and needles. Subparallel colorless straight or curved fibers occurred in three of the samples; however, these fibers were not seen in radial arrangements or associated with chromite grains, as is typical of the "horsetails" in demantoid from Russia. Also seen in two samples was prominent angular yellowish green and brownish orange color zoning.

Blue, biaxial positive kyanite from Nepal. Dr. Laurent Sikirdji also showed this contributor a large parcel (about 100 stones) of faceted blue kyanite from Nepal that he acquired in Bangkok in late 2001. Such material was briefly mentioned in the Spring 1999 Gem News (p. 51). Unlike the typical gem-quality kyanite from Brazil, the vast majority of kyanite from Nepal is homogeneous in color and nearly free of inclusions. The stones in this parcel ranged from approximately 1 to 3 ct and were oval cut.

Dr. Sikirdji loaned this contributor two stones for further study: a homogeneously colored 1.42 ct oval that was typical of the parcel, and a 1.67 ct dark blue oval with a distinct near-colorless zone across the width of the stone (figure 14). This color zonation is the reverse of that often observed in the Brazilian material, which typically has a strong blue band cutting through an area of much lighter color. Both gems had a specific gravity of 3.60. The R.I. values were 1.710–1.727 and 1.711–1.728, respectively, with a birefringence of 0.017. These values are fairly typical for kyanite. However, contrary to many gemological reference books (e.g., R. Webster's *Gems*, 1994; GIA's *Gem Reference Guide*, 1995), the optic sign of these kyanites was biaxial positive, not negative. This was first pointed out by Y. Lulzac ("Manuel de Détermination des Pierres Taillées de Joaillerie ou de Collection," Nantes, France, 2001, privately published), who stated that kyanites are commonly biaxial positive, and only rarely negative.

The Nepalese samples show the strong light blue–dark blue pleochroism that is typical of kyanite. When exposed to short-wave UV radiation, they revealed a weak but distinct yellowish green luminescence in the homogeneous sample and in the colorless band of the zoned stone. The long-wave UV reaction appeared similar, but much weaker and not very distinct.

Quantitative chemical analyses were performed with a JEOL-5800LV scanning electron microscope (SEM) equipped with a Princeton Gamma Tech energy-dispersive IMIX-PTS detector. The composition of the homogeneous

stone, as well as both color parts of the other kyanite, were very similar: 35.13–35.32 wt.% SiO₂ and 61.64–62.07 wt.% Al₂O₃. The slightly low totals (about 97 wt.%) may be explained by the presence of light elements (e.g., traces of water) that cannot be detected by this method. A very small amount of iron was detected as well—about 0.3 wt.% Fe₂O₃—in the dark blue zones. In the homogeneous stone and the near-colorless zone, the level is below the detection limit (0.3 wt.%) for this instrument, although the iron peak height was lower in the near-colorless zone.

UV-Vis absorption spectroscopy was performed on a Varian Cary 5G spectrophotometer. The random-orientation spectra of both blue kyanites were similar: a weak, sharp doublet at 380–385 nm, another doublet at about 430–450 nm, and a broad band with a maximum at about 610 nm, with somewhat noticeable shoulders around 530 and 650 nm. This broad band is responsible for the color, and was much weaker in the near-colorless zone. These spectral features are reminiscent of those of blue sapphire, which suggests that the weak, sharp bands are due to Fe³⁺ in octahedral coordination, substituting for Al³⁺. The broad band at about 610 nm is likely caused by Fe²⁺–Fe³⁺ charge transfer, and the shoulder at about 530 nm is possibly due to Fe²⁺–Ti⁴⁺ charge transfer. This interpretation is consistent with the chemical analysis (Ti would be at concentrations well below detection limits, and only low Fe concentrations are necessary) and the data review provided by R. G. Burns (*Mineralogical Applications of Crystal Field Theory*, Cambridge University Press, 1993, pp. 129–130). EF

Pargasite from China. At the Best Western Executive Inn hotel, Yunfu Gao and Qing Mei showed this contributor some interesting green crystals that were being sold as emerald from Wenshan, Hunan Province, China (figure 15). The crystals ranged up to 3.5 cm long, and were hosted by a white crystalline matrix. They were vivid green

Figure 14. These kyanites from Nepal (1.67 and 1.42 ct) were found to be biaxial positive. Note the distinct near-colorless layer across the width of the stone on the left. Courtesy of Laurent Sikirdji; photo by A. Cossard.

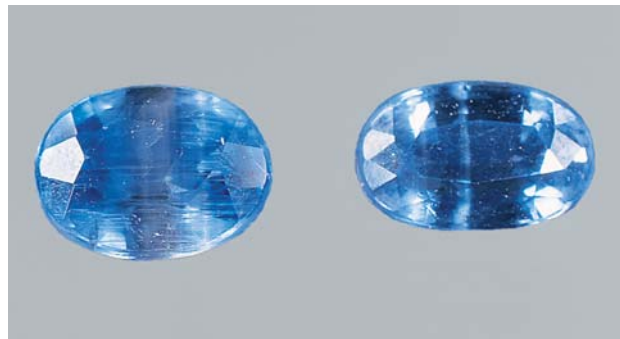


Figure 15. This vivid green, 3.5-cm-long crystal from Hunan Province in China was identified as pargasite. Courtesy of Samir-Pierre Kanaan; photo by Maha Tannous.

and semitransparent to translucent; some also contained small areas that could be faceted.

However, their diamond-shaped cross-section was not typical of emerald, so this contributor purchased some samples and took them to Dr. Robert Downs, professor of mineralogy at the University of Arizona (in Tucson), for analysis. Raman spectroscopy of the green mineral was inconclusive, since there was no matching spectrum in his Raman database. The white matrix was identified as a carbonate (calcite and/or dolomite). Next, the green mineral was analyzed by X-ray powder diffraction. On the basis of the resulting pattern, it was identified as pargasite (an amphibole), with cell parameters closely matching those for a chrome-bearing pargasite published by M. Raudsepp et al. (*American Mineralogist*, Vol. 72, 1987, pp. 580–593).

Green pargasite crystals of this size are quite rare. The dealer also was selling red spinel crystals from the same locality, and some of the pargasite specimens contained the red octahedrons. The same mineral association (with smaller pargasite crystals) is known from marble layers near Hunza, Pakistan; specimens from that locality were available at Andreas Weerth's TGMS show booth this year. Gem-quality pargasitic hornblende is known from Sri Lanka and the Baffin Island area in Nunavut, Canada, but so far only yellowish or greenish brown to dark brown stones have been faceted from those localities (B. Wilson, pers. comm., 2002; see also W. Wight, "Check-list for rare gemstones—Hornblende," *Canadian Gemmologist*, Vol. 15, No. 4, 1994, pp. 110–113).

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Cultured pearls with gem inlays. The jewelry design team of Gabriele Weinmann and Wigbert Stapff of Weinmann + Stapff, Heidelberg, Germany, has developed a novel procedure for setting inlays of various gem materials into cultured pearls. These Magic Pearls™ (patent pending) were available at the Pala International booth during the AGTA show. The manufacturing process involves removing one or more imperfect sections of a cultured pearl and setting a



Figure 16. The Magic Pearls™ in this necklace are accompanied by emerald beads. The Australian South Sea cultured pearls (15.0–17.5 mm) have been inlaid with opal and 18K gold. Courtesy of Weinmann + Stapff; photo by Robert Weldon.

precisely cut piece of gem material into the resulting cavity with a rim of gold or platinum. Opal is the principal material used for the inlay (figure 16), although a variety of other gems (e.g., tourmaline, topaz, and emerald) also are employed depending on the color of the cultured pearl and the client's preference. Both round and baroque cultured pearls from every major freshwater and saltwater pearl-producing region are used, in sizes ranging from 8 to 30+ mm in diameter.

Ruby from northern Kenya. Tim Roark of Tim Roark Imports, Atlanta, Georgia, showed GNI editor Brendan Laurs some rounded fragments of ruby from an unspecified new deposit in northern Kenya (figure 17). According to Mr. Roark, the deposit is basaltic in origin, and was discovered in early 2002. About 1–1.5 kg/month of rough has been produced, yielding faceted stones in the 0.25–1.5 ct range. The largest ruby faceted so far weighed approximately 2 ct. Some of the material was heated in an attempt to brighten its color, but little change was seen. The stones in figure 17 show an attractive red color without heat treatment.

Black spinel from Mexico. A rich alluvial deposit of high-quality black spinel was discovered in January 2000 by Arturo Hernandez in the mountains near the village of Acaoneta (22.30°N, 105.21°W), between Mazatlán and Puerto Vallarta in Nayarit State. Mr. Hernandez and this

contributor showed GNI editor Brendan Laurs a parcel of the rough and cut spinels during the Tucson shows.

To date, the spinel has been recovered from four tributaries (see, e.g., figure 18) that originate from Mesa del Malpais (elevation 300 m), located about 7 km northwest of Acaoneta. The productive area, which covers 3.5 km², is underlain by alkali basalt flows and interlayered mafic tuffs of Tertiary age. Black spinel has been found in significant concentrations in a few areas of both the tuffs (which are typically altered to clay) and the basalt, the latter with accessory peridot and augite. However, the greatest concentration of spinels has been found in the alluvium, soil, and underlying decomposed material.

Since its discovery, the high-grade surface material has been worked intermittently by Margarita Mining Co. (Arturo Hernandez and Ray Fortier), employing up to 20 local miners at a time. This material averages about 1 kg of spinel per cubic meter, and in some areas contains up to 5 kg/m³. Currently, the miners sort the material using square sieves with 0.7, 1.0, 1.5, and 2.0 cm mesh, discarding pieces smaller than 0.5 cm. About 90% of the production by weight will produce stones of 0.5–1.0 ct; the top 10% will finish 3 ct stones on average, but 15–20 ct gemstones are not uncommon. So far, the largest rough recovered was a 66.2 gram water-worn pebble, and the largest faceted stone weighs 34.46 ct.

The dominant octahedral morphology of the spinel is modified by cube and dodecahedron faces in some crystals; rarely, dodecahedra are dominant. Spinel-law twinning on {111} is common, often resulting in unusual elongate forms and macles. Three rough and three cut samples were loaned by this contributor to GNI for examination (figure 19). GIA's Elizabeth Quinn recorded the following properties on two faceted samples (14.05 and 20.17 ct): R.I.—1.762 and

Figure 17. These unheated rubies (2.53–3.39 ct) are from a new deposit in northern Kenya. Courtesy of Tim Roark Imports; photo by Maha Tannous.



~1.772 (unclear reading), S.G.—3.79 and 3.82, and both were inert to long- and short-wave UV radiation. The R.I. and S.G. values are consistent with the spinel-hercynite series ($MgAl_2O_4$ - $Fe^{2+}Al_2O_4$), and an X-ray powder diffraction analysis by GIA's Dino DeGhionno also indicated that the spinel contains some hercynite component. SEM-EDS qualitative chemical analyses of several samples by Dr. Shane Ebert at the University of British Columbia (Vancouver, Canada) revealed dominant aluminum, as expected, with major amounts of Mg and Fe.

The Acaponeta deposit is unusual for the prevalence of relatively large crystals of black spinel that are appropriate for jewelry applications. Because it takes a high polish, the spinel is particularly suitable for checkerboard cuts and faceted beads (again, see figure 19).

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More on cuprian elbaite tourmaline from Nigeria. Several dealers in Tucson were selling the new cuprian elbaite from Nigeria (see, e.g., Fall 2001 GNI, pp. 239–240; C. C. Milisenda, "Cuprian tourmalines from Nigeria," *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 50, No. 3, 2001, pp. 121–122). The stones were being marketed under various trade names, such as African Paraíba, Indogo tourmaline, and Blue Glacier tourmaline. Most of them showed a similar light greenish blue color that is reportedly derived from the heat treatment of blue-violet to "amethyst"-colored material.

Marcelo Bernardes (Manoel Bernardes Ltd., Belo Horizonte, Brazil) loaned four samples of the tourmaline (0.77–1.10 ct; figure 20) to GNI editor Brendan Laurs for gemological examination and chemical analysis. GIA's Elizabeth Quinn obtained the following gemological properties: color—light to medium greenish blue; pleochroism—very weak to weak, light greenish blue and very pale greenish blue; R.I.— $n_o=1.618$ – 1.620 , $n_e=1.636$ – 1.638 ; birefringence—0.018–0.019; S.G.—3.06–3.07; Chelsea filter reaction—yellowish green; inert to long- and short-wave UV radiation, except for one stone that fluoresced very weak bluish green to long-wave UV; and a cutoff at 650–660 nm seen with a desk-model spectroscope. Microscopic examination revealed two-phase (liquid-gas) inclusions, "fingerprints," fractures with low relief, negative crystals, and colorless mineral inclusions that appeared to be feldspar. These properties are comparable to those reported in the Fall 2001 GNI section for this tourmaline, and overlap those of elbaite from Paraíba, Brazil (see E. Fritsch et al., "Gem-quality cuprian-elbaite tourmalines from São José da Batalha, Paraíba, Brazil," Fall 1990 *Gems & Gemology*, pp. 189–205). Although the Nigerian tourmaline commonly is heated to bring out the greenish blue color, none of the samples showed evidence of heat treatment.

Electron-microprobe analyses of the four samples



Figure 18. An alluvial deposit of high-quality black spinel was found in January 2000 in Nayarit State, Mexico. Arturo Hernandez, who discovered the deposit, is standing in an exploratory pit in La Vieja creek that yielded approximately 5 kg of spinel from 5 m³ of alluvium. Photo by William Rohtert.

Figure 19. The Mexican spinel is typically found as slightly rounded octahedrons (top, 11.43–33.88 ct). The material shows good luster and has been cut in relatively large sizes (bottom, 14.04 ct cushion shape, 28.04 ct faceted bead, and 20.16 ct round brilliant). Courtesy of Margarita Mining Co.; photo by Maha Tannous.

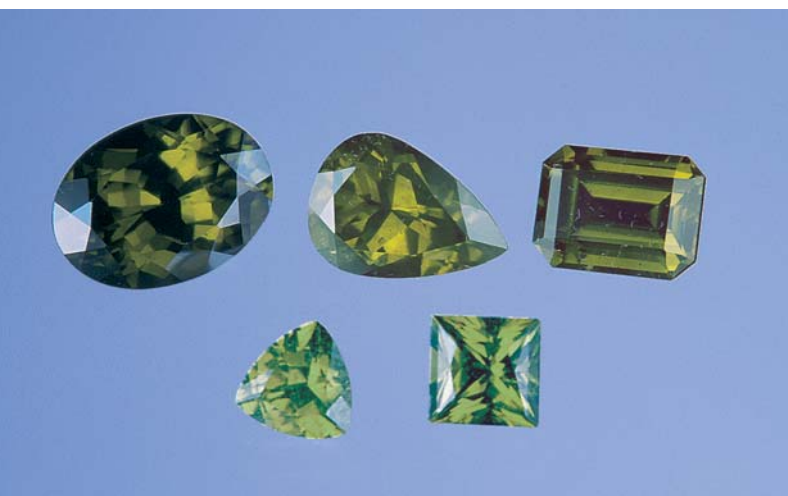




Figure 20. Greenish blue copper-bearing tourmalines from Nigeria were widely available at the 2002 Tucson show. The cuprian elbaïtes shown here (0.77–1.10 ct) contain up to 0.23 wt. % CuO. Courtesy of Manoel Bernardes Ltd.; photo by Maha Tannous.

were performed at the University of New Orleans. The results confirmed that the tourmalines are elbaïte, with 0.04–0.23 wt. % CuO. There were significant variations in the copper content within each sample; the largest variation was 0.04–0.15 wt. % CuO in five point analyses. The only other chromophore present in significant amounts was manganese (0.06–1.72 wt. % MnO), which also showed considerable variation within each sample. Minute amounts of bismuth (up to 0.09 wt. % Bi₂O₃) also were detected, but the levels were near the detection

Figure 21. These vesuvianites (0.57–3.59 ct) come from a new deposit south of Nairobi, Kenya. Photo by Maha Tannous.



limit for the instrument. Titanium and Fe were not detected, nor was Mg, V, Cr, Zn, Ba, or Pb. As stated in Shigley et al. ("An update on 'Paraíba' tourmaline from Brazil," Winter 2001 *Gems & Gemology*, pp. 260–276), cuprian elbaïtes from Nigeria and Brazil share overlapping chemical as well as gemological properties. Those authors reported that they know of no way to separate similar-appearing material from the two countries.

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Vesuvianite from Kenya. Transparent vesuvianite is attractive and durable enough to be worn in jewelry, but it is more commonly sold as a collector's stone. At the AGTA show, Tim Roark had faceted vesuvianite from a new location south of Nairobi, Kenya, that was discovered in April 2001. Mr. Roark reported that of approximately 1–2 tons of rough removed, only about 1–2% has been facetable. The stones, which resemble peridot, were available in sizes up to 5 ct; larger stones were too dark to be marketable. In April 2002, Mr. Roark learned that the local government recently closed the mining operation due to its location near a game park.

This contributor obtained standard gemological properties on five faceted transparent to semitransparent samples (0.57–3.59 ct; figure 21) varying from medium to dark yellowish green to medium yellow-green. The samples were moderately to heavily included; microscopic examination revealed heavily "roiled" graining that imparted a pronounced heat-wave effect. This patchy strain is sometimes called an internal "micro-granular" texture due to the aggregate reaction seen in the polariscope. The stones also contained small dark opaque crystals, clusters of small transparent near-colorless crystals, cotton-like clouds, and other mineral impurities.

Each stone yielded only a single R.I. value, which ranged from 1.712 to 1.720, with the lower measurements recorded on samples that were more yellow than green. Vesuvianite typically shows birefringence (0.001–0.012); however, no birefringence was detected in these samples. No optic figure was discernible in the polariscope due to the graining.

The samples had S.G. values of 3.39–3.41, and were inert to long- and short-wave UV radiation. They gave a grayish pink reaction to the Chelsea filter. When examined with a desk-model spectroscope, all samples displayed a strong absorption line at approximately 461 nm, which is typical of vesuvianite, and the three yellowish green stones also showed general absorption in the lower blue region of the spectrum (i.e., below approximately 440 nm).

EDXRF qualitative chemical analysis of two samples (i.e., the lightest and darkest) by Shane Elen of GIA Research detected Al, Si, and Ca as the major constituents, minor amounts of Fe, and traces of Ti, Mn, Zn, and As. In

addition, the dark yellowish green stone contained traces of Sr; this stone also appeared to contain higher concentrations of iron, but it is unknown at this time whether this contributed to the darker green color.

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Vesuvianite from Madagascar. On a recent buying trip to Madagascar, Tom Cushman of Allerton Cushman & Co. (Sun Valley, Idaho) purchased a small parcel of faceted, transparent green stones that were represented as tourmaline. He later identified them as vesuvianite. At the GJX show, this contributor (CPS) purchased two samples (each weighing 0.26 ct; figure 22) for examination at the Gübelin Gem Lab (GGL).

Both stones were confirmed as vesuvianite based on their gemological properties and Raman spectra. Standard gemological testing of the samples yielded results that were consistent with this color variety of vesuvianite: R.I.— $n_o=1.702$ and $n_e=1.706$; birefringence—0.004; optic character—uniaxial negative; S.G.—3.40, 3.42; pleochroism—weak, light green and yellowish green; and nearly inert to long- and short-wave UV radiation, with only a faint chalky yellow reaction to both wavelengths. Both stones were transparent, yet microscopic examination revealed some distinctive features, including swirled or undulating internal growth structures and color zoning. Raman microspectrometry was used to identify several opaque, black metallic platelets as magnetite (figure 23), as well as a number of transparent, colorless rounded masses and rod-like crystals as carbonates (calcite or aragonite; figure 24).

Figure 22. These two 0.26 ct vesuvianites came from a small parcel of faceted material purchased in Madagascar. Their yellowish green color is attributed to Cr^{3+} . Photo by Franzisca Imfeld.



Figure 23. Black metallic platelets of magnetite were abundant in both Madagascar vesuvianite samples. Photomicrograph by Christopher P. Smith; magnified 55 \times .

One of the samples also contained fine pinpoints and short, slightly iridescent needles dispersed throughout the stone.

Polarized UV-Vis-NIR absorption spectroscopy revealed a broad band centered at approximately 595 nm (yellowish green pleochroic color) or 610 nm (light green pleochroic color), as well as a series of weak, poorly defined bands between 688 and 704 nm that are attributed to Cr^{3+} . (The color of a similar vesuvianite from Quebec, Canada, has been attributed to Cr^{3+} , presumably in an octahedral site; see Fall 1991 Gem News, p. 185.) Another weak, broad band at approximately 463 nm is attributed to Fe^{3+} . For the yellowish green pleochroic color, a secondary absorption minimum was located at 535 nm with an absorption edge at approximately 450 nm. For the light green pleochroic color, a secondary absorption edge at 530 nm was superimposed on the main absorption edge at approximately 380 nm.

EDXRF qualitative chemical analysis of each sample recorded the major elements Ca, Al, and Si, with minor-to-

Figure 24. Colorless, transparent crystals of calcite or aragonite formed rounded masses, as well as elongate rod-like crystals, in the Madagascar vesuvianite samples. Photomicrograph by Christopher P. Smith; magnified 75 \times .





Figure 25. A diffuse star can be seen in this opal triplet (10 × 8 mm), which is composed of a black basalt base, a glass top, and a wafer of opal from Spencer, Idaho. Courtesy of Idaho Opal Mines Inc.; photo by Maha Tannous.

trace amounts of Cr, Fe, Mn, Ti, and V, as well as Sr and Y. Relatively more Cr was recorded in the sample that had a slightly less distinct yellowish modifier to its color.

This is the first instance of gem-quality, chromium-colored yellowish green vesuvianite from Madagascar that GGL is aware of. In addition, we believe this is the first time that magnetite and calcite/aragonite have been identified as inclusions in vesuvianite.

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Figure 26. This 29.9 ct (approximately 3.0 cm wide) aquamarine termination plate from Minas Gerais, Brazil, displays an attractive natural etch pattern. Courtesy of Robert Bentley Co.; photo by Maha Tannous.

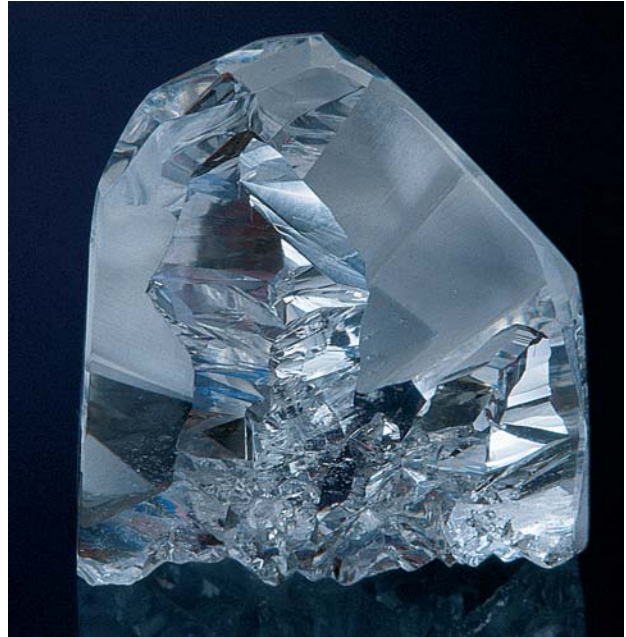


Figure 27. Two large open tubes are seen in this polished quartz (approximately 4.0 × 3.0 cm) from Afghanistan. Courtesy of Robert Bentley Co.; photo by Maha Tannous.

SYNTHETICS AND SIMULANTS

Star opal triplets. Although not new, some unusual black star opal triplets were seen in the Pueblo Inn room of Bob and Susan Thompson of Idaho Opal Mines Inc., Dubois, Idaho (see, e.g., figure 25). The samples had attractive play-of-color and displayed various asterism phenomena such as three- or six-rayed stars and “points.” (Points are spots of light near the edge of the cabochon that are located at the same positions as rays, but do not extend to the top of the cab.) According to Bob Thompson, they were constructed from an opal wafer sandwiched between a black basalt backing and a Pyrex glass top. The opal was mined near Spencer, Idaho, from vugs within a decomposed rhyolite that has been affected by nearby geysers.

The optical phenomena shown by these opal triplets were studied by J. V. Sanders (“Star opal from Idaho,” *Lapidary Journal*, Vol. 29, No. 11, 1976, pp. 1986–2010), who attributed the star effect to “an optical diffraction phenomenon from imperfections in the crystal-like packing arrangement of the transparent silica particles” (p. 1992). Thus, unlike the stars in other stones, the asterism in these opals is not visible without the glass top that refracts the diffracted light toward the viewer. To determine if a particular opal will display a star, Mr. Thompson looks first for a distinctive “rolling flash” in the basalt-backed opal layer, and then wets the opal and covers it with the glass top.

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MISCELLANEOUS

Interesting etch features and cavities in beryl and quartz.

At the AGTA show, Robert Bentley Co. had several gem crystals that displayed unusual natural surface patterns or internal features. Some of them were partially polished to bring out their attractive qualities when set in jewelry. Two specimens in particular—an aquamarine termination plate and a colorless quartz crystal—caught the attention of this contributor.

Beryl crystals typically show a hexagonal prismatic habit with a flat basal termination. After growth, some of the faces may undergo light to moderate local dissolution, commonly called “etching.” This usually results in numerous small pits scattered over the crystal faces. The aquamarine specimen in figure 26 is the flat termination of a crystal that reportedly was mined in Minas Gerais, Brazil, and shows interesting “road map”-like dissolution

patterns. All of the faces other than the etched surface have been polished to emphasize the patterns. Narrow notched lines are developed in orientations parallel to the prism faces, and locally intersect. Hexagonal pits on the surface and tubes parallel to the c-axis also are present. All of the dissolution features reflect the symmetry of the crystal structure as well as growth imperfections.

Although quartz occasionally contains open tubes and negative crystals, these inclusions generally are small. The remarkable polished quartz from Afghanistan in figure 27 displays two large tube-like cavities in different directions. The larger cavity measures approximately 3 cm long and 1 cm in the diameter. The cavities have roughly hexagonal cross-sections, and their internal surfaces show an array of small faces and steps.

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GNI REGULAR FEATURES

COLORED STONES AND ORGANIC MATERIALS

Recent emerald production from Hiddenite, North Carolina.

Several emerald-bearing fissures have been found recently near Hiddenite, North Carolina, about 80 km northwest of Charlotte. Approximately 3,400 carats of mixed-quality rough have been recovered from seven fissures, and on January 11, 2002, an eighth vug yielded two large emerald crystals. The smaller one was particularly well crystallized and estimated to weigh about 40 ct (see figure 28).

Gems & Gemology editor Alice Keller visited the locality on January 27 with the owner of the property, James Hill of North American Emerald Mines. At the site, she observed the two emerald crystals *in situ* with quartz and mica, in a fissure that cross-cut the gneiss host rock. The exposed portion of the smaller emerald measured approximately 3–4 cm long and 2–3 cm in diameter; it was translucent to transparent bluish green. The larger crystal was strongly zoned, with the darkest green color concentrated at the surface. Some of the other material that Mr. Hill recently mined also showed this color zoning, with deep “emerald” green outer portions and pale green to nearly colorless cores. Mr. Hill removed the wall section that contained the two large emeralds *in situ* using a hydraulic diamond chainsaw; he hopes to sell it to a museum. So far eight emeralds have been faceted from the recent production, with the largest weighing 8.18 ct.

The emerald-bearing fissures were located with ground penetrating radar (GPR) after the weathered overburden was removed to expose the gneiss (figure 29). Using GPR, Dan Delea of Geophysical Survey Systems Inc. in North Salem, New Hampshire, has identified more than 40 anomalies—which are thought to represent mineralized

fissures—within about 3 m of the surface on the 14 acre site. According to Mr. Hill, all of the fissures excavated to date have been associated with a “limonite” seam in the hard rock. He believes that deeper penetration of the radar will reveal more fissures.

In late March 2002, Mr. Hill found another mineralized

Figure 28. This emerald crystal (3–4 cm long and 2–3 cm in diameter) was found in January 2002 near Hiddenite, North Carolina. The 1.76 ct emerald in the inset was cut in April 2002 from the recent production. Photos by Robert Weldon.





Figure 29. The weathered overburden in the back-ground has been removed to expose the gneiss hosting emerald-bearing fissures at this North Carolina emerald mine. Ground penetrating radar was then used to locate mineralized fissures. Photo by Robert Weldon.

fissure on the property, outside the area surveyed by GPR. One side of the fissure was peeled back to reveal a wall that was approximately 2.4 m wide and 1.2 m tall, containing crystals of albite, muscovite, pyrite, and black tourmaline. Two emerald crystals weighing about 10 ct and 30 ct were found in loose material at the bottom of the fissure.

Emeralds were first found in North Carolina, the only state in the U.S. known to produce significant emeralds, more than a century ago. Since then, several large emeralds have been recovered (see, e.g., D. L. Brown and W. E. Wilson, "The Rist and Ellis Tracts, Hiddenite, North Carolina," *Mineralogical Record*, Vol. 32, No. 2, 2001, pp. 129–140). Mr. Hill's last major discovery occurred in late 1998, when he unearthed a 71 ct emerald that was faceted into the 7.85 ct "Carolina Prince" and the 18.88 ct "Carolina Queen."

Star emerald from Madagascar. Six-rayed star emerald is one of the rarest asteriated gem materials known. Only a few specimens have been described. These were reportedly from Santa Terezinha, Brazil (see Gem News: Spring 1995, pp. 60–61; and Fall 1995, p. 206), and from Nova Era, Brazil, and an unknown source (U. Henn and H. Bank, "Beryll-Katzenaugen und Sternberylle," *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 46, No. 2, 1997, pp. 113–117). Compared to star sapphires, for example, asterism in emerald is always relatively weak.

The 6.80 ct six-rayed star emerald described here reportedly originated from Morafeno in the Mananjary area of eastern Madagascar. Mines in this area have yielded a small but continuous production of gem-quality rough during the last few years. The 12.5 × 11.1 mm cabochon was purchased by a German dealer in summer 2001 from a Malagasy gem merchant. The emerald showed a whitish sheen and a weak six-rayed star. The sample had refractive indices of 1.581–1.588 (measured on the flat base) and a specific gravity of 2.73. Pleochroism was bluish green parallel to the c-

axis and yellowish green perpendicular to c. Absorption spectra seen with a spectrophotometer consisted of the normal Cr- and Fe-related bands of natural emerald.

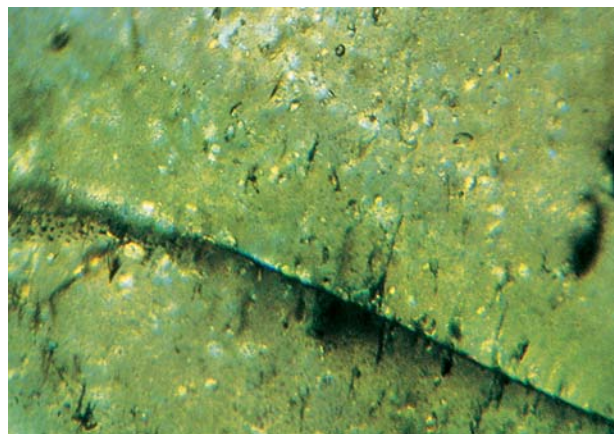
Microscopic examination revealed distinct growth and color zoning parallel to two prism faces as well as to the basal pinacoid. Many small, tabular, birefringent inclusions also were present (figure 30). These minerals were oriented with their flat face approximately parallel to the basal pinacoid of the host emerald; they are probably responsible for the whitish sheen and may also contribute to the weak six-rayed star, but the exact mechanism of star formation and the identity of these inclusions is unknown. KS

Tourmaline "slider" in quartz. Generally speaking, small pieces of rough or broken rock crystal quartz have little value. Sometimes, however, such mineral scraps may contain interesting inclusions that have special appeal for gemologists and collectors.

Recently this contributor received an interesting piece of rock crystal from John R. Fuhrbach, a jeweler and gemologist from Amarillo, Texas, who had obtained it in Zambia. The quartz contained two irregularly shaped rods of green tourmaline and a hexagonal prism of brownish pink tourmaline. The two green crystals reached the surface of the quartz on natural crystal faces, whereas the brownish pink tourmaline was partially exposed on a fractured surface. To get a better look at the tourmalines, with Mr. Fuhrbach's permission we asked Leon Agee of Agee Lapidary in Deer Park, Washington, to polish a flat window on the sample. After cutting, the quartz weighed 29.32 ct.

During the polishing process, Mr. Agee noticed that the brownish pink tourmaline crystal backed away from the polishing wheel. In fact, the vertical up-and-down dis-

Figure 30. The abundant tabular inclusions seen here are probably responsible for the whitish sheen and may also contribute to the asterism in this 6.80 ct emerald from Madagascar. Photomicrograph by Karl Schmetzer; magnified 40×.



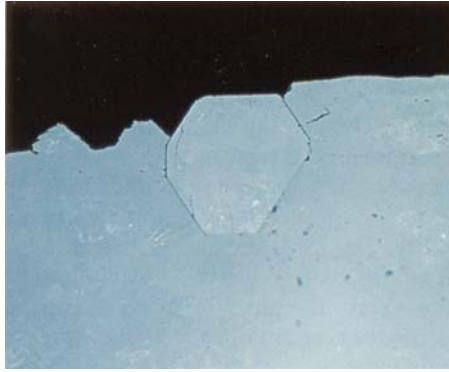
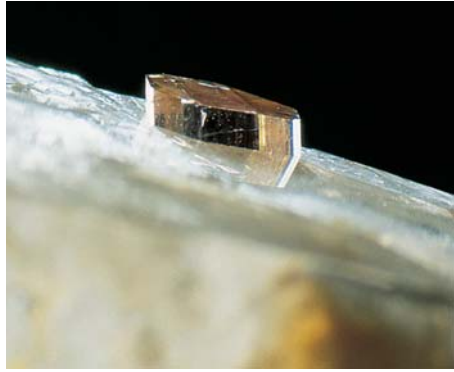


Figure 31. With very little pressure, this tourmaline inclusion could be pushed completely through the quartz host in either direction (left). In reflected light, the almost perfect fit of the tourmaline in quartz can be seen. Photomicrographs by John I. Koivula; magnified 5 \times .

placement of this crystal was easily accomplished with only light pressure (figure 31, left). When viewed in reflected light (figure 31, right), the hexagonal cross-section of the tourmaline seemed to have a nearly perfect fit within the quartz. This immediately brought to mind the sliding rutile needles in quartz reported by this contributor in the Fall 1998 Gem News section (pp. 225–227). This type of free-moving inclusion was thought to be unusual because of the degree of crystal growth perfection required for such an inclusion to glide through the host mineral surrounding it, while still seeming to have a perfect, tight fit.

All lapidaries have probably encountered mineral inclusions that “just popped or pulled out” of a gem they were trying to cut. Many more crystal inclusions than previously thought might actually be free to move if they were exposed to the surface.

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MISCELLANEOUS

Illusion Mount™ stone holders. An interesting modification to a traditional way of displaying gems was developed in April 2001 by John Patrick of El Sobrante, California. The Illusion Mount™ employs pre-cut sheets of clear plastic to suspend a stone within the round or square boxes that are commonly used by gem dealers (figure 32). The holder creates the effect of the stone “floating” in air, and permits examination from several directions without the need to remove the gem from the container. The small opening that cradles the stone in the holder is available in several sizes and shapes, and larger holes can be cut in the plastic if desired. Mr. Patrick has chosen Rio Grande (Albuquerque, New Mexico) as the sole distributor of this product.

EXHIBITS

GIA Museum exhibits in Carlsbad. Through the end of October, the Rotunda Gallery at GIA in Carlsbad, California, is featuring “Gems in Art—Art in Gems,” an exhibition of gems in works of art other than jewelry. Cameos, intaglios, and other carvings, as well as *objets d’art* and *objets de vertu* (decorative yet functional objects

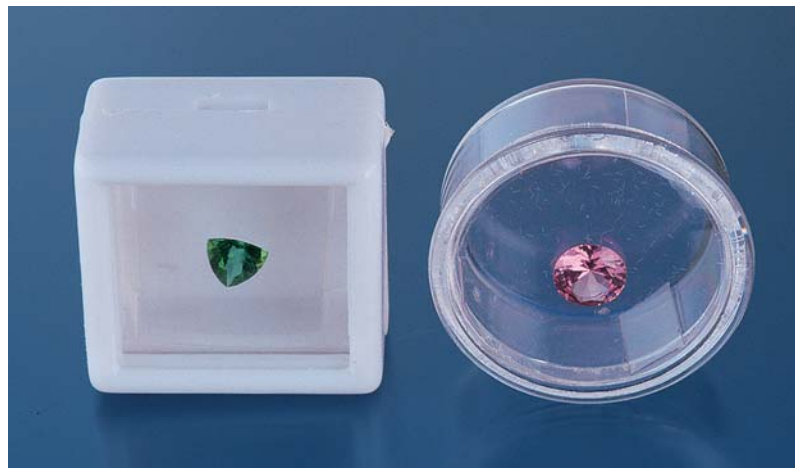
such as inlaid boxes), by leading gem artists will be on display. From June 6, 2002 to February 6, 2003, in the Museum Gallery, “Opal and the Dinosaurs—Discover the Link” will feature rare opalized fossils from Australia. This exhibit will also explore opal formation and mining in Australia, and show fine opal in rough and cut form, as well as opal jewelry. For more information on these free exhibits, contact Alexander Angelle at 800-421-7250, ext. 4112 (or 760-603-4112), or e-mail alex.angelle@gia.edu.

ANNOUNCEMENTS

The JCK Show—Las Vegas. Held at the Sands Expo & Convention Center on May 31–June 4, this show will host a comprehensive educational program beginning May 29. To register, call 800-257-3626 or 203-840-5684. Visit <http://jck-vegas2002.expoplanner.com>.

3rd World Diamond Conference. Held June 17–18 at the Fairmont Hotel Vancouver in Vancouver, Canada, this year’s conference will feature presentations by mining com-

Figure 32. The Illusion Mount™ uses a pre-cut sheet of plastic to suspend a gem within the round or square containers used by many dealers. The stone can be viewed from several directions without removal from the container. Photo by Maha Tannous.



pany executives, industry analysts, financiers, and government officials from several countries involved in the diamond trade. Visit www.iiconf.com/Diamond2002Main.asp, call 305-669-1963, or e-mail iiconf@iiconf.com.

Jewelry 2002: A Celebration of Jewelry. The 23rd Annual Antique & Period Jewelry and Gemstone Conference will be held July 20–25 in Hempstead, New York. The program emphasizes hands-on jewelry examination techniques, methods of construction, understanding materials used throughout history, and the constantly changing marketplace. Visit www.jewelrycamp.org, call 212-535-2479, or e-mail jwelrycamp@aol.com.

11th Quadrennial IAGOD Symposium and GEOCONGRESS 2002. The 11th Symposium of the International Association on the Genesis of Ore Deposits will be presented in association with the Geological Society of South Africa's biennial southern African earth science meeting on July 22–26 in Windhoek, Namibia. The program will include an open session on "Cathodoluminescence of Gems and Other Minerals," as well as a pre-meeting field trip titled "Post-Collisional Pegmatites, Gemstones and Industrial Minerals, Central Namibia" (July 17–21). Participants will visit topaz, aquamarine, jeremejevite, and tourmaline deposits. Visit www.geoconference2002.com, phone 264-61-251014, fax 264-61-272032, or e-mail geoconference2002@conferencecelink.com.na.

JA New York Summer Show. On July 28–31, Jewelers of America will present this show at the Jacob K. Javits Convention Center in New York City. A range of educational programs and seminars will be offered. Prior to the JA show, GIA Career Fair will take place July 26 at the Javits Center. Career Fair will offer recruiting and networking opportunities, career counseling, and more. Information on the JA show is available at www.ja-newyork.com, or call 800-950-1314, ext. 4983 (or 646-654-

4500). To learn more about GIA Career Fair, call 800-421-7250, ext. 7337 (or 760-603-7337).

FIPP 2002. The 12th International Gemstones Show and 14th Open Air Precious Stones Show will take place August 14–17 in Teófilo Otoni, Minas Gerais, Brazil. Attendees will have the opportunity to participate in seminars and excursions to local gem mines. Visit www.geabrasil.com or e-mail geabr@uai.com.br.

IMA2002. On September 1–6, the 18th General Meeting of the International Mineralogical Association will take place in Edinburgh, Scotland. Scientific sessions will include "Gem Materials" and "Cathodoluminescence Microscopy Applied to Gemstones and Other Minerals." Visit <http://www.minersoc.org/IMA2002> or e-mail info@minersoc.org.

Colorado gems. On September 7–10, a symposium titled "Gemstone Deposits of Colorado and the Rocky Mountain Region" will take place at the Colorado School of Mines in Golden, Colorado. Lectures and field trips will cover the mineralogy, geology, and field occurrence of gem and crystal deposits in this region. This symposium precedes the Denver Gem and Mineral Show (September 13–15); the theme of this year's show is "Gemstones of Colorado." Contact Dr. Peter Modreski at 303-236-5639 or e-mail pmodreski@usgs.gov.

AGTA Spectrum Awards competition. AGTA's Spectrum Awards recognize outstanding jewelry designs from the U.S. and Canada that feature natural-color gemstones and cultured pearls. They also include a Cutting Edge competition to honor the lapidary arts. The deadline for entering the 2003 competition is September 27, 2002. Winning entries will be displayed at the 2003 AGTA GemFairs in Tucson and Las Vegas (in connection with the JCK Show). For entry forms and more information, visit www.agta.org or call 800-972-1162.



For regular updates from the world of Gems & Gemology, visit our website at:
www.gia.edu/gandg/

The Dr. Edward J. Gübelin Most Valuable Article Award

G*ems & Gemology* is pleased to announce the winners of the 2002 Dr. Edward J. Gübelin Most Valuable Article Award, as voted by the journal's readers. Our special thanks to the many *G&G* readers who participated in this year's voting.

The first-place article was "Modeling the Appearance of the Round Brilliant Cut Diamond: An Analysis of Fire, and More About Brilliance" (Fall 2001), which presented the latest results of GIA's research on the interaction of light with colorless round brilliant cut diamonds of various proportions. Receiving second place was "The Current Status of Chinese Freshwater Pearls" (Summer 2001), a report on the latest culturing techniques being used at Chinese pearl farms. Third place was awarded to "Discovery and Mining of the Argyle Diamond Deposit, Australia" (Spring 2001), which examined the development of the world's largest diamond mine by volume.

The authors of these three articles will share cash prizes of \$2,000, \$1,000, and \$500, respectively. Following are photographs and brief biographies of the winning authors.

Congratulations also to Francisco Brooks-Church of San Francisco, California, whose name was drawn from the many entries to win a five-year subscription to *Gems & Gemology*.

First Place

*Modeling the Appearance of the Round Brilliant Cut Diamond:
An Analysis of Fire, and More About Brilliance*

Ilene M. Reinitz, Mary L. Johnson, T. Scott Hemphill, Al M. Gilbertson,
Ron H. Geurts, Barak D. Green, and James E. Shigley

Ilene Reinitz is manager of Research and Development at the GIA Gem Trade Laboratory in New York and an editor of *G&G*'s Gem Trade Lab Notes (GTLN) section. Dr. Reinitz, who holds a Ph.D. in geochemistry from Yale University, has written numerous articles for *G&G* and other publications. **Mary Johnson**, manager of Research and Development at the GIA Gem Trade Laboratory in Carlsbad, is also an editor of the GTLN section and a frequent contributor to the journal. Dr. Johnson received her Ph.D. in mineralogy and crystallography from Harvard University. **Scott Hemphill**, a GIA research associate, has been programming computers for more than 30 years. Mr.



Ilene M. Reinitz



Mary L. Johnson



T. Scott Hemphill



Al M. Gilbertson



Ron H. Geurts



Barak D. Green



James E. Shigley

Hemphill holds a B.Sc. in engineering and an M.Sc. in computer science from the California Institute of Technology. **Al Gilbertson** is a research associate with GIA Research in Carlsbad. A noted gemologist and appraiser, Mr. Gilbertson has published several articles on diamond cut and clarity. **Ron Geurts** is Research and Development manager at GIA in Antwerp, Belgium. Mr. Geurts has 27 years of experience in diamond grading and the development of grading instruments and techniques. **Barak Green** is a technical writer for GIA Research in Carlsbad. Mr. Green holds a master's degree in anthropology from the University of California, San Diego, where he currently teaches writing and rhetorical analysis. **James Shigley**, who holds a Ph.D. in geology from Stanford University, is director of GIA Research in Carlsbad. This marks his sixth Most Valuable Article first-place award.

Second Place

The Current Status of Chinese Freshwater Cultured Pearls
Shigeru Akamatsu, Li Tajima Zansheng, Thomas M. Moses, and Kenneth Scarratt

Shigeru Akamatsu is former manager of the Pearl Research Laboratory and currently general manager of the Sales Promotion Department, K. Mikimoto & Co. Ltd. A graduate of the Tokyo University of Fisheries, he is vice-president of the CIBJO Pearl Commission. **Li Tajima Zansheng** is president of Stream Co., Tokyo and Hong Kong. Mr. Li, a graduate of Yokohama National University, began dealing Chinese freshwater cultured pearls in 1986. **Thomas Moses** is vice president of Identification Services at the GIA Gem Trade Laboratory in New York. Mr. Moses, who attended Bowling Green University in Ohio, is also an editor of the GTLN section. **Kenneth Scarratt** is laboratory director at the AGTA Gemological Testing Center in New York. A member of the *Gems & Gemology* Editorial Review Board, Mr. Scarratt is one of the very few to have been entrusted with examining the British Crown Jewels.

Third Place

Discovery and Mining of the Argyle Diamond Deposit, Australia
James E. Shigley, John Chapman, and Robyn K. Ellison

James Shigley is profiled in the first-place entry. **John Chapman** is an independent diamond scientist in Perth, Australia. Mr. Chapman, who has a bachelor's degree in physics, has spent the past 15 years in the diamond industry doing geological assessments, economic analyses, and gemological research. **Robyn Ellison** is a senior business analyst with Argyle Diamonds in Perth, Australia. With an MBA from the University of Western Australia and an extensive background in the diamond industry, she has been closely involved in the strategy and planning of Argyle's marketing initiatives for the last 10 years.



Shigeru Akamatsu



Li Tajima Zansheng



Thomas M. Moses



Kenneth Scarratt

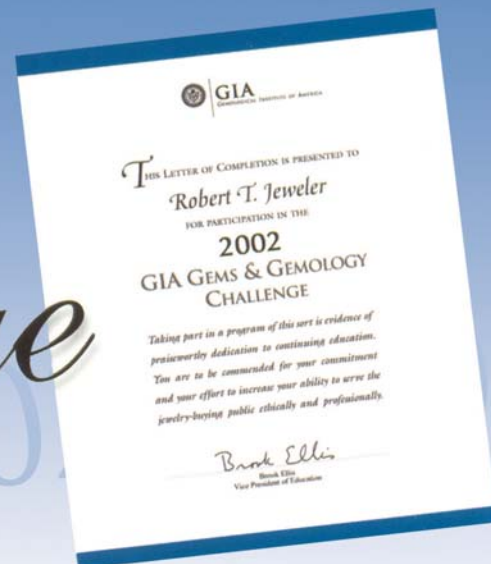


John Chapman



Robyn K. Ellison

GEMS & GEMOLOGY Challenge



The following 25 questions are based on information from the four 2001 issues of *Gems & Gemology*. Refer to the feature articles and “Notes and New Techniques” in those issues to find the **single best answer** for each question; then mark your choice on the response card provided in this issue. (Sorry, no photocopies or facsimiles will be accepted; contact the Subscriptions Department—dortiz@gia.edu—if you wish to purchase additional copies of this issue.) Mail the card so that we receive it no later than Monday, August 5, 2002. Please include your name and

address. All entries will be acknowledged with a letter and an answer key **after the due date**.

Score 75% or better, and you will receive a GIA Continuing Education Certificate. If you are a member of the GIA Alumni Association, you will earn 10 Carat Points toward GIA’s Alumni Circle of Achievement. (Be sure to include your GIA Alumni membership number on your answer card and submit your Carat card for credit.) Earn a perfect score, and your name will also be featured in the Fall 2002 issue of *Gems & Gemology*. Good luck!

- The most common method of producing or enhancing color in South Sea “golden” cultured pearls involves
 - irradiation.
 - high pressure and high temperature.
 - a chemical or organic dye.
 - bleaching.
- Australia’s Argyle diamond mine is a major source for
 - exceptionally large diamonds.
 - brown and pink diamonds.
 - vivid blue diamonds.
 - well-formed cubic rough that is easily polished.
- Considering fire and brilliance together for round-brilliant cut diamonds, cutters should remember:
 - There are many sets of proportions that will yield average to above average results for both.
 - It is possible to determine a single set of proportions that will deliver maximum performance in a single round brilliant.
 - Smaller table size increases results for both.
 - Facet size was found to have little effect.
- Ammolite is
 - a mineral with the composition CaCO_3 that is found in metamorphic rocks.
 - a trade name for the iridescent nacreous layer of certain fossil ammonites.
 - being formed today in mollusks found in the Pacific and Indian Oceans.
 - identical in all respects to the iridescent shell material called lumachelle.
- The bright orange color of gem spessartine from Ramona (San Diego County, California) is achievable only with low ____ contents.
 - Fe
 - Mn
 - Ca
 - Al
- Which of the following was [were] found to have a significant effect on the amount of fire produced by a round brilliant diamond?
 - Culet size
 - Girdle thickness
 - Lower-girdle facet length
 - Both A and B, taken together
- One historical source of inspiration for the works of North American gem cutters has been the ____ era, in which gem carvings and glass were included in pieces of fine jewelry.
 - Edwardian
 - Art Nouveau
 - Art Deco
 - Victorian
- The best explanation for the iridescence of Ammolite is

- A. interference.
 B. diffraction.
 C. the incorporation of chromophores during formation.
 D. diffusion treatment of the rough material after it has been mined.
9. Indications that the asterism in a polished gem has been artificially created might include
 A. an unusual number of rays in the star.
 B. an unnatural appearance of the rays in the star.
 C. a gem variety that rarely displays asterism.
 D. all of the above.
10. Argyle diamonds are found in
 A. eclogitic kimberlite.
 B. peridotitic kimberlite.
 C. olivine lamproite.
 D. lamprophyre.
11. The greatest production of gem-quality “Paraíba” tourmaline from the São José de Batalha mine occurred in
 A. 1982–1983.
 B. 1990–1991.
 C. 1998–1999.
 D. 2000.
12. The most diagnostic chemical elements for identifying synthetic red beryl are
 A. V and Cr.
 B. Cu and Zn.
 C. Mn and Fe.
 D. Co and Ni.
13. The vast majority of diamonds from Australia’s Argyle mine are polished in
 A. Antwerp.
 B. Israel.
 C. India.
 D. Thailand.
14. Fire in a round brilliant diamond is
 A. the same as dispersion.
 B. the result of dispersion.
 C. the amount of light emanating from the crown.
 D. the result of diffusion.
15. Although there is no universally accepted definition, the term *malaya* is generally used for garnets that are pink to pinkish orange, composed primarily of
 A. spessartine-almandine.
 B. intermediate pyrope-almandine.
 C. intermediate pyrope-spessartine.
 D. low-Fe, low-Cr pyrope.
16. A characteristic feature of hydrothermal synthetic red beryl is the presence of _____-related absorption bands between 4200 and 3200 cm^{-1} .
 A. iron
 B. titanium
 C. cobalt
 D. water
17. As used in the article, “Paraíba” tourmaline is a trade term that
 A. may not be applied to a cuprian tourmaline with more than 2 wt.% CuO.
 B. may be applied to any tourmaline, regardless of geographic origin, that contains 0.1–2.0 wt.% CuO.
 C. may only be applied to a tourmaline that contains at least 0.1 wt.% CuO and comes from Brazil’s Paraíba State.
 D. applies to any elbaite from Brazil’s Paraíba State regardless of color and CuO content.
18. Since the late 1990s, spessartine production from Ramona, California, has been overshadowed by fine material from
 A. Madagascar and Tanzania.
 B. Namibia and Nigeria.
 C. Colombia and Canada.
 D. Afghanistan and Pakistan.
19. Ammolite currently is fashioned primarily into
 A. stabilized solids.
 B. free-form naturals.
 C. assembled stones (triplets).
 D. assembled stones (doublets).
20. To achieve the best luster and color, Chinese pearl culturers typically
 A. culture mussels that are at least 5 years old.
 B. insert pieces of tissue into the posterior mantle lobe of the *H. cumingi* mussel.
 C. insert pieces of mantle tissue from the Akoya oyster.
 D. use beads fashioned from wax.
21. Spessartine from Ramona, California
 A. is characterized by abundant inclusions of fine apatite crystals.
 B. may have linear clouds and inclusions of albite and columbite.
 C. has R.I. and S.G. values that distinguish it from other pegmatite gem spessartines worldwide.
 D. is impossible to distinguish from Mexican fire opal of the same color.
22. Since the early 1980s, deposits of the relatively rare gem mineral jerejevite have been reported in each of the following localities except
 A. Namibia.
 B. the Eifel region of Germany.
 C. Madagascar.
 D. Tajikistan.
23. The following characteristic(s) are indicative of natural yellow color in South Sea cultured pearls from *Pinctada maxima*:
 A. absorption in the UV region between 330 and 385 nm.
 B. brown fluorescence to long-wave UV radiation.
 C. very light blue fluorescence to long-wave UV radiation.
 D. both A and B.
24. Inclusions of _____ provide unequivocal evidence that a pale purplish pink pyrope is from Italy’s Dora Maira Massif
 A. ellenbergerite
 B. dolomite
 C. wollastonite
 D. tinaksite
25. For more than 70 years, _____ has formed the backbone of pearl identification.
 A. Raman spectrometry
 B. infrared spectroscopy
 C. proton-induced X-ray emission [PIXE] analysis
 D. X-radiography

EDITORS

Susan B. Johnson
Jana E. Miyahira-Smith

Christie's Guide to Jewellery

By Sarah Hue-Williams, 160 pp.,
illus., publ. by Assouline Publishing,
New York, 2002. US\$18.95

This book derives its impetus from the myriad questions that Christie's jewelry specialists have fielded over the years from clients, consigners, and the curious public. The implied questions are answered in a nontechnical, user-friendly manner. The introductory chapter, "What to Look for in a Jewel," is particularly useful. It breaks the jewel down into components of intrinsic value, quality of materials, design, signature, provenance, condition, and that elusive "Factor X—the overall appreciation of the beauty of a jewel . . . influenced by individual sentiment and style." The individual knows best how much he or she values a particular piece, which is something the retailer should *always* keep in mind.

The second chapter, which travels in time from Georgian to contemporary eras, is richly accentuated with emblematic photographs of jewelry and their famous (and infamous) wearers. The second half of the book concentrates essentially on the Big Four—diamond, ruby, sapphire, and emerald. Rich in tidbits, this chapter will add the "romance" to any jeweler's sales technique.

Surprisingly, there are only four modest pages on Christie's considerable 200+ year history, which demonstrates the intent of the book: to discuss jewels and jewelry, not the firm. This compact book could serve as a primer for those who wish to start an estate jewelry department but are clueless as to eras, motifs, designs, and

styles. Clearly the book is not meant to be a gemological text or an in-depth look at estate jewelry. Rather, this overview is a great start toward properly evaluating estate materials, one that encourages readers to investigate further on their own.

GAIL BRETT LEVINE

Publisher, Auction Market Resource
Rego Park, New York

The Theory & Practice of Goldsmithing

By Erhard Brepohl, 536 pp., illus.,
publ. by Brynmorgen Press, St.
Portland, ME, 2001. US\$70.00*

The enormous effort involved in bringing this text from its original German-language version to the English translation is a testament to its quality and worth. Dr. Brepohl's original version was published in 1964, in what was then East Germany. The text remained primarily behind the Iron Curtain until after the Berlin Wall fell in 1989. It was during this time that Dr. Brepohl revised and expanded the text, and then Charles Lewton-Brain and Tim McCreight—renowned goldsmiths and authors in their own right—obtained the rights to translate the book into English. After 10 years, the translation was completed, and Dr. Brepohl's knowledge became available to the English-speaking world.

The Theory & Practice of Goldsmithing is a thorough survey of the entire goldsmithing field. It gives very technical explanations for the basic tools of the trade, using wonderful illustrations, chemical formulas, and physics equations. Advanced techniques also are covered in detail, with

step-by-step instruction and explanations for how and why the different techniques work.

This text is intended for intermediate to advanced goldsmiths. Although the discussion starts with the basics, it quickly advances in complexity. A jeweler with a solid understanding of bench skills will learn many new tricks of the trade, but a novice may have some difficulty understanding the information. So often, the true meaning of a text is lost in the translation. In this case, however, the translation from German to English was well executed, and the text is easily read and understood. The writing style is deliberate, organized, and flows well from one topic to the next.

Dr. Brepohl begins with the characteristics of the metals used in the industry. He explains how metals bend, deform, harden, and react to heat and chemicals. The topics proceed in complexity and difficulty through hand skills and tools to production techniques such as casting and die striking. There are particularly good chapters on hinges, catches, and findings. I was enthralled by the superb diagrams and technical drawings. I suspect that many jewelers will be inspired, as I was, to make their own versions of these projects. However, some of the charts, graphs,

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

and equations can be difficult to understand unless you have an engineering or physics background.

The book is of sturdy construction and will hold up well to heavy use as a reference guide. It is an excellent investment for any goldsmith's shop.

MARK MAXWELL

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Fabergé Eggs: A Retrospective Encyclopedia

*By Will Lowes and Christel
McCanless, 286 pp., illus., publ. by
Scarecrow Press Inc., Lanham, MD,
2001. US\$65.00*

"Companion" books, which illuminate and explain the background of great art, music, and literature, have been a welcome tradition for at least the last century. The authors of this book are lifelong devotees of famed jeweler Peter Carl Fabergé's *objets d'art*. They have created an excellent companion to Fabergé's works, one that will be a major resource for decades to come.

The decorative Easter eggs that the House of Fabergé created for the Russian imperial family between 1885 and 1917 represent the pinnacle of Fabergé craftsmanship and have become the stuff of legends, sought after by some of the world's wealthiest collectors. Less well known is that Fabergé also created a number of major eggs for other wealthy clients. All are discussed in this work.

The introduction explains the authors' methods in presenting the history of each of the 66 Fabergé eggs, including some for which current whereabouts are unknown or that are unavailable for public viewing. It also provides brief biographies of recognized Fabergé scholars.

The first chapter takes advantage of the recently opened Russian archives to offer new research on Czarinas Marie and Alexandra Fedorovna, for whom Fabergé created many of his most exquisite eggs. The chapter describes how Fabergé walked a tight-

rope trying to please the mercurial members of the Russian Imperial family. First there was the brusque, commanding Czar Alexander III and the witty, outgoing Czarina Marie. They were followed, on Alexander's death in 1894, by the equivocating and easily dominated Nicholas II and his aloof, shy Czarina Alexandra. To complicate matters, Alexandra and her mother-in-law had an extremely difficult relationship, and "a negative word from either of them would have surely ended [Fabergé's] commissions." The chapter also gives short summaries of the meanings behind the themes of the famous eggs, as well as a brief, well-written account of the tragic fates of Nicholas and Alexandra. A subchapter titled "Let the Sales Begin" recounts the intrigue and mystery that surrounded these treasures after the fall of the regime, and offers conjecture on the fates of the eggs that have been lost.

The main body of the work discusses chronologically, and in detail, the 66 eggs. Listed are the workmaster who supervised construction and the hallmarks, materials, and dimensions of each. Additional information includes background notes, provenance, exhibitions, and published references. The descriptions go into considerable detail about the outside decorations, the "surprises" inside each egg, and the stand. In writing the background for each of the eggs, the authors attempt to "humanize" them by relating stories about their creation and presentation.

The provenance section records all the known owners, including sales venues and prices paid. The exhibitions section cites all the public showings, and the references list major pertinent books and articles on each egg. The final chapter, "Who's Who in the House of Fabergé," lists all the leading designers and workers employed by Carl Fabergé as well as showing and explaining all the hallmarks found on the eggs.

Appendices detail the auction of 16 of the eggs and the exhibitions from 1900 to 1997. A glossary explains technical and French expressions used in

the descriptions and—valuable for a gemologically oriented audience—correct names for materials that had been misidentified in the past. (For instance, bowenite used in three of the eggs was often described as pale jade.)

There are color photos of 26 eggs in the middle of the book, but it is unfortunate that the photos could not have been placed with the descriptions of the appropriate egg. Including page references for photos would have been very helpful to the reader.

The most complete collections of Fabergé eggs are on view at the Forbes Magazine Collection in New York, and the Kremlin Armory Museum in Moscow. This book will serve as an excellent guide for those lucky enough to see the exhibits of these exquisite, intricate works of art, and as an invaluable resource for anyone researching the eggs or the House of Fabergé.

RUSSELL SHOR

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Colored Gemstones: The Antoinette Matlins Buying Guide

*By Antoinette Matlins, 180 pp.,
illus., publ. by Gemstone Press,
Woodstock, VT, 2001. US\$16.95**

Diamonds: The Antoinette Matlins Buying Guide

*By Antoinette Matlins, 184 pp.,
illus., publ. by Gemstone Press,
Woodstock, VT, 2001. US\$16.95**

To really appreciate the value of these books, think back to the way things were before such buying guides existed. Most books on gems either covered jewelry history or gemology. Little or no information was available on how to make an intelligent buying decision. For the most part, consumers had to rely on the knowledge and experience of their favorite jeweler. Many of today's consumers want more information and more options, and they are willing to spend the time and money needed for that purpose. To answer critical buying questions, it takes an author who has been immersed in the

jewelry business, has seen the full range of material, and is able to share those experiences in a thorough yet easy-to-read manner. Antoinette Matlins has managed to do just that with her *Colored Gemstones and Diamonds* buying guides.

Colored Gemstones starts out with the lore and romance of colored stones, including various charts for birthstones, zodiac stones, and anniversary stones. From there you get a practical lesson in examining a stone and the four C's of colored stone value. Next are examples of various colored stone laboratory reports, followed by an important chapter on synthesis and treatment. A seven-page chart lists the types of treatment for each gem, along with their frequency, stability, care required, and comments. A separate chapter titled "Fraud and Misrepresentation in Colored Gems" exposes some of the deceptive practices and terminology used in the trade.

The chapter "Buying Colored Gems" presents color options and comparative price lists to help the reader make an informed choice. This is followed by 50 pages of information on every major colored gem from alexandrite to zoisite, which is supported by a 16-page center section with more than 100 full-color photos. Additional chapters cover subjects that range from choosing a reputable jeweler to the care and cleaning of gems.

Ms. Matlins's *Diamonds* buying guide handles everything from early lore and history to the latest information on diamond cut and treatments. Cut is presented in two chapters on shape and proportions, and is also an important part of a third chapter, on diamond grading reports. The author offers information on early cuts and classic shapes, as well as new cuts such as Gabrielle, Spirit Sun, and Context. She not only discusses the concept of "ideal proportions," but she also shows how the various percentages, angles, and other cutting factors affect beauty and value.

Diamond color is addressed in two chapters. The first one covers GIA's D-to-Z color grading system, as well as how fluorescence can affect beauty and

value. The second chapter deals with fancy-color and treated-color diamonds.

The subject of treatments appears at appropriate times throughout the book, with information about such enhancements as fracture filling, laser drilling, and HPHT. The author also discusses their effect on value and the importance of disclosure. Additional chapters include coverage of clarity, carat weight, and choosing a setting; "Important Information Before & After You Buy"; and the selection of a reputable jeweler.

Although these informative buying guides are aimed at the retail consumer, they are also useful for anyone in the business of colored stones or diamonds.

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MEDIA REVIEW

The Gem Hunter in Afghanistan, an *Epo-film production, Bristol, England, 2002. 52 minutes, available in VHS and DVD formats. US\$29.95.* "A journey to visit the oldest mine in the world" is how this exciting video documentary describes its storyline. Featuring Gary Bowersox, an American gem dealer who has traveled to central Asia for decades, *The Gem Hunter in Afghanistan* is a professionally produced travelogue of his clandestine entry into northern Afghanistan during the summer of 2001 to visit the region's 7,000-year-old lapis lazuli mines.

Beginning in the Pakistani gem trading city of Peshawar, Bowersox negotiates the intricacies of local gem buying customs, with a monologue that is at times quite profound. His own voice alternates with that of a professional narrator quite effectively throughout the film.

With his trusty sidekick Khudai dealing with the obstacles of third world travel, Bowersox and the film crew head north in a minibus into the Hindu Kush Mountains, maneuvering through washed-out roads and avoiding police checkpoints. The

excellent soundtrack accompanying the journey is at times suspenseful, at times dramatic, but never obtrusive. Along the way, one is treated to the rich panoply of cultures that comprise the population at this crossroads of the ancient world.

At the end of the road, they switch to horseback and begin the three-day trek across the rugged mountains, sleeping in caves, and into the back door of Afghanistan. The terrain is bare, the frigid air is almost palpable, and the views are breathtaking.

Using cinematic dissolves, the scenes become ethereal as the party crosses paths with the ghosts of explorers from millennia past—Marco Polo and the armies of Alexander the Great. They are all traveling along the Silk Road, the legendary trail between Europe and China, over which trade has flowed for centuries—gems, spices, and now guns.

Deeper into Afghanistan, they reach the first villages; here, except for the ubiquitous Toyota pickups, the people are still living in the Middle Ages. Farther on, a side trip to the Panjshir Valley in search of emeralds begins with a poignant clip of the late Ahmed Shah Massoud, then the leader of the Northern Alliance, talking about the bright future of his country, the one he fought for but never saw. (Massoud was assassinated shortly before the attacks of September 11.) Remnants of the Russian incursion in the form of unexploded Soviet bombs litter the landscape, providing blasting powder for the industrious gem miners.

The tale comes to a close as they finally reach the lapis mines, with Bowersox pondering the fate of this nation with such a troubled past. Little did anyone know what lay just months ahead.

From this gemologist's perspective, one shortcoming is that there are so few gems seen in a story set in an area so rich in gemstones. But this is well compensated for by the insightful portrait offered of this rarely seen part of the world.

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COLORED STONES AND ORGANIC MATERIALS

Cultured pearls and colour-changed cultured pearls: Raman spectra. L. Li and Z. Chen, *Journal of Gemmology*, Vol. 27, No. 8, 2001, pp. 449–455.

Raman spectra were obtained from natural- and treated-color (i.e., dyed and irradiated) Chinese freshwater cultured pearls, as well as Tahitian cultured pearls. The spectra were useful in identifying the dyed cultured pearls, but not the irradiated cultured pearls. Chemical analyses (by atomic absorption for 16 elements) of four of the Chinese samples (white, orange, purple, and dyed dark purple) showed no characteristic variations. Compared to the Chinese samples, chemical analysis of one Tahitian cultured pearl showed a distinctly lower Mn content (1 ppm vs. 241–643 ppm) and possibly elevated contents of Na, Sr, and Fe. WMM

Research on relationship between colour and Raman spectrum of freshwater cultured pearl. Y. Gao and B. Zhang, *Journal of Gems and Gemmology*, Vol. 3, No. 3, 2001, pp. 17–20 [in Chinese with English abstract].

The Raman spectra of 500 natural-color freshwater cultured pearls from Zhuji, in Zhejiang Province, were studied to determine the cause of their color variations. The samples were divided into several color groups: white, light yellow-white, light yellow, yellow, light pink, pink, light purple, dark purple, and purple-black.

The Raman spectra of the organic components in all the cultured pearls were similar. However, the intensities of the Raman scattering peaks attributable to the organic components varied with color. The intensities of these peaks relative to those of aragonite were quantified with the ratio $R = S1/S2$, where S1 is the integrated area from 1165 cm^{-1} to 1095 cm^{-1}

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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(representative of the organic components), and S2 is the integrated area from 1095 cm^{-1} to 1070 cm^{-1} (representative of aragonite). The R value increased with the darkness of the color. For example, white cultured pearls had $R \sim 0.06$, while purple-black samples had $R \sim 12.73$. Therefore, organic components play a significant role in the color of these freshwater cultured pearls. TL

Study on the composition and structure of pearls. L. Y. Shi and S. G. Guo, *Journal of East China University of Science and Technology*, Vol. 27, No. 2, 2001, pp. 205–210 [in Chinese with English abstract].

Fifty freshwater cultured pearls from Zhejiang Province, China, were divided into eight groups on the basis of their luster and color, and all samples were studied by optical microscopy, X-ray diffraction, and scanning electron microscopy. The cultured pearls consisted of aragonite with small amounts of water and organic components; no calcite was found. In those samples with good luster, the aragonite crystals had a uniform size of about 2 μm and occurred in typical polygonal plate-like forms in regularly stacked layers. However, in those with poor luster, the aragonite crystals varied from plate-like to grain-like, and their size ranged from sub-micron to several microns. They also contained many tiny pores among the aragonite crystals, which are a major cause of the poor luster in those cultured pearls. These results are similar to those reported for Akoya cultured pearls. TL

Farming and processing fine quality, large, round freshwater pearls. B. Pan and Z. Wen, *Modern Fisheries Information*, Vol. 17, No. 2, 2002, pp. 15–17 [in Chinese].

With the increasing popularity of fine-quality large, round Chinese freshwater cultured pearls, bead-nucleation technology has been developing rapidly in China. However, there is little information on this new technology in the public domain. These authors—experienced researchers at the Freshwater Fisheries Research Center in the Chinese Academy of Fisheries Science, Wuxi—attempt to remedy this situation by briefly reviewing the current status of bead nucleation technology in Chinese freshwater cultured pearls.

There are two types of bead nucleation procedures currently being used: the normal (one-stage) approach and a new two-stage operation. The one-stage procedure is the same as that described in the article “The current status of Chinese freshwater cultured pearls,” by S. Akamatsu et al. (Summer 2001 *Gems & Gemology*, pp. 96–113). Three- to five-year-old mussels, typically 15–18 cm, are used. The best seasons for implantation are between September and November or between March and May.

The two-stage procedure is an experimental technique called the “cultured pearl cell solution method,” which is currently the subject of active research at several institutions in China. Based on modern bio-engineer-

ing technology, it involves the production of a special solution that contains a very high concentration of pearl cells (derived from the mantle tissue of a pearl-producing mussel). The bead nucleus is first immersed in this solution for an unspecified period (first stage), and sometime later (second stage) it is inserted into a pocket in the mantle lobe of a mussel *without* the piece of mantle tissue that is used in the typical one-stage bead-nucleation operation. Although large, round cultured pearls can be produced with this technology, the cost is significantly higher than that of the normal nucleation procedure.

Few details of the new procedure are given, but the authors express confidence that this technology will be a significant breakthrough in the bead nucleation of Chinese freshwater cultured pearls. TL

Fibrous nanoinclusions in massive rose quartz: HRTEM and AEM investigations. C. Ma, J. S. Goreva, and G. R. Rossman, *American Mineralogist*, Vol. 87, 2002, pp. 269–276.

In an earlier study (abstracted in the Winter 2001 *Gems & Gemology*, p. 348), these same authors found that pink nanofibers (<1 μm wide) were the cause of the pink coloration in massive rose quartz from 29 world localities. Although the fibers had many similarities to dumortierite (including X-ray diffraction pattern and pleochroism), their exact nature remained elusive. This article is a continuation of the earlier study; for this report, the authors used advanced techniques such as HRTEM (high-resolution transmission electron microscopy) and analytical electron microscopy (AEM) on samples of massive rose quartz from California, South Dakota, Brazil, Madagascar, and Namibia to determine precisely the mineralogical, crystallographic, and chemical characteristics of the fibers.

The authors determined that the nanofibers in all samples are related to dumortierite, but there are distinct differences. Compared to dumortierite, the fibers contained a greater amount of Fe substituting for Al in the M1 lattice sites. The pink coloration of the fibers results from intervalence charge transfer between Fe^{2+} and Ti^{4+} in the M1 site. TL

Fluid inclusions in emerald from the Jos complex (central Nigeria). Y. Vapnik and I. Moroz, *Schweizerische Mineralogische und Petrographische Mitteilungen*, Vol. 80, No. 2, 2000, pp. 117–129.

The fluid inclusions in three emeralds from small miarolitic cavities in the Jos granitoid ring complex were studied. The crystals ranged from bluish green to yellowish green, and had eye-visible color zoning. Small multiphase inclusions were found in the central part of the crystals, whereas large multiphase inclusions were present in the outer areas. Halite, as well as calcite \pm Mg-calcite \pm aragonite, were the daughter phases identified in 20 multiphase inclusions by Raman analysis. Also present were

volatile-rich inclusions that were mainly composed of CO₂ and water. The authors infer that the conditions during the early and intermediate growth stages of the emeralds were T~400°–450°C and P~0.2–0.3 kbar. The fluid compositions and the daughter phases can be used to separate Nigerian emeralds from those mined in Colombia.

KSM

Geochemistry of agates: A trace element and stable isotope study. J. Götze, M. Tichomirowa, H. Fuchs, J. Pilot, and Z. D. Sharp, *Chemical Geology*, Vol. 175, No. 3–4, 2001, pp. 523–541.

Agate samples from 18 world localities—representing Precambrian to Recent volcanic rocks of diverse composition—were studied to provide information on their genesis and origin. In general, most trace elements in agates showed variations comparable to those of their various parent rocks. Elevated concentrations of certain pigmenting elements (e.g., Mn, Co, Cr, As) were commonly found in dispersed micro-inclusions (e.g., fine-grained iron oxides). The trace-element signatures suggest that agate is formed by circulating fluids during syn- and post-volcanic alteration of the host rocks.

Oxygen isotope compositions ($\delta^{18}\text{O}$ +16.4‰ to +33.4‰) varied with locality; heavier $\delta^{18}\text{O}$ concentrations were characteristic of agates from acidic volcanic rocks. Significant variations (up to 10‰) within single agate samples may be explained by kinetic effects during isotope fractionation (e.g., the formation of agate from a non-crystalline precursor), or by mixing processes involving meteoric and magmatic fluids. The temperature of agate formation varies from about 50° to 250°C, depending on the composition of the fluids.

TL

Geology of the amber-bearing deposits of the Greater Antilles. M. A. Iturralde-Vinent, *Caribbean Journal of Science*, Vol. 37, No. 3–4, 2001, pp. 141–167.

Detailed geologic descriptions are presented of the rocks that host and surround the amber deposits of the Dominican Republic and nearby countries. Commercial amber production (including unique blue amber from the El Cacao mine) is derived solely from the upper portions of the Yanigua and La Toca Formations in the Dominican Republic. Only trace occurrences of amber are known in Puerto Rico, Jamaica, and Haiti; no amber has been found to date in Cuba. Amber is virtually always associated with lignite (low-grade coal), except possibly in Jamaica.

The Yanigua and La Toca Formations consist of amber-bearing lignite in discontinuous beds with carbonaceous clays, sandstone, thin shale beds, and thick basal conglomerates. Using paleontological data, the author dated the amber-bearing occurrences as Early to Middle Miocene (~16 million years ago), and reconstructed the paleo-environments during formation of Dominican Republic amber.

The author proposes that the creation and deposition of amber in the Dominican Republic began with an abun-

dance of *Hymenaea protera* (the extinct resin-producing tree from which Dominican amber is derived). Environmental conditions (namely, a warm, humid climate) that induce resin production from the trees were required, followed by rapid burial of the resin (so it was protected from weathering). Diagenesis (chemical and physical modifications) of the resin into amber during burial was the final step. The possibility exists that commercially exploitable amber will be found in rocks of Early to Middle Miocene age in other locations within the Antilles. No gemological or production data are presented.

Keith A. Mychaluk

Mass mortalities of Japanese pearl oyster in Uwa Sea, Ehime in 1997–1999. T. Morizane et al., *Fish Pathology*, Vol. 36, No. 4, 2001, pp. 207–216 [in Japanese with English abstract].

Since 1996, mass mortalities of the Japanese pearl oyster *Pinctada fucata martensii* have occurred in western Japan. The deaths are accompanied by a reddish brown discoloration of the tissues, particularly the adductor muscle. To investigate the cause of the mortalities, from 1997 to 1999 the authors studied the entire culturing process, as well as environmental factors, in the Uwa Sea. Farmed and experimentally cultured pearl oysters were monitored, and histopathological examinations were performed.

The tissue discoloration appeared first in oysters from the southern part of the Uwa Sea, which experienced high temperatures in June, and then extended to all the culturing areas from August to November. Death occurred approximately one month after the appearance of the discoloration. As water temperature declined in October and November, the mortalities tended to decrease. Thus, the disease is highly dependent on water temperature. Low water temperatures during the previous winter appeared to suppress the occurrence of the disease in the following growing season, whereas high temperatures accelerated its occurrence and severity.

TL

An overview of China's pearl industry. H. Xie and L. Li, *Australian Gemmologist*, Vol. 21, No. 3, 2001, pp. 120–123.

In China, pearls were used as ornaments as early as 770–476 BC. The Chinese were the first to cultivate pearls, some 900 years ago. Freshwater cultured pearls were popular during the Qing Dynasty, between 1644 and 1912, but pearl farming had disappeared by the end of that era. Modern pearl cultivation began in the 1950s to 1960s and accelerated in the 1990s. The freshwater cultured pearl farms are mainly in Zhejiang Province, while saltwater pearl culturing is widely distributed in the coastal areas of Guangxi and Guangdong Provinces, as well as Hainan Island. During the 1990s, annual production of cultured pearls reached ~1,000 tons, of which 20 tons were cultured in saltwater. Prospects for the Chinese pearl culturing industry are discussed.

RAH

DIAMONDS

Brine inclusions in diamonds: A new upper mantle fluid.

E. S. Izraeli, J. W. Harris, and O. Navon, *Earth and Planetary Science Letters*, Vol. 187, No. 3–4, 2001, pp. 323–332.

Micro-inclusions in cloudy diamonds from the Koffiefontein kimberlite pipe, South Africa, were found to consist of three main types: silicates, carbonates, and brine. The silicates were either eclogitic or peridotitic, and both affiliations were associated with the carbonates and brine. The brine composition ranges were: water 30–42 wt.%; chlorine 19–22 wt.%; sodium and potassium 14–17 wt.%; Fe-Ca-Mg carbonates 22–25 wt.%; and silica 3–4 wt.%. These brines are different from previously described fluids trapped in fibrous diamonds, mainly in their high chlorine and low silica contents.

The close association of a carbon (carbonate)-bearing brine, silicate minerals, and diamond suggests that such brines are important to diamond growth in both eclogitic and peridotitic environments. The similarity of brine compositions in both environments may indicate that diamonds of both suites grew in a single event. Further, it is suggested that highly concentrated brine promoted diamond growth in the upper mantle. Diamonds with a high concentration of brine inclusions, as in these cloudy samples, are uncommon. Their scarcity suggests that brine is trapped only under unique growth conditions. AAL

Defects in coloured natural diamonds.

F. De Weerd and J. Van Royen, *Diamond and Related Materials*, Vol. 10, No. 3–7, March–July 2001, pp. 474–479.

Characterization of natural fancy-color (pink, "canary," chameleon, Australian blue-gray-violet, and certain Cape yellow) gem-quality diamonds with UV-Vis-NIR, FTIR, and EDXRF spectroscopy, as well as topographic short-wave UV radiation, showed that diamonds of different colors share similar properties. The brown and pink diamonds exhibited signs of plastic deformation, and the color of each was correlated to the deformation planes. Pink coloration resulted from two broad absorption bands—one with a maximum at 550 nm, and the other with a maximum in the ultraviolet region that extended into the visible spectrum. The brown diamonds displayed similar UV-Vis-NIR spectra, but had an additional absorption band in the infrared region at approximately 4150 cm^{-1} . Cooling a pink diamond to 77 K or irradiating it with short-wave UV radiation altered the broad absorption band centered at 550 nm, resulting in a more brownish appearance. This suggests that both a charge-transfer effect and plastic deformation may be responsible for the pink color.

At room temperature, the "canary" diamonds were bright yellow, whereas the chameleon diamonds appeared grayish "olive" green. Both types luminesced yellow to long-wave UV and red when exposed to blue light (450 nm). The "canary" diamonds exhibited several sharp absorption lines between 500 and 800 nm, but the nature of the defects

responsible for this absorption profile is not known. When heated to 250°C, cooled to 77 K, or exposed to short-wave UV, the chameleon diamonds turned bright yellow. Spectral analysis pointed to the existence of an energy-transfer effect, which is evidenced by changes in the broad absorption band responsible for the "olive" green color.

The Australian blue-gray-violet diamonds and some of the Cape yellow diamonds showed similar absorption lines between 700 and 1020 nm. The samples tested were type Ia with large concentrations of infrared-active hydrogen. Both color groups luminesced yellow to long-wave UV. The blue-gray-violet diamonds also phosphoresced, indicating energy-transfer effects. The authors suggest that a possible mechanism for this energy transfer may be the high concentration of hydrogen pinning the Fermi level. They also acknowledge that the influence of hydrogen on the Fermi level is still under investigation. SW

Diamonds from the Espinhaço Range (Minas Gerais, Brazil) and their redistribution through the geology record.

M. L. S. C. Chaves, J. Karfunkel, A. Hoppe, and D. B. Hoover, *Journal of South American Earth Sciences*, Vol. 14, No. 3, 2001, pp. 277–289.

Geologic and gemological evidence support the concept that diamond-bearing alluvial deposits presently found in Brazil's Espinhaço Range experienced several generations of extensive fluvial transport from a distant, unknown, primary source.

Geologic studies recognize three distinct periods in the history of these diamonds. The first was a Precambrian magmatic event (≥ 1.75 billion years [By]) in east-central Brazil, during which the diamonds were emplaced in the crust. During the second period (~1.75–1.70 By), the diamonds were eroded from their primary rocks and deposited in the Espinhaço basin, where several episodes of reworking occurred. Evidence for this includes the presence of diamonds in conglomerates of this age and the absence of certain diamond indicator minerals such as Cr-pyrope and chromite (extensive transport is required for the destruction of these minerals). During the third period, over the past ~550 million years, several more episodes of reworking occurred. Recent river systems have reworked all the earlier sources to produce economic gravels in some places.

Gemological data detailing the quality and concentration of diamonds from the Espinhaço Range also support a long transport history. Although the crystals are small (averaging 0.20–0.30 ct), their quality is higher than diamonds recovered directly from a primary deposit. Fluvial reworking and redistribution is a very efficient natural sorting process that preferentially destroys weaker and more included crystals. LT

New old miners.

G. Roskin, *Jewelers' Circular Keystone*, Vol. 172, No. 6, June 2001, pp. 78, 81, 82, 84.

Significant amounts of good-quality reproductions of antique-cut diamonds are currently entering the market,

and some are being sold without disclosure as genuine "old cut" stones. Some of these "new old cuts" can be recognized as such because they are cut for maximum weight retention, not beauty or attractive symmetry. For example, these stones have thick girdles that may be faceted, whereas the genuine cuts usually have thin, knife-edged frosted girdles. Further, the newer stones generally have smaller culets, and are likely to be shallower than old-cut diamonds. Original "Asscher cut" diamonds can be identified by larger facets that are less symmetrical than modern ones. Jewelers who sell the old-cut reproductions must be sure to properly disclose them to their customers. *KSM*

Optics may hold key to derailing contraband diamond trade. S. Redfearn, *Optics and Photonics News*, Vol. 13, No. 2, February 2002, pp. 20–22.

It is estimated that "conflict" diamonds (i.e., those that have been used to finance rebel uprisings or terrorist groups in Africa) constitute about 4% by value of the diamond market worldwide. At present, no reliable scientific method exists to identify such diamonds, but two avenues of research involving optical instruments may prove helpful.

Prof. George Rossman, of the California Institute of Technology in Pasadena, California, is studying soil and clay contaminants on the surface of diamonds using a mass spectrometer. Because these surface materials could be characteristic of certain countries, it is hoped that they will provide information about a diamond's geographic origin. The Royal Canadian Mounted Police is attempting to analyze internal impurities in diamonds using a spectrometer in conjunction with laser ablation; they also hope to identify impurities that will be characteristic of a specific geographic region. Although each approach has its challenges, the fundamental barrier to the success of both methods lies in the absence of a reliable database of conflict diamonds to use for comparison. Without accurate analytical technologies to identify conflict diamonds, the diamond industry and law enforcement agencies will have to continue to rely on secure transportation and documentation to keep these diamonds from entering the market. *DD*

Superdeep diamonds from the Juina area, Mato Grosso State, Brazil. F. V. Kaminsky, O. D. Zakharchenko, R. Davies, W. L. Griffith, G. K. Khachatryan-Blinova, and A. A. Shiryaev, *Contributions to Mineralogy and Petrology*, Vol. 140, No. 6, 2001, pp. 734–753.

Alluvial diamonds from the Juina area in western Brazil were characterized in terms of their morphology, syngenetic mineral inclusions, carbon isotopes, and nitrogen contents. Like other Brazilian diamonds, they showed a predominance of rounded dodecahedral crystals. However, their mineral inclusions were unique, being dominated by ultrahigh pressure ("superdeep") phases. Ferropicriase was the dominant inclusion; it coexisted with ilmenite, Cr-Ti

spinel, a phase with the major-element composition of olivine, and SiO₂. Ca-Si-perovskite inclusions coexisted with titanite, "olivine," and native Ni. Neither Cr-pyropite or Mg-chromite was found. The spinel inclusions were low in Cr and Mg, and high in Ti. Most of the ilmenite inclusions had low Mg, and some had very high Mn (up to 11.5 wt.% MnO).

This suite of inclusions is consistent with the derivation of most of the diamonds from depths near 670 km, and it adds ilmenite and relatively low-Cr, high-Ti spinel to the known phases of the superdeep paragenesis. These diamonds have a narrow range of $\delta^{13}\text{C}$ (–7.8 to –2.5‰), low nitrogen contents, and a predominant aggregated B center. These observations have practical consequences for diamond exploration; specifically, they suggest that "indicator minerals" associated with superdeep diamonds may not conform to traditional models (e.g., there may be no high-Cr pyropites). *RAH*

The United States of America: A cornerstone of the world gem diamond industry in the 20th century. A. A. Levinson and F. A. Cook, *Geoscience Canada*, Vol. 28, No. 3, September 2001, pp. 113–118.

This article traces the development of the U.S. consumer market for gem diamonds from the mid-19th century, starting with the "diamond culture" that began developing after the Civil War. By the end of that century, declared imports of all gem diamonds, rough and polished, had reached a "considerable \$17 million." Even at that time, America's economic situation had a profound influence on the world diamond market: The steep depression of 1893 caused De Beers to halve its mine production.

The percentage of world consumption of gem diamonds sold in the U.S. during the 20th century is presented. (Note that the authors distinguish between weight and value from 1975 to 1999, but could not for the period from 1906 to 1975.) Between 1914 and 1961, American consumers accounted for 75%–80% of world gem diamond sales, after which America's market share began declining and Japanese sales began rising.

By 1980, Japan had become the second major diamond-consuming nation (defined by the authors as a market that consumes at least 10% of the world's diamond supply by weight or value for a consecutive period of 10 years). Between 1988 and 1995, the Japanese slightly exceeded American diamond consumption (by value) during several of those years, with each country generally accounting for between 31% and 33% of the world market. Japanese consumption began declining in 1996 because of the country's economic downturn, but there was a corresponding rise in American consumption. Currently, the U.S. and Japan consume a combined 60%–70% of world gem diamond production by both value and weight.

The article concludes that throughout the 20th century, the world gem diamond industry has depended largely on a single consumer market: the United States. As new diamond mines are brought into production in

the 21st century, consideration must be given to the abilities of the market—especially the U.S. and, to a lesser extent, Japan—to absorb these additional diamonds.

RS

GEM LOCALITIES

Australian trade buoyed by new ruby and sapphire deposits.

J. Henricus. *Jewellery News Asia*, No. 210, February 2002, pp. 82, 84, 86, 88, 90.

Using modern geoscience and satellite-mapping techniques, geologists have located new, high-grade sapphire deposits in Australia with particular success in the Kew Valley and the Eastern Feeder Valley, both in the Kings Plains Creek sapphire field of northeastern New South Wales. These new deposits could support sapphire mining for up to 20 years. The Eastern Feeder Valley contains an estimated 1.5 million cubic meters of sapphire gravels with an estimated 200 million carats of salable rough. New deposits with good-quality sapphires have also been found at Lava Plains, in northern Queensland.

Despite recent decreases in production by some companies, the Australian corundum industry as a whole is optimistic because of the new finds. More Australian companies are starting to market their higher-quality stones independently, rather than sell their entire production in rough form to cutting centers, particularly Thailand. At least one major mining company has its production cut at its own factory in Bangkok and is selling polished directly to the trade.

JEM-S

The chemical composition of Burma jadeite ore and its significance. J. Yang, *Kuangwu Yanshi (Journal of Mineralogy and Petrology)*, Vol. 21, No. 4, 2001, pp. 28–30 [in Chinese with English abstract].

The results of electron-microprobe analyses for jadeite from Myanmar (Burma) are reported, and the color-producing mechanisms are discussed. The characteristic assemblages of selected trace elements (Cr, V, Co, Ni, Cu, Sn, Pb) and rare-earth elements (La, Ce, Sm, Eu, Yb, Lu) indicate that the jadeite was derived from serpentinized peridotite. This conclusion should help in prospecting for jadeite.

RAH

Textures and genesis of jadeite ore from Burma. J. Yang and Z. Wang, *Journal of Chengdu University of Technology*, Vol. 28, No. 4, 2001, pp. 363–365 [in Chinese with English abstract].

Fluid inclusions in over 100 thin sections of various textural types of jadeite from Myanmar were studied. The inclusions were two-phase (liquid-gas), and the salinity of the fluids ranged from 7.4%–8.3%. The fluid inclusion data suggested that the jadeite formed at temperatures of 200°–350° C and pressures of 500–800 MPa. The rare-earth element europium occurred mainly in the form of Eu^{2+} , which suggests that reducing conditions existed during jadeite formation.

TL

La collezione di gemme del Vicentino al Museo Civico “G. Zannato” in Montecchio Maggiore (Vicenza) [Gems from the Vicenza area in the collection of the Museo Civico “G. Zannato” of Montecchio Maggiore (Vicenza)]. M. Boscardin, *Museologia Scientifica*, Vol. 16, No. 1, 2000, pp. 51–60 [in Italian with English abstract].

A collection of some 500 samples, including faceted and cabochon gems, and polished or engraved ornamental stones, has been assembled in this museum in Vicenza, northeastern Italy. Prominence is given to “enhydros” (a variety of chalcedony in which entrapped water can be seen in the polished face, also termed “Vicenza drop”), and to specimens of xonotlite and johannsenite (gems peculiar to the Vicenza district).

RAH

Formation of the Denchai gem sapphires, northern Thailand: Evidence from mineral chemistry and fluid/melt inclusion characteristics. P. Limtrakun, K. Zaw, C. G. Ryan, and T. P. Mernagh, *Mineralogical Magazine*, Vol. 65, No. 6, 2001, pp. 725–735.

The Denchai gem sapphire deposits in Phrae Province, northern Thailand, are closely associated with late Cenozoic alkaline basaltic rocks. The sapphires occur in placer deposits in paleo-channels at shallow depths. Electron-microprobe analyses gave 0.32–1.98 wt.% Fe_2O_3 , 0.01–0.23 wt.% TiO_2 , <0.01 wt.% Cr_2O_3 , 0.01–0.03 wt.% Ga_2O_3 , and <0.03 wt.% V_2O_5 .

Three types of primary fluid/melt inclusions were recognized. Type I are CO_2 -rich inclusions with three phases (liquid H_2O , liquid CO_2 , and vapor), with the vapor phase comprising 10–15 vol.%. Type II are polyphase inclusions (vapor+liquid+solid) with a fluid bubble (20–30 vol.%), an aqueous phase (10–15 vol.%), and several solid phases. Type III are silicate-melt inclusions of vapor bubbles, silicate glass, and solid phases. PIXE analyses revealed high K (~4 wt.%) and Ca (~0.5 wt.%), Ti (~1 wt.%), Fe (~2 wt.%), Mn (~0.1 wt.%), and V (<0.03 wt.%), in addition to Rb (~70 ppm) and Zr (~200 ppm) in the silicate glass. The Ga_2O_3 contents and $\text{Cr}_2\text{O}_3/\text{Ga}_2\text{O}_3$ values (<1) of the sapphires favor their formation by magmatic processes. The presence of CO_2 -rich fluids and high K in the silicate melt inclusions link the origin of these sapphires to CO_2 -rich alkaline magmatism.

RAH

Sri Lanka gem industry: Past, present and future. P. G. R. Dharmaratne, *Gemmologie: Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 50, No. 4, 2001, pp. 199–206.

Sri Lanka has long been a major source of gemstones, and over the past century its gem trade has become one of the island's leading industries. Laws governing the leasing and mining of lands, and regulating the gem trade and its exports, have evolved over time to nurture a growing, sustainable trade. In recent years, new gem discoveries in traditionally productive areas have dwindled, and explo-

ration has shifted to new alluvial areas previously considered off-limits, such as plantations and forest preserves.

Sri Lanka has made a significant effort to protect its lands without hampering the island's economic development. Use of most machinery such as bulldozers and backhoes is now prohibited, and a percentage of money collected from land leases is designated for reclamation. To expand the gem industry, the government has offered tax benefits to members of the trade, import and export barriers have been lowered, and exploration for primary (rather than alluvial) gem deposits has been encouraged. Through legislative incentives, Sri Lanka hopes to offer a diverse array of gems and jewelry to the trade's international buyers, and to provide a stable market that will be attractive to foreign investors. The article contains interesting statistics (number of licensed gem miners, dealers, and lapidaries, and the value of gem and jewelry exports) for the decade 1991–2000. DD

INSTRUMENTS AND TECHNIQUES

Brandt proportion loupe. T. Linton, A. Cumming, N. Masson, and B. Sweeney, *Australian Gemmologist*, Vol. 21, No. 4, 2001, pp. 161–164.

Rapid sight methods for assessing diamond-cut proportions at 10× magnification are based on the capacity of a particular cut to provide a symmetrical pattern of reflections from the table and crown facets in the pavilion facets. The visibility of this pattern of light-to-dark reflections can be enhanced by viewing these reflections as red-enhanced images. This paper represents an evaluation by a committee of the Gemmological Association of Australia of a Triplet Proportion Loupe produced by Selwyn Brandt of The House of Jewellery (Sydney, Australia) that produces such red-enhanced images. It uses a modified 10× loupe that creates red reflections of the table and crown facets in the pavilion facets of diamond and so makes interpretation of rapid sight methods for assessing the quality of a diamond cut considerably easier to achieve. RAH

Dispersion measurement with the gemmologist's refractometer—Part 1. D. B. Hoover and T. Linton, *Australian Gemmologist*, Vol. 20, No. 4, 2000, pp. 506–516.

This paper reviews the history of the critical-angle refractometer, which may be used to measure dispersion, and the use of dispersion by gemologists. The theory behind the calibration of the critical-angle refractometer to measure dispersion is developed. RAH

Dispersion measurement with the gemmologist's refractometer—Part 2. D. B. Hoover and T. Linton, *Australian Gemmologist*, Vol. 21, No. 4, 2001, pp. 150–160.

Details are given of the procedures used by the authors to obtain an empirical calibration of two commercial criti-

cal-angle refractometers. This involves selection of light sources, linearization of dispersion curves by the Sellmeier equation, and details of the measurement process. Problems are recognized with values given in the literature for the dispersion of many gem materials. It is suggested that a thorough reexamination of gemstone dispersion data is needed. RAH

JEWELRY RETAILING

Going, going...gone! Moving merchandise on Internet auction sites. A. DeMarco, *Jewelers' Circular Keystone*, Vol. 172, No. 12, December 2001, pp. 76, 78, 80, 81.

Retail jewelers who once had to scrap jewelry that went unsold over a long period of time have found success offering it on the Internet auction site eBay. David Jewelers of Erie, Pennsylvania, reported that its online sales increased 50% since opening on eBay because it has developed a national clientele. Most of its eBay sales are inexpensive gold items that had been in stock for several months. Zales also sells through eBay in its "Zales Value Vault," which features inexpensive pieces.

Some gem dealers have closed their offices to sell their merchandise through eBay. Davidoff Jewelry of New York offers wedding and engagement rings to consumers exclusively through the auction site. At \$20 per listing, the cost runs up to \$20,000 a month.

eBay reported that 40%–50% of its jewelry business is conducted by independent jewelers working through the site, with another 15%–20% conducted by liquidators and mass merchandisers. The sales mix of jewelry-related items on eBay is 25% jewelry and 5%–10% watches and gemstones. The remainder is jewelry supplies, fixtures, and "raw materials" of all types. Other Internet auction sites are gaining popularity as well. RS

Virtually gone. I. Solotaroff, *Modern Jeweler*, Vol. 100, No. 11, November–December 2001, pp. 43–44, 46, 47, 49.

After rapid growth in 1999, online sellers of diamonds and diamond jewelry faded by the end of the following year. While brick-and-mortar jewelers and many diamond dealers reviled the upstart businesses, celebration over the demise of online diamond selling is premature. Several survivors, including Blue Nile and Diamond.com, have "gotten their numbers in line" and are expecting profits this year with anticipated sales of \$50 million and \$30 million, respectively. Blue Nile reported its first profits in August 2001, one of the first for any jewelry e-tailer. Diamond.com reported that their loose diamond sales average \$4,000–\$5,000.

An anonymous jewelry manufacturer quoted in a *Seattle Times* report cited in this article said that Blue Nile was "the second- or third-largest U.S. buyer of certified diamonds" (presumably behind Tiffany and Wal-

Mart), with 1% of U.S. bridal sales. The article also claimed that Blue Nile's sales were three times that of its nearest online competitor, with repeats and referrals accounting for 40% of its business. Blue Nile, which originally targeted male buyers, is now gaining female customers who have received Blue Nile products as gifts.

RS

PRECIOUS METALS

Coloured carat golds for investment casting. D. Zito, *Gold Technology*, No. 31, Spring 2001, pp. 35–42.

This article reports on testing of 18K yellow gold alloys with the additions of minor amounts of zinc (Zn), silicon (Si), cobalt (Co), and iridium (Ir), individually (for Zn) and in combination, for practical performance in investment casting. The goal was to maximize alloy castability. In addition to alloy composition, the shape of the casts was varied.

The addition of Zn, Si, and Co to 18 K yellow gold produced very slight color differences, but the addition of Ir resulted in a more desirable brightness to the metal. The grain size of an alloy was increased with the addition of Zn and decreased with Ir; a finer grain size improves the appearance and workability of the gold.

Vickers hardness evaluations of cast alloys showed only minor differences, with the exception of the Si-Co alloy, which is 5% harder. Age-hardening treatment increased hardness by 75% when compared to cast alloys. Greater hardness is desirable due to easier finishing and an improved outcome. Tensile tests found that Zn- and Ir-containing alloys were more reliable and better for casting. Si-bearing alloys performed best in deoxidation tests. With the scanning electron microscope, polished surfaces showed reduced pore size (gas porosity) in the alloys containing Zn+Ir, Zn+Si+Co, and Zn+Si+Ir.

The author concluded that 18K yellow gold alloys containing suitable elements perform better in the investment casting process. The preparation of these alloys should be done by metallurgical experts. PT

SYNTHETICS AND SIMULANTS

Jadeite and resin doublet—D-jade and its identification. C. M. Ou Yang and S. K. Fan, *Journal of the Gemological Association of Hong Kong*, Vol. 22, 2001, pp. 14–16.

Jadeite and materials that simulate it with a deep color and low transparency are sometimes cut thin (~1 mm) to improve their transparency. These materials may also be “base-dug,” or cut thicker and then hollowed out from the back. Even with this procedure, the thinness can create durability problems so the hollow is filled with resin. The result is a jadeite-and-resin doublet. The most popular material used to make the doublets is “dry green” (Ganqing), which is not true jadeite but predominantly the mineral kosmochlor. Another common starting

material is “Hte Long Sein” jadeite. It is important to recognize that the doublets consist of only 10%–20% jadeite (or other gem material); the balance is resin.

The authors feel that the jadeite-and-resin doublets should be called “D-jade” (“D” for doublet) to differentiate them from “A-jade,” “B-jade,” and “base-dug” jade. The identification of “D-jade” that is unmounted or in an open-back bezel setting can be done fairly easily, by noting the presence of transparent resin (with its resinous luster) on the base, measuring specific gravity (much lower than jadeite, floats in 2.88 heavy liquid), or obtaining an infrared spectrum (the epoxy resin differs from “B-jade” resin). For a set stone, this doublet can be recognized by illuminating the stone from the top and looking for scattering or reflections of the light in the underlying resin. JS

TREATMENTS

Heat treatments of Tanzania ruby as monitored by ESR spectroscopy. P. Winotai, T. Wichan, I. M. Tang, and J. Yaokulbodee, *International Journal of Modern Physics B*, Vol. 14, No. 16, 2000, pp. 1693–1700.

In Thailand, heat treaters enhance the appearance of slightly bluish rubies from Umba, Tanzania, by removing the blue color; clarity is also improved in the process. The ideal conditions under which this is accomplished were determined experimentally. Samples weighing 2–3 ct were heated at a rate of 4°C per minute, in an oxygen atmosphere. They were held at 1,200°, 1,300°, 1,400°, 1,500°, and 1,600°C for periods of 12 hours, and then cooled at 5°C per minute to room temperature.

ESR (electron spin resonance) spectrometry showed that the Fe³⁺/Cr³⁺ ratio increased almost linearly with increasing temperature, indicating that Fe²⁺ was being converted to Fe³⁺; this change resulted in a decrease in the blue color as the influence of Cr as a red chromophore became dominant. X-ray diffraction analysis showed a sharp decrease in the c/a (axial) ratio of the crystal structure at 1,200°C; this also contributed to a decrease in the blue color. Evaluation of the samples with the CIE L*a*b* color index showed that the most intense red occurred in those heated to 1,300°C. The authors concluded that the best temperature for removing the blue component of Umba ruby, and improving its clarity, is 1,300°C. KSM

Optimization of heat treatments of African green sapphires. P. Winotai, S. Saiseng, and T. Sudyoadsuk, *Modern Physics Letters B*, Vol. 15, No. 20, 2001, pp. 873–882.

The green color in corundum is caused by Fe²⁺ (or sometimes a high Fe²⁺/Ti⁴⁺ ratio). Yellow is commonly caused by Fe³⁺ (or Ni³⁺ to give a golden color). This article gives details of the optimum heat treatment developed for changing the color of sapphires from Umba, Tanzania, from green to yellow. The treatment involves the oxidation of Fe²⁺ to Fe³⁺; the effects of other trace chromophores

(e.g., Ti, V, and Cu) are ignored as they are generally very low in abundance (<0.2%).

The heating process took place in an oxygen atmosphere. X-ray diffraction studies showed the smallest c/a ratio of the crystal structure after heating to 1,200°C, which was confirmed by a shift in the visible-range emission spectra towards shorter wavelengths. ESR spectrometry showed that the amount of Fe²⁺ converted to Fe³⁺ in the heated samples increased linearly with temperature. An evaluation of the samples with the CIE L*a*b* color index confirmed that the change from green to an optimum yellowish green color occurred at 1,300°C. At higher temperatures, the color became bluish green.

Alethea Inns

Identification of GE POL™ diamonds. E. Fritsch, J.-P. Chalain, and H. Hänni, *Australian Gemmologist*, Vol. 21, No. 4, 2001, pp. 172–177.

GE POL diamonds are brownish type IIa diamonds that have been decolorized by an undisclosed high pressure-high temperature process. These color-enhanced diamonds can be identified by a laser-inscription ("GE POL") on their girdle and transparency to short-wave UV; they also may show weak to moderately intense cross-hatched graining, generalized haziness, etched surface-reaching cleavages, and rare mineral inclusions surrounded by discoid stress fractures. Using Raman photoluminescence spectrometry, the intensity of the nitrogen-vacancy (N-V) centers that absorb or emit light at 637 and 575 nm, respectively, give a 637/575 nm ratio greater than 2.5, whereas for untreated stones this ratio is less than 1.6. The full width at half maximum (FWHM) of the 637 nm band is higher in GE POL diamonds than in natural-color type IIa diamonds.

RAH

MISCELLANEOUS

Apparatus and method for grading, testing, and identifying gemstones. L. K. Aggarwal, U.S. Patent No. 6,239,867 B1, May 29, 2001.

This patent, assigned to Imagestatistics Inc. of Philadelphia, Pennsylvania, describes a method and associated apparatus for the standardized grading of gemstones. The system gauges the spectral response of a gemstone using a plurality of light sources, or *multispectral imaging*. The sources are not clearly identified but include both laser and white light, and both visible and invisible spectra are generated; various filters are required. The data generated (pixel data sets) are entered into a processor that contains a database obtained from reference specimens. The patent claims that the system is capable of identifying and grading a gemstone, as well as assessing its aesthetic and/or monetary value.

To achieve standard grading, the system is said to measure many physical properties (including brilliance, fluorescence, color, and flaws), as well as gemological attributes such as proportions. Yet no examples are presented of gemstones that have been graded by this system and com-

pared with results obtained by conventional methods in a gemological laboratory.

AAL

Investment demand for gold up 17%, jewellery down 10%.

Jewellery News Asia, No. 208, December 2001, p. 34.

The World Gold Council reported that demand for gold as an investment surged to 106 tonnes during the third quarter of 2001, an increase of 17% over the same period in 2000. The September 11 terrorist attacks were cited as the chief reason. The major investment buyers were located in Japan, South Korea, Vietnam, Malaysia, and the U.S.

However, global demand for gold jewelry declined 10% from the same period in 2000, to 649 tonnes of gold. This resulted in a net 7% decrease in gold consumption for the third quarter, as investment demand failed to offset the decline in jewelry demand. Demand for gold as an investment in Japan rose 91% from the previous year, while gold jewelry sales declined 7%. Jewelry demand in India, the world's largest gold-consuming market, declined 17%, while jewelry demand in the U.S. fell 2%.

RS

Shades of meaning: How does a gem's color emotionally impact the buyer? S. Wade, *Colored Stone*, Vol. 14, No. 6, 2001, pp. 38–41.

How does the color of a gem affect the buyer emotionally? What does a person feel when they see red? The answers to such questions are found in psychological studies that are uncovering deep links between our personalities and colors, proving that our psyches associate certain colors with certain emotions. Many of us are affected or react in the same manner when we see certain colors. We associate colors such as red and orange with passionate emotions that create a sense of appreciation or romanticism. Blue and green, on the other hand, are associated with calming effects or a sense of relaxation. The Institute for Color Research says 60%–70% of all purchase decisions are based solely on color.

Many people have an immediate emotional connection to metal and jewels. Mixing a warm metal (gold) with a warm stone (ruby), or a cooler metal (silver or platinum) with a blue, purple, or green stone, creates an "instinctive acceptance." Instead of asking clients their favorite color, the salesperson should find out what color makes them happy, or which color makes them think "I'd like to wear that." Studies have also shown that certain personality types prefer certain colors. Introverts favor blue, while extroverts tend to prefer red.

It remains to be seen whether future research will uncover further connections between our personalities and colors. For now, we do know that color is all about feeling. One has to feel good about wearing a stone of a certain color.

Michelle Walden