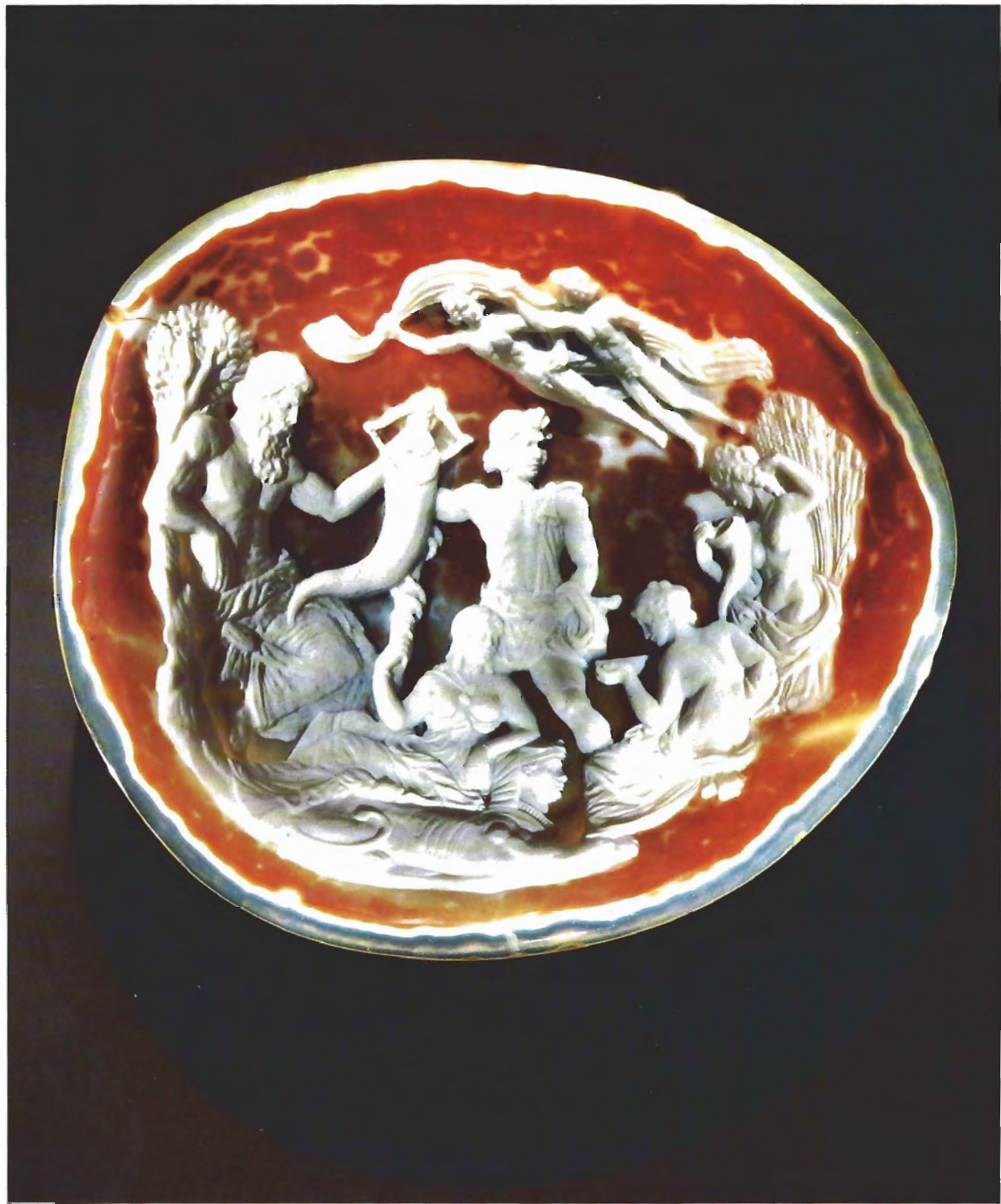


Gems & Gemology

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Gems & Gemology

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ABOUT THE COVER: This cameo bowl (8 in. × 7 in. × 2¼ in. deep; 20 cm × 18 × 6 cm deep) was fashioned from a single block of agate by master carver Richard Hahn, of Idar-Oberstein, Germany. It is representative of the fine carvings and other gem materials on display at the recently expanded and remodeled Deutsches Edelsteinmuseum in Idar-Oberstein, which is described in the article by Peter Keller in this issue. The bowl is courtesy of Gerhard Becker, Idar-Oberstein. Photo © 1983 Harold and Erica Van Pelt—Photographers, Los Angeles.

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Gems & Gemology welcomes the submission of articles on all aspects of the field. Please see the Suggestions for Authors for preparing manuscripts in the Summer 1983 issue of the journal or contact the Managing Editor for a copy. Letters on articles published in *Gems & Gemology* and other relevant matters are also welcome.

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SYNTHETICS MANUFACTURERS: SOME HELP, SOME HINDER

RICHARD T. LIDDICOAT, JR. Editor-in-Chief

Over a period of time, the laboratories of the Gemological Institute of America have worked with a number of individuals and firms whose occupation is the synthesis of gem materials. The products of many of these manufacturers have been described in the pages of this journal. In the process we have found wide variations in attitude toward the consuming public, the jewelry industry, and gem testing laboratories. There are huge differences in the degree to which manufacturers cooperate in their efforts to help jewelers and gemologists distinguish their products from natural counterparts. Some manufacturers provide information and samples before marketing a new product, some make continuing supplies available without charge, or at cost for use in instructional purposes; and a few go so far as to try to build some identifying characteristic into their manufactured gem materials.

Unfortunately, there are others who are not only uncooperative in the avenues mentioned, but seem to make every effort to make products that are indistinguishable from natural gemstones.

It is one thing for a very well equipped scientific gemological laboratory to be able to distinguish natural from artificial materials, but it is something else for the average, relatively poorly equipped small jeweler to detect the artificial product. Synthetics cut by hand by native workers in the Orient often have a deceptively natural appearance that one limited to the use of a loupe or even a microscope, but without significant experience, would find almost impossible to detect.

It is our opinion that the manufacturer owes the consuming public, as well as the jewelry industry, a high degree of cooperation, and that he or she should make every effort to ensure that synthetic gem materials are as readily identifiable as it is in the realm of possibility for that manufacturer to accomplish.

We commend those who do their best to assist. We condemn the approach of those who do their best to deceive.

KASHMIR SAPPHIRE

By David Atkinson and Rustam Z. Kothavala

The unique beauty of gem sapphires from Kashmir has brought fame to a locality about which little has been reported in recent years. After an initial burst of activity 100 years ago, the production of these gemstones has slowed to a trickle and the majority of the corundum from these mines today is of industrial grade. Despite evidence of other gem mineral occurrences in the area, difficult terrain and political factors have impeded their exploitation. This article, the result of an expedition to the deposits in 1981, chronicles the history of the Kashmir mines, describes the characteristics of the sapphires found there, and examines the outlook for the future of this area.

ABOUT THE AUTHORS

Dr. Kothavala, formerly lecturer on geology and director of the Science Center at Harvard University, is the owner of Crystals of India, a firm that specializes in mineral and gem specimens from India, and Rustam, a mineralogical consulting firm, in Oakland, California.

Mr. Atkinson is the owner of Terra, a firm specializing in rare gems and gem minerals, in Santa Barbara, California.

Acknowledgments: The authors are indebted to Meher, without whose material aid and contacts the expedition could not have succeeded. Dr. R. V. Gaines has generously provided specimens, references, and critical commentary.

Acknowledgment is also due to R. Miller, of Reginald C. Miller, Inc., New York, for his observations; J. Koivula, of the Gemological Institute of America, for his study of the Hixon Kashmir sapphire; Si and Ann Frazier, of Berkeley, California; and the Los Angeles County Museum of Natural History for their cooperation. The expedition owes its initial inspiration, in 1973, to R. A. Bideaux of Tucson and Professor Clifford Frondel of Harvard University.

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Since their discovery in 1881, the legendary sapphire deposits of Kashmir have acquired a reputation based on a mixture of fact and fantasy that is usually associated with the ancient gem mines of the world. Situated in the high Himalaya Mountains of northwest India and described in early reports as "the region beyond the snows," the locality is so remote that to this day only a handful of trained geologists have visited the site. Consequently, little has been published on the deposits in recent years and even less on the stones mined there. Because outsiders were strictly forbidden to enter the Paddar region of Kashmir until 1979, Dr. Kothavala's earlier efforts to visit the sapphire deposits were refused. In 1981, he invited Mr. Atkinson to join him in a renewed attempt to reach the mines. Until the authors' visit during the summer of 1981, the last known Westerner to inspect the site was R. V. Gaines in 1944. Accounts of that trip were published in 1946 and 1951 (Gaines). First reports, although informative and detailed, pertain only to the early years and lie scattered among the voluminous records of government geologists during the days of the British raj. More recently, in 1961, the state government of Jammu and Kashmir undertook a detailed feasibility survey, but the results of this study remain confidential. One reason for the dwindling worldwide interest in these mines is the paucity of fine gems produced after 1908. Such scarcity would long ago have doomed the locality to insignificance were it not for the unique beauty of the few stones that still emerge. Similarly, the inaccessibility of the mines is tempered only by the awe-inspiring beauty of their surroundings. Even the 19th-century geologists felt compelled to devote entire paragraphs to describe carpets of wildflowers and majestic scenery in their otherwise staid reports.

Few gemologists would dispute that a fine Kashmir stone displays a character that sets it apart in a world relatively abundant in corundum gems (figure 1). Over the years, the term *Kashmir* has come to signify the most desirable and expensive of blue sapphires. The protracted

territorial dispute between India and Pakistan over the state of Kashmir, plus the outlawing of private trade in Kashmir sapphires since the early 1880s by the maharajah, have conspired to surround the mining and trading of these stones with an aura of secrecy and suspicion. Add to that the extreme cultural isolation of the local people, whose small villages lie in narrow valleys among mountains that rise to more than 6,000 m (20,000 ft), and one has the necessary ingredients for a legend that compares with Shangri-La (figure 2).

The purpose of this article is to set the particular conditions pertaining to the area in perspective. It seeks to chronicle the major developments at this occurrence in the 100 years since its discovery, review what little literature exists on the subject, and provide some insights into the very limited but continuing trade in Kashmir sapphires today. In addition, a brief commentary on the geology of the area and a discussion of the gemological characteristics of Kashmir stones are provided.

HISTORY

As early as 1882 (Mallett) and 1890 (La Touche), reports by government geologists to the Geological Survey of India concurred that the discovery of sapphires in a glacial cirque above the village of Sumjam, on the southwest slopes of the rugged Zanskar Range (figure 3), was the result of a land-



Figure 1. This 6.7-ct sapphire from the Hixon Collection at the Los Angeles Museum of Natural History displays the distinctive velvety texture for which Kashmir stones are renowned. Photograph © 1978 Harold and Erica Van Pelt—Photographers, Los Angeles, CA.

slide that took place some time in 1881 (see chronology in box). Minor quakes and avalanches are frequent in this geologically active region. It is clear from various letters and communications by missionaries and traders who lived in the area at the time that the local inhabitants had been aware



Figure 2. Zanskari traders, crossing the high mountain passes, were first responsible for bringing the sapphires from Paddar to the attention of the outside world. Photo by Meher.

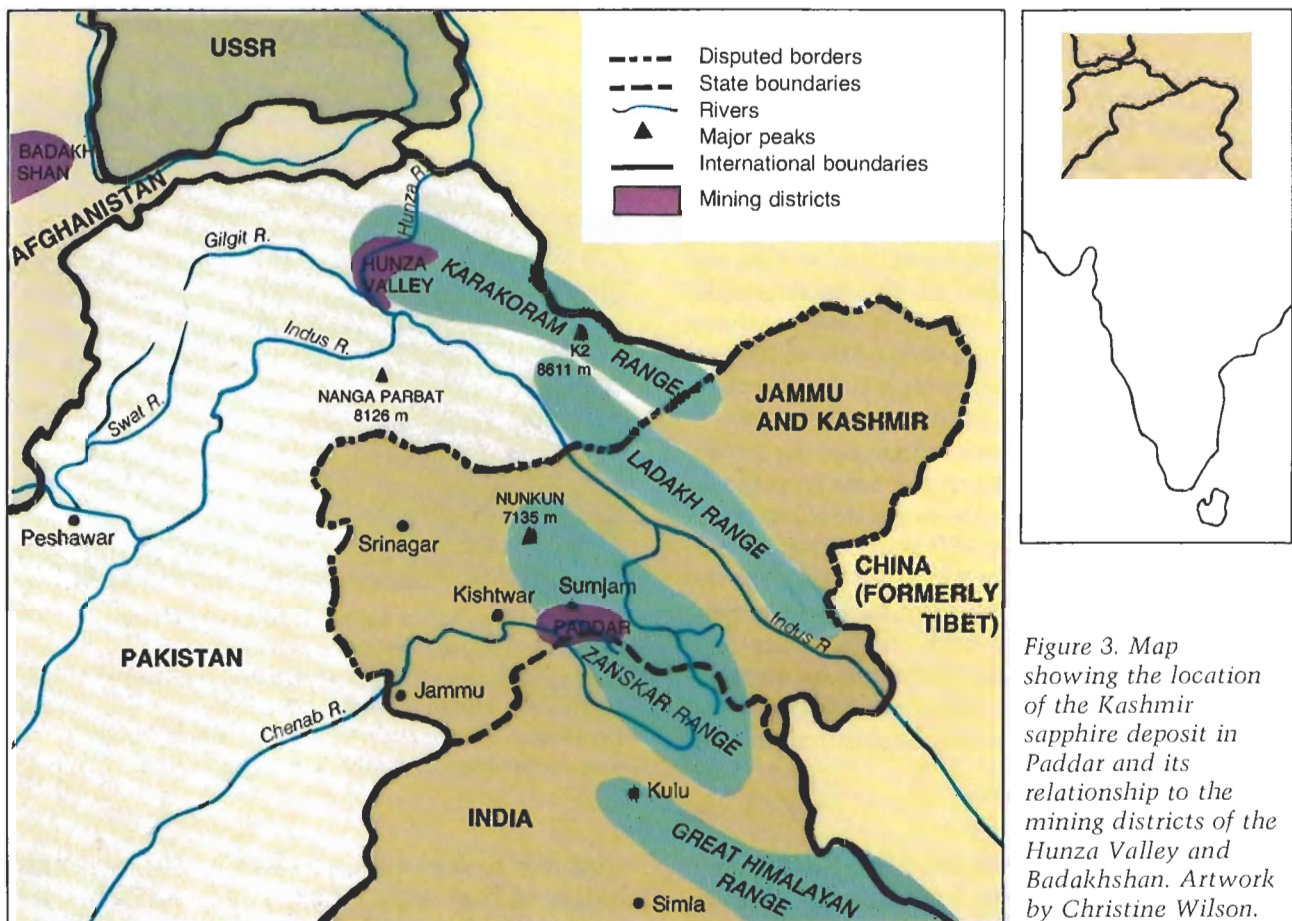


Figure 3. Map showing the location of the Kashmir sapphire deposit in Paddar and its relationship to the mining districts of the Hunza Valley and Badakhshan. Artwork by Christine Wilson.

of several different corundum deposits (Mallett, 1882; Shepard, 1883). Conversations with villagers during the expedition in 1981 verified that opaque, grayish corundum crystals had been used as flints and as crude abrasive tools from very early times. The exposure in 1881 of a concentrated pocket of gemmy blue crystals sparked enough local excitement to initiate exchanges with itinerant traders from the neighboring valleys of Zaskar and Lahul. After crossing the Umasi-La Pass (5,290 m) in order to reach Sumjam, in the valley of Paddar, these merchants were at first skeptical and had to be cajoled into trading the *nilam* ("blue stone") for salt on a weight for weight basis. Eventually, these stones found their way to larger commercial centers, usually in the company of more traditional and humble minerals, notably borax and salt. It was in the marketing centers of Kulu and Simla (the summer capital of India) that the crystals were positively identified and their true value recognized. The news spread quickly. By the end of 1882, a syndicate of jewelers had paid the equivalent of US\$90,000 for a lot of fine crystals (Mallett, 1882).

From these reports it can be inferred that the early production was quite abundant.

By 1883, the maharajah of Kashmir had claimed his rightful ownership of the mines and declared all private trade in the stones a punishable offense. Not surprisingly, the local Paddaris, disconnected from affairs of state, deeply resented the stationing of a contingent of the maharajah's elite Dogra guards at the mine. This sentiment persists still in the valley, where the authors had the opportunity to talk with both the local villagers and the police stationed at the mines. Until 1887, various government officials were dispatched to the mine to oversee the collection of sapphire on behalf of the state and to prevent rampant smuggling and raiding of the site, which later became known as the Old Mine (figure 4). Their efforts reaped enormous wealth for the state, and led to the fabled collection of crystals and gems held at the state treasury (some of which are described later in this article). As dramatically as it had begun, production slowed to a trickle as the initial pocket of sapphire was worked out. In 1887, the Kashmir Durbar acquired the services

CHRONOLOGY OF THE KASHMIR DEPOSITS

- 1881** A landslip exposes blue crystals embedded in altered pegmatites high on the north wall of the cirque. Local villagers begin trading for consumer goods. Tibetans from Zaskar trade salt for sapphires, weight for weight. Crystals begin to appear in Kulu, to the south.
- 1882** Crystals begin to appear in Simla, where syndicates of jewelers rush to buy them. About this time, the maharajah of Kashmir dispatches troops to guard the mine and prohibit dealing.
- 1883-1887** Mining operations are in the hands of the maharajah's army officers. Crystals up to 12.5 cm long and 7.5 cm wide are dug from the site, which would later become known as the Old Mine. The finest large stones are recovered during this period.
- 1887** T. D. La Touche undertakes the first detailed survey of the deposits for the Geological Survey of India in response to a request for assistance by the Kashmir Durbar. He finds the initial pocket exhausted and turns his attention to the exploitation of placers, which lie below the scree and talus on the valley floor. In the process, the last great sapphire, a 933-ct parti-colored stone, is found.
- 1888** La Touche's ingenious attempt to create a fresh landslide to uncover new deposits fails. During the summer of 1888, 23,300 ct of sapphire are mined, but the material yields few stones over 10 ct.
- 1889-1906** A 16-year lull in official operations. The flow of sapphires is restricted to illegal activities.
- 1906** The first mining by private interests is permitted. The maharajah of Kashmir grants a lease to the Kashmir Mining Company. The company's mining engineer, C. M. P. Wright, after detailed analyses, reworks the earlier placer deposits and obtains many fine stones.
- 1907** An experimental trench is dug a few hundred meters to the southeast of the Old Mine. Although some corundum crystals are discovered, the potential value of what will later be known as the New Mines complex goes unnoticed.
- 1908** Difficulties of climate and conditions force Wright to abandon the project.
- 1911** The area is worked for a season by the state mining and prospecting officer, Lala Joti Prashad. Only gray and semitranslucent corundum is found, confirming the popular belief that the source is depleted.
- 1924** Noted Himalayan geologist Pandit Labhu Ram Badyal undertakes a detailed mapping of the area, and announces the discovery of several occurrences of sapphire (some pink).
- 1926** A prospecting license is granted to Lala Jagan Nath, who reopens the trench begun by Wright in 1907. Over 60 kg of sapphire-bearing corundum are removed from these "New Mines" until the license is revoked in 1927 for undisclosed "irregularities."
- 1927** Over 450 kg of rough corundum crystals are extracted from Lala Jagan Nath's trench in 15 days.
- 1937** Production of sapphire falls significantly, marking an end to the second phase of mining in Paddar.
- 1938-1943** The lowest yields are reported during this period, undoubtedly a result of the outbreak of World War II.
- 1944** R. V. Gaines visits the deposits, gaining access from the south. The first Western geologist to visit the site in many years, he collects some specimens, which are later lost.
- 1945-1951** Sporadic mining by private lessees. Although production is substantial, the stones are not as good as those found during the early years.
- 1952-1959** The government of Kashmir mines the deposits intermittently, mostly at an operating loss, while maintaining exclusive control of the mine.
- 1961** The Kashmir government's assistant geologist, P. L. Raina, compiles a detailed but confidential report on the Kashmir mines.
- 1969** The last public sale of rough sapphire to date takes place in Srinagar.
- 1970-1979** Various agencies of the state and central governments, in turn, survey the deposits and formulate mining strategies, but no new developments occur. Most years, the production is not profitable. Helicopters are employed to transport the yield to processing centers further south. Few major stones appear in the government takings.
- 1979** Mining operations cease. The government once again considers negotiating a lease with closely scrutinized but independent operators.

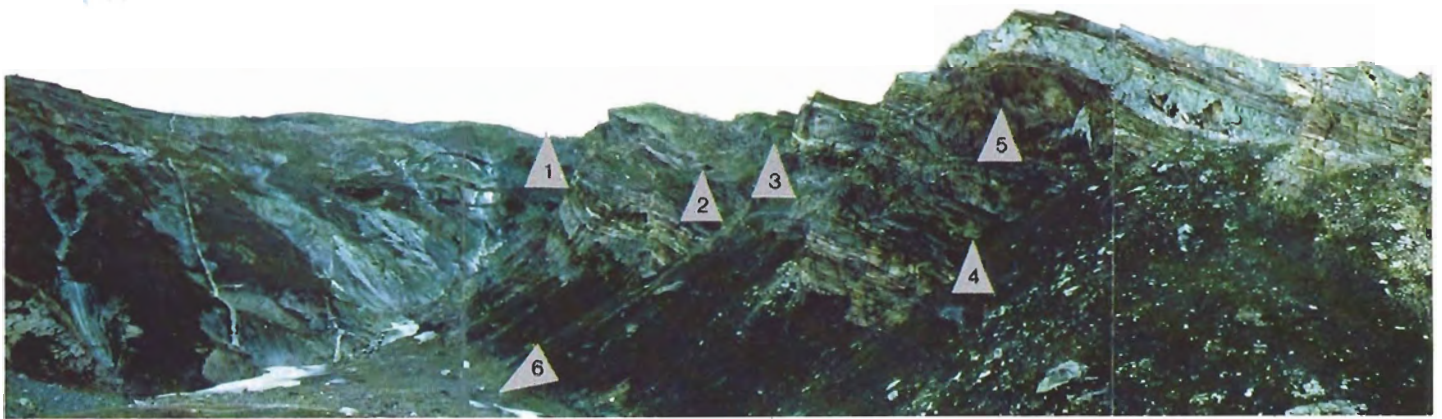


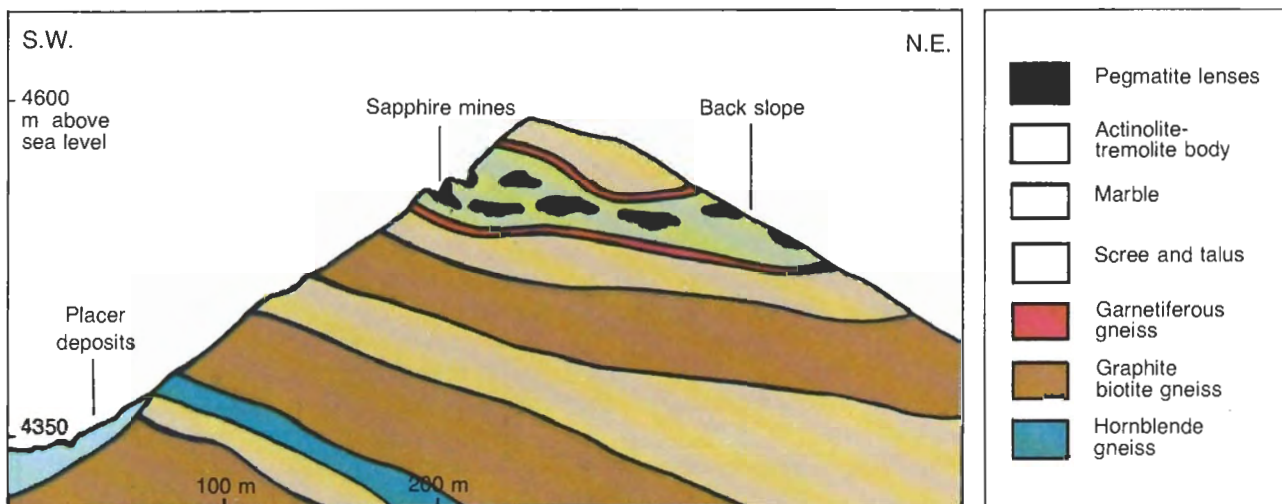
Figure 4. Panorama of the cirque in which the sapphires were first found, showing (1) Rubellite Mine, 4,650 m; (2) Old Mine, 4,500 m; (3) New Mines, 4,550 m; (4) burrows dug by early miners for shelter;

of the Geological Survey of India's deputy superintendent, T. D. La Touche, to carry out the first detailed survey and estimate of future potential. La Touche's results were presented in his landmark report of 1890. Since then, only one comprehensive survey has been published (Middlemiss, 1931). Later surveys, undertaken by various government agencies since India's independence in 1947 and extending to the late 1970s, remain confidential.

On the recommendations of La Touche, crude washing troughs were constructed, using lumber carried from hundreds of meters below the mine. However, his attempts to exploit the alluvial deposits already discovered on the floor of the cirque at the base of the Old Mine yielded only

one spectacular stone, and the mine was abandoned for 16 years until the government leased the prospect to private interests (*Minerals Yearbook*, 1906). It is evident from the frequent change in lessees that followed that the combination of impossibly harsh mining conditions, constant raiding by unauthorized parties, and the lack of major crystals made mining less and less attractive. Nevertheless, several interesting developments during this period pointed the way to future potential for the mines. La Touche had reported finding loose blocks of corundum in matrix on the north slope behind the Old Mine, known as the "back slope" (see figure 5), but was unable to trace this material to its exact source. In addition, he postulated the existence of further

Figure 5. Schematic cross section through the northeast wall of Kudi Valley shows pegmatite lenses distributed through the altered marble (actinolite-tremolite). Only those lenticles at the surface have been excavated. After Middlemiss, 1931.





(5) geologically important actinolite-tremolite body; (6) placers; and (7) typical pegmatite intrusion with large pegmatite boulder below. From photos by R. Kothavala.

placer deposits beneath the floor of the cirque. To this day, no success has been reported in finding these deposits. In 1906, C. M. P. Wright, of the Kashmir Mining Company, lessee of the mine, reworked the earlier placer deposit with some success before abandoning the mines in 1908. On his departure, he did report several occurrences of new sapphire outcrops only a few hundred meters from the exhausted Old Mine. In his opinion, however, they were of little significance (Middlemiss, 1931).

The failure of sporadic mining during the next decade to produce any exciting crystals seemed to confirm the belief that the sapphire workings at Sumjam had finally been depleted. Nevertheless, in 1924 the government commissioned a detailed mapping of the area, and several new sapphire outcrops were identified. In the years that followed, a second phase of mining was begun at the "New Mines" (again, see figure 4). The results, although not as spectacular as earlier, were most profitable for the private operators—so much so, it appears, that the government decided to take matters into its own hands once more. In 1927, for undisclosed "irregularities," the mining lease was revoked and state mining laws were hastily revised (Middlemiss, 1931). A government-controlled mining project carried out that year yielded the largest seasonal production in the history of the area (see table 1). Proposals for a state gem-cutting operation were drawn up, and a revival of the sapphire industry seemed imminent. In 1928, however, an experimental batch of rough was cut in Delhi and the results analyzed. Of over 900 ct of finished stones, fewer than 20 pieces could be classed as excellent quality, only two as large as

TABLE 1. Production (in kilograms) of rough corundum in Kashmir from 1888 to 1951.^a

Season	From placers	From New Mines
1888	19.0	—
1907	12.1	51.3
1908	3.0	27.8
1926	—	64.2
1927	—	455.2
1928	—	40.1
1933	—	287.0
1934	—	215.0
1935	—	160.0
1937	—	37.0
1938	—	<1.0
1943	—	12.0
1945	—	73.2
1946	—	122.1
1949	—	211.1
1950	—	28.1
1951	—	60.1

^aTable compiled from various sources (La Touche, 1890; Holland, 1930; Middlemiss, 1931; Minerals Yearbook, 1935–1940; Coggin Brown, 1956). No exact details are available on what percentage of these mine runs were gem crystals, but all of the sources quoted agree that this percentage declined steadily after 1908.

6 ct and one of 10 ct (Middlemiss, 1931).

The new material could not compare with the early stones. Tenders were therefore accepted once more from private parties, and scanty reports suggest that at least three different operators worked the mines until 1951. Despite large quantities of rough extracted (over one million carats in 1949, when 50 workers were employed full time during the season) only a minute quantity of "incom-



Figure 6. Large, well-formed but opaque corundum has been found at the foot of Hags̄hu glacier 15 km from the mines, but has never been traced to its exact source. This crystal measures 5 cm × 3 cm. Photo by Van Pelt.

parable" stones emerged. With the final dismantling of the maharajah's political power in 1967, the last connections between the maharajah of Kashmir and the Paddar mines were broken. Effective control of the mines now rests with the state government of Jammu and Kashmir. Over the past 30 years mining has been intermittent. In 1981 the mines were inactive, although at the time of writing negotiations are once again under way to lease the area to private interests.

GEOLOGY

The Zanskar Range occurs in an area of discontinuity in the Great Himalayan mountain range and is separated from the Karakoram and Hindu Kush ranges by the feature known as the Indus suture, through which the Indus River flows. Although very little is known about the crystalline rocks of Zanskar, the local formations bear many similarities to those of the Hunza Valley, 350 km to the north, which was recently described by Gübelin (1982). One important difference is the age of the metamorphics, which are Cambro-Silurian (Lydekker, 1883), as distinct from the younger Eocene rocks of the Karakoram Range (Gansser, 1964).

The mineralogy of the Paddar deposit is relatively simple but appears to be unique among

known sapphire occurrences. Medium-grade metamorphic strata of coarse marble up to 30 m thick, locally interbedded with biotite gneisses and schists, make up the steep ridge near the top of which the mines are located (again, see figure 5). These gneisses are alternately graphite and hornblende rich, and rather dramatic examples of metamorphic crystallization abound. Elsewhere, the gneisses are garnetiferous. One specimen collected from the floor of the cirque displays garnet crystals (weathered) of fine color up to 2.5 cm across in biotite schist. At various places, the marble appears to have undergone local modification, forming lens-shaped bodies of actinolite and tremolite. These lenses consist of felted and radiating aggregate crystals that vary in color from an olive green to a bright mint green. The lenses range from approximately one meter to hundreds of meters long and 30 m thick. A huge actinolite/tremolite "eye" is clearly visible, surrounded by marble, in the panorama of the cirque shown in figure 4.

In many places along the mines ridge, the stratified beds are intruded by feldspar pegmatites. Where these intrusions are quartz-free and surrounded by the actinolite-tremolite bodies, sapphires occur in the greatest concentration. The corundum crystals are found in lenticles or disc-shaped pockets of plagioclase feldspar which has been kaolinized. Although these pockets are usually only approximately 1 m thick and 3 to 4 m long, the sapphires "occur as thickly as plums in a pudding" (Middlemiss, 1931). Here and there at depth, the weathered china clay gives way to solid pegmatite, which required the use of dynamite in later years (see "Mines" below). The lenticular intrusions appear to be quite pervasive and have been located on the slopes behind the mines ridge, where they show no signs of kaolinization. On this "back slope," and in several other places as far as 14 km from the mine, blocks of pegmatite containing corundum (figure 6) have been found, though they rarely have been traced to their actual source. Such blocks of "corundiferous granite" (La Touche, 1890) suggest that further gem deposits may someday come to light. During the 1981 expedition, a sample of pegmatite was found in which corundum crystals up to 2.5 cm in length form over 60% of the rock. This was collected on the floor of the cirque and almost certainly came from some point high on the mines ridge. At the extreme right of figure 4 can be seen an enormous block of pegmatite.

Several reports have been made of corundum crystals found in contact with the bordering graphite biotite gneisses, and it is in these instances that the pink sapphire crystals (rare in this locality) have been observed (Middlemiss, 1931). Such a cluster of pink sapphire crystals is pictured in figure 7 next to a more typical blue crystal. References to rubies found in the Paddar district are few (e.g., Shepard, 1883). Although such occurrences are not unlikely, these reports remain unverified.

Several associated pegmatite minerals have been recovered from the mines and surrounding areas. Most notable among these are rubellite up to 7.5 cm in length (found at a locality only 300 m from the Old Mine), and green tourmaline up to 2.5 cm in length and aquamarine up to 20 cm in length and 7.5 cm in diameter (found at various localities). Since none of these gem materials has been found in quantity, they have never been seen as potentially profitable. Rare examples of such crystals are pictured in figure 8. Other reported mineral occurrences include hambergite (Burton, 1913), cookeite, prehnite, amblygonite, lazulite, amethyst (Mallett, 1905), black and brown tourmaline (Bauer, 1906), kyanite associated with quartz (La Touche, 1890), and fluorite (Middlemiss, 1931). Occurrences of spodumene and green euclase described by La Touche (1890) were later found to be amblygonite (Mallett, 1905) and tourmaline (Gaines, 1951), respectively. It has also been noted that the important actinolite/tremolite formation is a common feature of the regional geology (Middlemiss, 1931). The implications are



Figure 7. Rare examples of crystals from Kashmir that have escaped cutting. The cluster of pink crystals with blue tips (2 cm × 1 cm) is typical of material found close to biotite schists (specimen courtesy of R. V. Gaines). The pale blue crystal on the right (2.5 cm × 1 cm) is typical of the material found in the alluvial placers. Photo by Van Pelt.

clear: further deposits of sapphire and more common pegmatite minerals are certain to exist in the area. Their discovery, however, may be delayed indefinitely by the treacherous terrain and long, harsh winters.

THE MINES

The mines are situated in the northeast wall

Figure 8. Aquamarine and tourmaline have been found in Kudi Valley. The crystals pictured are from another locality only 8 km from the sapphire mines. An included crystal of black tourmaline can be seen within the aquamarine. Tourmaline inclusions have also been observed in Kashmir sapphires. The aquamarine crystal pictured here is 10 cm × 3.5 cm. Specimens courtesy of R. V. Gaines. Photo by Van Pelt.



Figure 9. The Kudi police post is a small stone corral from which government guards control access to the mines. Photo by R. Kothavala.



of a small glacial cirque known as Kudi Valley, approximately 1,000 m long and 400 m wide (33°26'40"N, 76°23'14"E). On both sides, the stratified cliffs rise to a height of over 4,500 m near the level of perpetual snow. The floor of the valley, at 4,100 m, is covered with scree and talus of unknown depth. The only known placer deposit was found on the north side of this valley in a depression directly below the mines. Dominating the mouth of this hanging valley and giving it its name is *Kudi* ("rock" in the local dialect), an enormous monolith. Beneath an overhanging portion of this rock, the small corral-like enclosures that serve as the Kudi police post overlook the precipitous 1,000-m slope that is the only approach to the mines (figure 9). The nearest village is Sumjam, a dreary collection of seven huts 3.2 km to the east and about a thousand meters lower (figure 10).

With no roof, often engulfed in clouds, a contingent of four policemen maintain a constant vigil of the mines under miserably harsh conditions. During years when the mines are operative, miners pitch camp nearby. The burrows dug into the cliffs by early laborers for shelter (La Touche, 1890) are still visible today (again, see figure 4). Elsewhere in the valley are the ruins of former police shelters. The guard station near the top of the mines ridge, referred to by Gaines (1951) as the "black house," has since burned to the ground. As already observed, the local Paddaris harbor no great affection for the government police. Consequently, all of their supplies must be carried from the police post at Machel, 8 km away. Even to gather firewood, the guards must clamber down

over 600 m to the tree line, where a few scrubby birch trees have taken root on the barren slopes. Since the Paddaris refuse to work the deposits, all mining labor must be imported from neighboring districts. Access to the valley of Paddar is over tortuous tracks, rarely more than a meter wide. In many places, this trail crosses narrow bridges or is cut into sheer rock faces which drop away over 300 m to the roaring river below (figure 11).

In 1981, because of official obstacles and an exceptionally rainy summer, it took eight strenuous days to make the journey of some 110 km between Kishtwar and Sumjam. The route is difficult and the mining season is short. The snows usually melt in late June and begin again in late September, but several seasons have been reported where mining was confined to 15 days or less (Middlemiss, 1931). Consequently, the high wages necessary to entice workers into these circumstances further decrease the profitability of large-scale mining efforts. Under such conditions, it is little wonder that mining has been haphazard. The most advanced techniques used to date have been those involving hand augers, blasting, and washing.

Following is a list of mining areas in Kudi Valley; their locations can be seen in figure 4:

Old Mine. An insignificant pit at 4,500 m (14,775 ft) is all that remains of the small pocket that produced so many fine stones. The crystals were worked from the soft china clay by hand and using hand tools. Early reports likened the work to "digging for potatoes" (Mallett, 1882). The crystals typically were large and covered by a tenacious coating of kaolin. After the stones were



Figure 10. Sumjam, at an elevation of 3,100 m, is the last outpost of civilization in Paddar, and consists of seven adobe huts housing five families. Photo by Meher.

cleaned, they were observed to be heavily zoned but with large gemmy portions.

New Mines. Only a hundred or so meters away are a series of adits at 4,550 m. They are distributed over a small area "about as large as the foundation of a small house" (Middlemiss, 1931). In recent times, much blasting has been done here. Typically, the percentage of gem corundum found in this deposit is lower than that taken from the Old Mine and the crystals are smaller (2.5–5 cm). Rare occurrences of the pink sapphires mentioned earlier have been reported from these mines. The concentration of crystals is high, approximately 20% of the pegmatite host. According to Middlemiss, one shovelful typically would yield eight crystals. The adits are heavily barred and locked. The extent of the deposit is not known.

Placers. By bringing water from a nearby spring to bear on one section of the valley floor, La Touche (1887–1889) and later Wright (1906–1908) were able to find some large stones. An expedition dispatched from Srinagar in 1928 to look for new placer deposits returned empty-handed. Apparently misreading La Touche's maps, the mining engineer dug for the placer deposits on the steep slopes rather than on the valley floor. Amazingly, no more is known today about the valley floor than when Wright left in 1908. This is undoubtedly due to the difficulty of searching systematically without machinery. Pits from abandoned placer workings were still visible in 1981.

Rubellite Mine. Crystals of rubellite up to 7.5 cm long have been reported from this mine, which lies approximately 275 m from the Old

Figure 11. Access to the Kashmir mines requires traveling over more than 100 km of treacherous foot and pony trails. Narrow bridges such as this one, 300 m above a tributary of the Chenab River, are common. Photo by R. Kothavala.



Mine at 4,650 m (15,250 ft). However, they do not occur in any quantity, and the site is often covered by snow and ice year round. Therefore, little is known about the extent of the deposit.

Back Slope. The excavation of pegmatite outcroppings on the slope behind the mines has so far failed to reveal any major pockets.

Some nearby localities are:

Hagshu. Little has been said of the large corundum crystals found at the foot of the Hagshu glacier by La Touche in 1887. Although this locality is only 15 km from Kudi Valley, the pegmatite vein has never been traced. It is believed to be somewhere in the inaccessible cliffs above. An example of the well-formed but opaque Hagshu corundum appears in figure 6.

Dangel. Only about 4 km southeast of Sumjam fragments of sapphire and aquamarine have been found on the slopes (Middlemiss, 1931). These have been traced to a pegmatite vein in the cliffs at 3,350 m (11,000 ft). Inasmuch as the fragments found here were small, the commercial prospects of this locality have not been explored.

Machel, Chishote. Aquamarine has been found elsewhere in Paddar, near these two villages, which are 8 km and 20 km, respectively, from Sumjam (Middlemiss, 1931). Again, little is known about these localities.

GEMOLOGY OF THE KASHMIR SAPPHIRES

Kashmir sapphires are, almost without exception, zoned. This distribution of color is usually associated with microscopic layers of liquid inclusions, which are responsible for the typical velvety luster known in the gem trade as "sleep" (see figure 1). An example of color zoning and the hazy effect produced by the accompanying tiny droplets of liquid can be seen in figure 12.

One rather ingenious method of approximating the Kashmir texture in a blue sapphire from another locality involves cutting the pavilion with a fine lap and leaving it unpolished, while polishing the crown and table in the normal manner. The rough pavilion is easily detected on close examination. The blue of the finest Kashmir sapphires, which is referred to in India as "peacock's neck," seems to lack the secondary modifiers of green and pink that are seen in so many other blue sapphires. Consequently, Kashmir stones have long been observed to maintain their vivid blue color under varied lighting conditions. Star

sapphires from Kashmir are reportedly of superb quality, but they are exceedingly rare (Hadford-Watkins, 1935).

Gemological Properties. A study of the 6.70-ct Kashmir sapphire from the Hixon Collection at the Los Angeles County Museum of Natural History (pictured in figure 1) showed the physical and optical constants to be quite normal for corundum: specific gravity, 4.03; refractive index, 1.762–1.770; inert to ultraviolet radiation; a weak red fluorescence to X-radiation; spectrum showing a weak absorption line at 450 nm (Fe) and in the red (Cr).

Inclusions. The reader is referred to Phukan's article (1966) for a comprehensive list of inclusions, with photographs, reported in a sample of nine Kashmir stones. By far the most common were the feather-like inclusions mentioned above. Flat films filled with a brown or yellowish liquid were also found to characterize Kashmir stones, and the fingerprint inclusions so common in Sri Lankan sapphires were observed in the Kashmir stones as well. Of particular significance are the opaque black prismatic crystals mentioned by Phukan. These would seem to confirm the early descriptions of cavities containing tourmaline prisms inside some corundum crystals from Kashmir. The most unusual of the recorded cavities contained a small, transparent tourmaline prism, which was light brown with an indicolite termination (Mallett, 1882). The black inclusion in the aquamarine crystal of figure 8 is a doubly terminated and flattened crystal of tourmaline, the c-axis of which runs perpendicular to that of the host. The occurrence of zircon crystals both with and without their usual accompanying strain halos are also of interest. Other solid inclusions observed, such as long, fine rutile needles and dust-like particles, are common to other localities as well. To summarize, the most widespread internal characteristics of Kashmir stones are zoning, liquid feathers, and flat brownish or yellowish liquid films.

FAMOUS KASHMIR SAPPHIRES

Compared to the Badakhshan mines of Afghanistan, the Mogok mines of Burma, and the Panna mines of India, the Kashmir deposits are in their infancy. It is therefore not surprising that the whereabouts of few famous Kashmir stones are known. We must remember that the Paddar deposits have produced major gems only very spo-

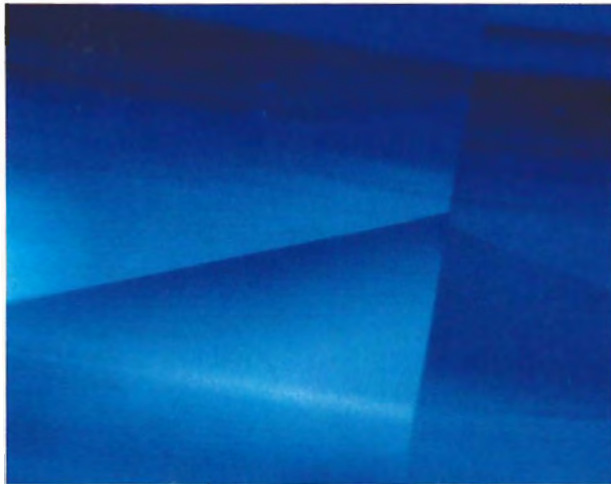


Figure 12. The zoning and hazy effect so common in Kashmir sapphires is seen in this photo of the Hixon sapphire. Magnified 20 \times . Photomicrograph by John Koivula.

radically, during an era of declining British influence in the Indian Empire. The rulers in the fiercely independent dominion of Kashmir were widely accepted as being above British law, and therefore immune from many of the tributary pressures usually incumbent on subjects of colonial empires. Those who wished to acquire remarkable Kashmir sapphires would most certainly have to pay for them. The closely guarded collection of prize crystals and faceted stones housed in the *toshakhana*, or State Treasury, was seen only by a privileged few. Some of the more important pieces are described here.

La Touche (1890) reports seeing several crystals about 12.5 \times 7.5 cm (5 \times 3 in.) that were blue and transparent in the center fading to colorless at the ends. Such crystals undoubtedly weighed thousands of carats. Of rough crystals, the largest and most impressive was a fragment almost spherical in shape and of a deep blue color, estimated to be "larger than a croquet ball." Many cases of cut stones of fine color "superficially as large as florins" were also described (Middlemiss, 1931). One can only surmise that such stones weighed over 20 ct. Several witnesses report large crystals in the possession of certain government officials in the 1880s (Mallett, 1882). Their whereabouts are now unknown. In 1887, La Touche exposed a gemmy crystal weighing over 930 ct. in the washings of the placers. Whether this was ever cut has not been recorded. Certainly, the royal jewels of the maharajahs of Kash-

mir and Jaipur were known to contain breathtaking examples. This is presumably still the case. Over the years, as production of large stones dwindled, the disposition of new important stones became less and less public. The presentation in 1934 by the Duke of Kent to Princess Marina of an engagement ring set with a large, square-cut Kashmir sapphire focused the attention of international jewelers on these stones, which were already in short supply (Hadford-Watkins, 1935). Few examples of rough or faceted Kashmir sapphires are on display in the major museums of the world.

The following account serves to illustrate the current availability of Kashmir stones over 20 ct. In early 1980, a leading authority and supplier of gem sapphires in the United States was nonplussed to receive rather urgent requests from a dozen different sources for a fine cushion-cut Kashmir sapphire of 25 ct. After learning that the sapphire was intended as a gift at a certain royal wedding, the dealer redoubled his efforts to locate a suitable stone. Only two pieces could be located, one of which was patently unavailable. Notwithstanding the auspicious circumstances, negotiations for the other stone broke down and the order was never filled (R. Miller, 1982, personal communication).

THE CURRENT SITUATION

The mines are not operating at this time. Permission to work the site falls under the jurisdiction of the Directorate of Mining and Geology, Jammu and Kashmir government, and a police guard maintains a year-round vigil at or near the site. In the past, gems have been sold at infrequent state government auctions. The most recent of these took place in Srinagar in 1969, where some 57,000 ct of gem rough were sold (*Australian Financial Review*, 1969). Judging by the proceeds of this sale (approximately US\$20,000) the number of important pieces must have been low. Details of a previous sale in 1965 are not known.

As a result of the rapid decline in official mining activity over the past 30 years, more and more of today's trade in Kashmir sapphires is falling into the hands of the indigenous population (figure 13). The strict laws forbidding private trade in sapphires are a deterrent against any organized collecting or excavating. Nevertheless, every year a handful of fine stones found by shepherds on the hillsides make their way out of the Paddar Valley to be sold in Delhi. Probably because of the in-



Figure 13. Production of Kashmir sapphires on a commercial scale today is nonexistent. Nevertheless, every year a trickle of fine gems finds its way to the world markets through the hands of the local people. Photo by Meher.

volvement of government interests, the majority of fine Kashmir sapphires have been marketed in the Indian capital rather than in the traditional gem center of Jaipur. How the gem sapphires find their way to buyers in Hong Kong, Switzerland, New York, and, until recently, Beirut is a closely guarded secret. From time to time, old cabochon pieces turn up on the market and are salvaged as faceted stones of considerable quality (R. Miller, personal communication, 1982).

It is evident that several deposits of sapphire and other gem minerals await discovery in the Paddar district. The difficult access makes the task of systematic mining and exploration exceedingly complicated. Furthermore, the realistic potential of the Kashmir area is impeded by political factors. Since Pakistan's partition from India in 1947, the mountainous state has never been free from tension. This insecurity has been compounded by China's occupation of Tibet in 1950, two Indo-Pakistan wars, in 1965 and 1971, and Russia's invasion of Afghanistan in 1979. In such an atmosphere, exploitation of mineral deposits is secondary to political and military preoccupations. Until this situation changes, we must expect that the appreciation and demand for fine Kashmir sapphires will be maintained by their great rarity.

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THE GEM DIAMONDMASTER AND THE THERMAL PROPERTIES OF GEMS

By D. B. Hoover

The GEM DiamondMaster is one of a number of thermal testing instruments introduced specifically to separate diamond from its simulants. Although originally reported to measure thermal conductivity, these instruments in fact measure the thermal inertia of the material being tested. This article explains thermal properties in general and thermal inertia in particular, and then describes the limitations and potential applications of thermal testing instruments such as the DiamondMaster. Included are suggestions for the use of the DiamondMaster to separate various colored stones.

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A number of methods and instruments have been introduced recently to distinguish diamond from its simulants on the basis of the unique thermal properties of diamond (Nassau, 1978; Read, 1978, 1980; Goldsmid, 1979; Goldsmid and Goldsmid, 1979, 1980; Thwaites et al., 1980; Hobbs, 1981). In particular, several thermal testing instruments—including the Ceres Diamond Probe[®], the Kashan Diamond Detector, and the Rayner Diamond Tester—have been made available for this purpose. GEM Instruments Corporation is currently marketing the DiamondMaster[®], a thermal testing instrument designed in Australia (Goldsmid, 1979) and manufactured by Pre-sidium Diamond PTE Ltd., Singapore.

Most of these instruments are said to measure or compare thermal conductivity. This is not strictly true. The DiamondMaster and other similar instruments, with which the author is familiar, measure or compare *thermal inertia* (Hoover, 1982). Although this physical property is not commonly known by name, it is familiar to all gemologists as the cold feeling of crystals and many gems in contrast to the warmth of glass or plastic when touched by the finger or tongue (Webster, 1975, p. 387). This property has been known since at least the 16th century, and was mentioned as a qualitative test for gems by Agricola in 1546 (Sinkankas, 1981). By providing a semiquantitative measure of thermal inertia, the DiamondMaster has been found useful for distinguishing between several other gems in addition to diamond and its simulants.

This article will examine the operation of the DiamondMaster as a specific example of a thermal probe and then provide a brief qualitative introduction to thermal properties so that the gemologist can appreciate the operating principles behind these new instruments, their limitations, and their broader applications. With regard to these broader applications, the use of the



Figure 1. The DiamondMaster[®], a thermal testing instrument manufactured by Presidium Diamond PTE Ltd. and marketed by GEM Instruments Corporation.

DiamondMaster to distinguish among gems other than diamond and its simulants is discussed. For this purpose, an extensive table of the thermal properties of gemstones, gem simulants, and metals used in jewelry is provided. It is believed that, as thermal testing instruments are improved, they will become important tools for gem identification.

The DiamondMaster used for evaluation and testing while preparing this article is a standard production model purchased by the author for his own use.

INSTRUMENT DESIGN

The DiamondMaster (figure 1) is a very simple instrument; its basic construction has been described by Goldsmid and Goldsmid (1980) and Goldsmid (1979). It consists of four main sub-units: the probe, a power source, an amplifier, and an indicating meter. The amplifier and meter provide a means for obtaining a reading from the probe and need no further discussion here. The power source provides voltage to operate the electronics and to energize the heat source in the probe. Power is obtained either from 3-volt inter-

nal batteries, or from 110-volt lines. Operation with external power was found to result in significant line noise in the instrument reading, which was not present when batteries were used. It is assumed that the noise is due to insufficient filtering in the power supply. The use of batteries is recommended whenever discrimination between gems other than diamonds is attempted.

The heart of the unit is the probe, which contains a heat source and a temperature-difference sensor (figure 2). The heat source is a 22-ohm resistor that receives about 2 volts from the power source. This gives a constant quantity of heat to the probe of 0.18 watts (0.043 calories/sec). The temperature sensor is a 22-mm-long copper rod, 0.4 mm in diameter, with constantan wires attached at either end. The copper-constantan junctions form a thermocouple, a common temperature-measuring device. The different temperatures at the two junctions produce a voltage that is proportional to this temperature difference. This voltage, or temperature difference, is what is measured by the instrument. The heat source is placed about midway along the copper wire. All of these parts, except the tip, are contained within

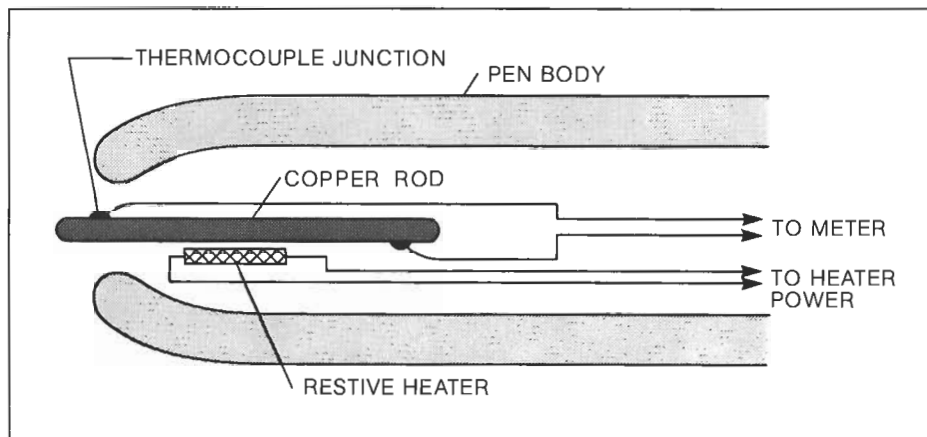


Figure 2. Diagrammatic sketch of the DiamondMaster probe, showing the principal components of the sensor.

the insulating probe housing, as shown in figure 2. Thermal insulation provided by the probe housing keeps the internal junction at an elevated temperature. When the probe is in use, heat flows down the copper rod into the gem being tested. The temperature at the tip junction is then approximately the same as the surface temperature of the gem.

When not in use, the probe tip is left in contact with air, which is a good insulator and thus has low thermal inertia. In still air, the tip rises to a temperature near that of the internal junction (about 65°C in the author's instrument). The exact value is determined by the position of the heat source and heat loss through the pen body. In the author's unit, the meter reads below zero with the tip in still air. This suggests that the probe tip, in this case, is hotter than the internal junction. If drafts are present in the room, heat is removed from the tip and a fluctuating and positive reading will be observed, as is easily noted by blowing on the tip. This points out the need, when using the instrument, to avoid areas with much air movement, such as modern air-conditioned offices.

The DiamondMaster thus provides a constant heat source; part of this heat is conducted through the tip to the test gem. The instrument measures the temperature difference between the hot internal junction and the surface temperature of the gem or other material being tested. Our question now is: What physical property is being measured, or approximated, by the instrument? The answer requires some understanding of the thermal properties of solids, as discussed below.

INTRODUCTION TO THERMAL PROPERTIES

Heat energy can be transferred by three methods: conduction, convection, and radiation. In solids

at room temperature, the principal means of heat transfer is by conduction. Consequently, in the following discussion, only conductive transfer will be considered.

The purpose of this section is to try to give a qualitative idea of the four intrinsic thermal properties that are important to an understanding of the operation and limitations of the new thermal probes. Those readers interested in a more technical discussion of thermal properties and the mathematical relationships between them are advised to consult any standard college physics text. For more advanced treatment, the classic text is Carslaw and Jaeger (1959).

The four intrinsic thermal properties of interest to us here are conductivity, diffusivity, inertia, and specific heat. The first three properties are not independent of one another. Given one of these properties plus the specific heat and density of a given solid, the other two can be calculated*. These calculations were made to obtain the values of inertia and diffusivity given in table 1, because conductivity is the most commonly measured of these properties. The mathematical relationships between these properties shows that a substance with high conductivity also will have high diffusivity and inertia, as can be seen in table 1. This may in part be the reason the probes are commonly thought to measure thermal conductivity.

Thermal conductivity is familiar to most of us because of the recent interest in energy conservation in our homes. It is a constant that relates the quantity of heat-per-second passing through

* $k = K/c\rho = K^2/I^2$ $I = \sqrt{Kc\rho} = K/\sqrt{k}$ $K = kc\rho = I\sqrt{k}$
 where K = conductivity, k = diffusivity, I = inertia,
 c = specific heat, and ρ = density.

TABLE 1. Thermal properties of gem materials, synthetics, and simulants as well as some metals at room temperature.^a

Material	Thermal conductivity (cal/cm °C sec)	Specific heat (cal/gm °C)	Density (gm/cm ³)	Thermal diffusivity (cm ² /sec)	Thermal inertia (cal/cm ² °C sec ^{1/2})
Gem Materials, Synthetics, and Simulants					
Diamond	1.6–4.8	0.12	3.52 ^c	3.79–11.4	0.822–1.42
Silicon carbide (synthetic)	0.215 ^d	0.2*	3.17 ^c	0.339	0.369
Periclase (synthetic)	0.110 ^d	0.2*	3.575 ^c	0.154	0.281
Corundum: c axis	0.0834 ^d	0.206	4.0 ^c	0.101	0.262
a axis	0.0772 ^d	0.206	4.0 ^c	0.0937	0.252
c axis	0.060 ^e	0.206	4.0 ^c	0.0728	0.222
Topaz: a axis	0.0446	0.2*	3.53 ^c	0.0632	0.177
mean, Gunnison, Colorado	0.0269	0.2*	3.531	0.0381	0.138
Pyrite: Colorado	0.0459	0.136	4.915	0.0684	0.176
Kyanite: c axis	0.0413 ^d	0.201	3.66 ^c	0.0562	0.174
b axis	0.0396 ^d	0.201	3.66 ^c	0.0539	0.171
mean, Minas Gerais, Brazil	0.0338	0.201	3.102	0.0461	0.158
Hematite: Itabira, Brazil	0.0270	0.169	5.143	0.0310	0.153
Spinel: locality unknown	0.0281	0.216	3.63 ^c	0.0358	0.148
Madagascar	0.0227	0.216	3.633	0.0288	0.133
Fluorite: locality unknown	0.0219	0.220	3.18 ^c	0.0313	0.124
Rosiclare, Illinois	0.0227	0.220	3.186	0.0324	0.126
Sphalerite: Chihuahua, Mexico	0.0304	0.115	4.103	0.0646	0.120
Sillimanite: Williamstown, Australia	0.0217	0.203	3.162	0.0339	0.118
Andalusite: Minas Gerais, Brazil	0.0181	0.202	3.102	0.0289	0.107
Pyrophyllite: North Carolina	0.0194	0.2*	2.829	0.0343	0.105
Jadeite: Japan	0.0159	0.206	3.196	0.0242	0.102
San Benito County, California	0.0110	0.206	3.350	0.0160	0.0873
Gahnite: Colorado	0.0103	0.2*	4.163	0.0100	0.102
Magnesite: Transvaal	0.0139	0.236	2.993	0.0198	0.0992
Rutile: c axis	0.0231 ^d	0.189	4.2 ^c	0.0291	0.135
a axis	0.0132 ^d	0.189	4.2 ^c	0.0166	0.102
mean, Virginia	0.0122	0.189	4.244	0.0153	0.0990
Grossular: Connecticut	0.0135	0.196	3.617	0.0188	0.0979
Chihuahua, Mexico	0.0134	0.196	3.548	0.0193	0.0967
Crestmore, California	0.0124	0.196	3.318	0.0190	0.0898
Quartz: c axis	0.0264 ^d	0.196	2.65 ^c	0.0578	0.125
c axis	0.0264 ^e	0.196	2.65 ^c	0.0509	0.117
a axis	0.0140 ^d	0.196	2.65 ^c	0.0270	0.0854
a axis	0.0160 ^e	0.196	2.65 ^c	0.0308	0.0912
mean, Jessieville, Arkansas	0.0184	0.196	2.647	0.0354	0.0978
Spodumene: Maine	0.0135	0.2*	3.155	0.0214	0.0923
Diopside: New York	0.0133	0.196	3.270	0.0208	0.0923
Madagascar	0.00969	0.196	3.394	0.0146	0.0802
Dolomite	0.0132	0.221	2.857	0.0209	0.0911
Olivine (peridot, Fo ₈₆ Fa ₁₄)	0.0115	0.2*	3.469	0.0166	0.0893
Elbaite: Keystone, South Dakota	0.0126	0.2*	3.134	0.0202	0.0889
Talc: Quebec	0.0124	0.221	2.804	0.0200	0.0878
Tremolite: Balmot, New York	0.0117	0.210	2.981	0.0186	0.0854
Ontario, Canada	0.0112	0.210	3.008	0.0177	0.0839
Amblygonite: South Dakota	0.0119	0.2*	3.025	0.0197	0.0850
Zircon: Australia	0.0109	0.140	4.633	0.0167	0.0839
Enstatite (En ₉₈ Fs ₂): California	0.0105	0.2*	3.209	0.0334	0.0821
Bronzite (En ₇₈ Fs ₂₂): Quebec	0.00994	0.2*	3.365	0.0148	0.0818
Spessartine: Haddam, Connecticut	0.00811	0.2*	3.987	0.0102	0.0804
Datolite: Patterson, New Jersey	0.0106	0.2*	2.996	0.0177	0.0798
Anhydrite: Ontario, Canada	0.0114	0.187	2.978	0.0204	0.0796
Almandine: Gore Mountain, New York	0.00791	0.2*	3.932	0.0101	0.0789
Staurolite: Georgia	0.00828	0.2*	3.689	0.0112	0.0782
Augite: Ontario	0.00913	0.2*	3.275	0.0140	0.0773
Pyrope: Navajo Reservation, Arizona	0.00759	0.2*	3.746	0.0101	0.0754

TABLE 1. Thermal properties of gem materials, synthetics, and simulants as well as some metals at room temperature.^a (Continued)

Material	Thermal conductivity (cal/cm °C sec)	Specific heat (cal/gm °C)	Density (gm/cm ³)	Thermal diffusivity (cm ² /sec)	Thermal inertia (cal/cm ² °C sec ^{1/2})
Andradite: Ontario, Canada	0.00738	0.2*	3.746	0.00984	0.0744
Smithsonite: Kelly, New Mexico	0.00612	0.2*	4.362	0.00701	0.0731
Beryl: c axis	0.0131 ^d	0.2*	2.70 ^e	0.0243	0.0842
a axis	0.0104 ^d	0.2*	2.70 ^e	0.0193	0.0750
mean, Minas Gerais, Brazil	0.00953	0.2*	2.701	0.0176	0.0718
Calcite: Chihuahua, Mexico	0.00858	0.218	2.721	0.0145	0.0713
Axinite: Baja California	0.00767	0.2*	3.306	0.0116	0.0712
Prehnite: Paterson, New Jersey	0.00854	0.2*	2.953	0.0145	0.0710
Rhodochrosite: Argentina	0.00731	0.184	3.584	0.0111	0.0695
Flint: Brownsville, Ohio	0.00886	0.2*	2.618	0.0169	0.0681
Epidote: Calumet, Colorado	0.00627	0.2*	3.413	0.00919	0.0654
Petalite: Rhodesia	0.00856	0.2*	2.391	0.0179	0.0640
Clinozoisite: Baja California	0.00574	0.2*	3.360	0.00854	0.0621
Idocrase: Chihuahua, Mexico	0.00576	0.2*	3.342	0.00863	0.0620
Sphene: Ontario, Canada	0.00558	0.188	3.525	0.00845	0.0607
Iolite: Madagascar	0.00650	0.2*	2.592	0.0126	0.0580
Zoisite: Liksviken, Norway	0.00513	0.2*	3.267	0.00785	0.0579
Aragonite: Somerset, England	0.00535	0.209	2.827	0.00906	0.0562
Microcline: Amelia, Virginia	0.00621	0.194	2.556	0.0126	0.0554
Ontario, Canada	0.00590	0.194	2.558	0.0119	0.0541
Albite (Ab ₉₉ An ₁): Amelia, Virginia	0.00553	0.202	2.606	0.0105	0.0540
Serpentine (lizardite): Cornwall, England	0.00558	0.2*	2.601	0.0107	0.0539
Orthoclase: Goodspring, Nevada	0.00553	0.2*	2.583	0.0107	0.0534
Sodalite: Ontario, Canada	0.00600	0.2*	2.326	0.0129	0.0528
Lepidolite: Dixon, New Mexico	0.00460	0.2*	2.844	0.00807	0.0512
Anorthite (Ab ₇ An ₉₃): Japan	0.00401	0.196	2.769	0.00737	0.0467
Fluor-apatite: Ontario, Canada	0.00328	0.195	3.215	0.00522	0.0454
Chlor-apatite: Snarum, Norway	0.00331	0.195	3.152	0.00539	0.0451
Labradorite (Ab ₄₆ An ₅₄): Nain, Labrador	0.00365	0.2*	2.701	0.00676	0.0444
Barite: Georgia	0.00319	0.113	4.411	0.00639	0.0399
Apophyllite: Poona, India	0.00331	0.2*	2.364	0.00699	0.0396
Leucite: Rome, Italy	0.00274	0.2*	2.483	0.00551	0.0369
Vitreous silica (General Electric)	0.00325	0.201	2.205	0.0074	0.0379
Hyalite: Spruce Pine, North Carolina	0.00290	0.2*	2.080	0.0070	0.0347
Glass: obsidian	0.00330 ^d	0.2*	2.4 ^e	0.00688	0.0398
ordinary flint (lead)	0.0018 ^d	0.117 ^e	3.5 ^d	0.00440	0.0272
very heavy flint (lead)	0.0012 ^d	0.117 ^e	4.5 ^e	0.00228	0.0251
Metals					
Copper	0.927	0.092	8.89	1.13	0.871
Silver 100%	1.00	0.056	10.5	1.70	0.767
Silver 69%, gold 31% (weight)	0.237	0.048*	12.3	0.401	0.374
Silver 34%, gold 66% (weight)	0.152	0.040*	15.5	0.245	0.307
Gold 100%	0.707	0.031	19.3	1.18	0.650
Aluminum	0.485	0.214	2.7	0.839	0.529
Platinum	0.166	0.032	21.4	0.242	0.337
Platinum, 10% iridium	0.074	0.032*	21.6	0.107	0.226

^aUnless another reference is indicated by a superscript letter, the values for conductivity and density were taken from Horai, 1971; for specific heat, from Robie and Waldbaum, 1968. * = Assumed value; not found in the literature.

^bBurgemeister, 1978.

^cWebster, 1975.

^dChemical Rubber Co., 1966.

^eClark, 1966.

^fWashburn, 1929.

a given thickness of material to the temperature difference across it. It is usually measured by steady-state experiments (Carslaw and Jaeger, 1959, p. 25). Typically, this consists of passing a known rate of heat through a slab of known thickness, and measuring the resultant temperature difference. Thus, in the case of our homes, we can reduce the rate of heat escape by putting in better insulation (a material of lower thermal conductivity) or by increasing the thickness of the insulation.

In crystalline materials, thermal conductivity is a function of the direction that heat flows, directly analogous to the refractive index. In general, the thermal and optical symmetry will be the same (Washburn, 1929, p. 230). Thus, non-isometric gems will have a conductivity dependent on the direction of heat flow during testing. The variation can be significant (Clark, 1966, p. 466); quartz, for example, shows a variation of 2:1. Unfortunately, the variation of conductivity with direction is known for relatively few gem species.

Specific heat is the amount of heat required to raise one gram of a substance one degree Celsius. It can be thought of as a constant which gives the amount of heat that can be stored in a given mass by raising the temperature. For most gem species, the specific heat varies little from 0.2 cal/gm °C. It has little value in discriminating between gems.

Thermal diffusivity is a parameter used to describe the velocity of heat flow in a substance. Consider what happens when a copper rod is heated on one end. Heat is conducted into the rod and starts to flow or diffuse along it. Some of the heat is used to raise the temperature of the rod; this is where the specific heat comes into play. The rest of the heat diffuses down the rod at a velocity characteristic of the material. The diffusivity specifies that velocity*. I have introduced this property because of its central importance to solutions of problems in heat flow and temperature distribution in solids. We will return to this in discussing stone size limitations for probe measurements.

Many readers may have noticed that a sterling silver spoon when used to stir hot coffee will get

too hot to handle much faster than a stainless steel spoon. This is a direct result of the much greater diffusivity of silver.

Thermal inertia is a property that measures how fast the surface temperature of a material can be changed by application of a given quantity of heat-per-second to the surface. If a material has high thermal inertia, then the surface temperature will rise very slowly. The name comes from analogy to mechanical inertia.

As mentioned above, the physical significance of thermal inertia is well known by gemologists who recognize the cold feeling of crystalline gems in contrast to glass or plastic. In this case, the fingers provide a source of heat that tries to raise the temperature of the material. If the material has high thermal inertia, the heat from the fingers cannot raise the surface temperature at a fast rate. The nerves in the finger tip sense this as a cold feeling that persists longer than for a substance such as glass or wood, which has low thermal inertia. The DiamondMaster works in exactly the same way except that it gives a more quantitative measurement.

Although thermal inertia is not a well-known property, its measurement has important applications in several areas. Geologists working in the field of remote sensing measure the variation of the surface temperature of the earth due to solar flux by means of airborne or satellite infrared photography. Through computer processing of these data, they are able to map variations in thermal inertia at the earth's surface. These maps provide an important means of discriminating between rock types (Watson, 1975; Watson et al., 1981; and Watson, 1982). The Ceres Diamond Probe operates in a similar manner, except that the heat source has a period of one second rather than the sun's one day (Read, 1980; Hoover, 1982).

In my article on the Ceres Diamond Probe (Hoover, 1982), the propagation of a thermal wave (i.e., a single-frequency sinusoidally varying temperature wave) down a thin insulated rod was explained. The results show that thermal waves travel at very slow velocities and are rapidly attenuated. The thermal pulse applied to a gem by the DiamondMaster may be considered as made up of all frequencies. However, since the reading is taken after about one second at maximum scale, the predominant frequency will be near one hertz (cycle per second). Thus, the heat penetration and

*The velocity is given by $V = \sqrt{4\pi fk}$, where f = frequency and k = thermal diffusivity.

volume of gem material measured will be about the same as is measured by the Ceres Probe.

The depth of heat penetration into the gem and the limitations it imposes on measurement accuracy can be estimated by considering the case of a simple one-dimensional flow of heat down a thin rod of various material. For this case, and no matter what the material, the amplitude of the thermal wave is attenuated to 0.0019 of its surface value after traveling only one wavelength.

At a frequency of one hertz, diamond has a velocity of 10 cm/sec and beryl, 0.47 cm/sec, giving corresponding wavelengths of 10 cm and 0.47 cm. If a rod of diamond or beryl, for example, were cut off at a half wavelength, 5 cm or 0.235 cm, then heat would be reflected back to the starting end, travelling a total distance of one wavelength. On return to the starting end, the thermal wave would have less than a 0.2% effect on the surface temperature. In effect, measurement of the temperature on one end would not be able to distinguish if the rod is one wavelength long or infinite in length. However, if the rod or the stone being tested is too small, sufficient heat will be reflected from rear and side facets so that the surface temperature will be greater than on a larger stone. This will give an incorrect value, making the stone appear to have too low a thermal inertia. The size problem is important in the quantitative measurement of colored stone melee and with most diamonds. If we wish to keep the size error under 5%, assuming a rod model as discussed above, the stone must have a minimum dimension that is not less than one-quarter wavelength. Corundum gives a useful guide because it has the largest thermal inertia, next to diamond, a gemologist is apt to encounter. For corundum, this minimum dimension is 0.27 cm. For diamond, the corresponding depth is 2.5 cm, or about one inch! Clearly, most diamonds give too low a response on these instruments. I must add that the above are conservative estimates, because heat in a gem flows in three dimensions, giving increased attenuation over that predicted by the one-dimensional assumption.

Thus the design of a particular thermal testing instrument, in particular the frequency of the thermal wave, determines the minimum size of stone on which accurate thermal inertia measurements can be obtained. This is not, however, the minimum size of stone that may be tested.

Knowing that melee diamonds, for example, will give too low a response, one can use known diamond melee to calibrate the instrument response as a function of size. The much greater thermal inertia of diamond over its simulants still permits easy differentiation even on very small stones. Loose melee may also be tested by placing the stones on a silver or copper plate, which effectively increases the apparent stone size, making it easier to distinguish diamond from its simulants. The Kashan Diamond Detector provides a special tip and plate for this purpose. Similarly, mounted diamonds benefit from the contact with the mounting, which provides an increase in apparent thermal inertia over a loose stone. One must, of course, be careful not to touch the mounting when testing because of the high thermal inertia of the metal.

CATALOG OF THERMAL PROPERTIES

It is hoped that the preceding discussion has given the reader a better understanding of how thermal probes operate, and a basis by which they may be used to discriminate between various gem materials. In table 1, the author has collected thermal properties for a number of gem species and related materials. Thermal diffusivity and inertia were calculated from the other listed properties. Because of the relationship between the thermal properties, it should be apparent that for nonisometric gems, diffusivity and inertia will vary with the direction of heat transfer in the same way conductivity varies.

The majority of conductivity values are from Horai (1971), and were made on powdered samples. Because of the random orientation of the grains, these are mean values of conductivity. As can be seen from the table, conductivities range from 0.002 cal/cm-sec-°C for glass to 4.8 for diamond, a range of over 2000:1. Thermal inertia, however, spans a range of about 50:1. The table is arranged in order of decreasing inertia, except where more than one value is given for a particular gem. Conductivity follows in almost the same order. Note also that the order is quite distinct from an ordering of gems based on density or refractive index. This can be advantageous for testing, especially if more precise instruments are developed. Comparison of the relative response of the DiamondMaster, given in figure 3, with corresponding values from table 1 shows that the in-

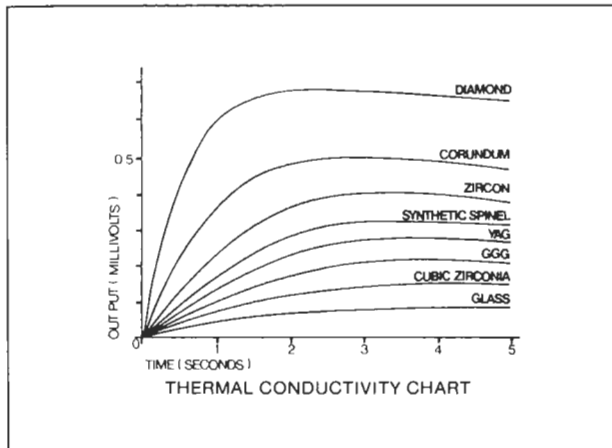


Figure 3. Graph provided with the DiamondMaster to show the measured response of the instrument for various gem materials.

strument gives a reasonable measure of inertia rather than conductivity.

DISCUSSION

Caveats When Using the DiamondMaster. For gem testing the important question is: How does one use the instrument to assist in separating gems, and for what separations does it have practical utility? Reasonable repeatability of measurements is of primary importance, and this is somewhat of a problem with the DiamondMaster. Remember that the instrument was only intended to distinguish diamonds. Small variations in the surface of the probe tip and contact angle make exact reproducibility impossible. Practice and care in use, however, will give reasonable results. If one then averages three or more readings, it should be possible to distinguish between the gems discussed below. Because of differences in each probe tip and in the setting of the calibration level on each instrument, known gems should always be used to establish the calibration of each instrument, and this should be checked periodically.

If the probe tip has flat areas or is rough, the difficulty of obtaining good repeatability will be increased. This can result from wear on the soft copper tip. When this occurs on my DiamondMaster, I very carefully dress and polish the tip. A more durable tip of spherical form, so that the contact angle would not affect the measurements, would make the instrument much better for quantitative measurements.

Certain other factors should be kept in mind when using the instrument. The surface finish of the material being tested can affect the measurement by changing the contact area with the tip. In fact, similar devices have been used to measure surface roughness (Powell, 1957). Thus, care should be used in interpreting readings on badly scratched or chipped gems. Internal features also can give rise to changes in thermal inertia. Zircon is an excellent example because it is a metamict mineral. Destruction of the crystal lattice is associated with a decrease in inertia. Thus, high zircon has a value near that of spinel, while some low zircons in the author's collection approach glass in value. This very large range for zircon limits the value of thermal methods in testing for this gem.

Gem species that form solid solutions, such as the garnet, plagioclase, and olivine groups, will show a change in inertia related to composition. The interesting point is that the thermal inertia is not a linear relation between end-member values, but will show a minimum value at some intermediate composition (Horai, 1971, p. 1299). As quantitative instruments that permit better reproducibility and increased precision of measurement are developed, this property may be particularly helpful when used with refractive index measurements in distinguishing between various members of such groups. Gemtek Gemmological Instruments manufactures the Gemmologist, a thermal device reported to distinguish between many colored stones as well as diamond (Read, 1983). To the author's knowledge, this is the only instrument specifically designed to have the increased sensitivity for effective measurement of colored stones.

Use of the DiamondMaster for Gems Other than Diamond. On the basis of the preceding discussion, the author has investigated the use of the DiamondMaster to help distinguish between various other gems. It was determined that while the instrument should not be used as the only test, it can be helpful as an ancillary test to confirm an identification. A careful observer should find the instrument useful in several determinations, as described below.

The distinction between ruby, red spinel, and pyrope (figure 4) is readily made. For these gems, the inertias given in table 1 are 0.222, 0.133, and 0.0754, respectively. Each differs from the other



Figure 4. These three stones, often indistinguishable by color, are easily separated on a thermal testing instrument like the DiamondMaster. In the author's experiments, representative samples of pyrope, similar to the 1.36-ct stone on the left, showed 0% of full scale on his instrument; samples of red spinel, similar to the 0.68-ct stone in the center, registered 35% of full scale; and ruby, similar to the 1.16-ct stone on the right, registered 60% of full scale, a measure of the high thermal inertia of corundum.

by about a factor of 2, a difference that appears to be easily measured by the instrument. Representative samples of these gems gave average readings of 60%, 35%, and 0% of full scale (remember that in air the meter reading is well below zero). The higher the thermal inertia of the stone is, the higher its reading on the scale will be. Similarly, sapphire, blue spinel, and benitoite also may be separated. Benitoite is not listed in table 1; however, tests on several stones show it to have an inertia near that of pyrope. On these and the following examples, the user should always keep in mind the discussion of the effect of size on measurements of materials of various thermal inertias. Known reference material is necessary for calibration of the instrument, and testing of very small stones should include reference stones of similar size.

A glance at table 1 shows that topaz has a relatively large inertia of 0.138. One would infer that it, too, could be easily distinguished from aquamarine, which has a value of 0.0718. This is the case, providing a simpler test for these gems than a refractometer.

Quartz also has a fairly large inertia. This is useful in helping to distinguish it from some of the other, similar-appearing gems. Likewise fluorite, with an inertia of 0.126, often may be separated from gems with which it might be confused.

In my experiments, I found that the DiamondMaster can be used to separate jadeite from nephrite, but that care is required. Jadeite gives a reading about 10% of full scale, while nephrite is near 0%. This is useful in testing carvings that are difficult to place on a refractometer. It is in-

teresting to note that the values of inertia shown in table 1 for jadeite and some amphiboles would suggest that the differentiation could not be made, at least with the present instruments. Either the literature values cited here are not representative, or the listed amphiboles are not representative of nephrite.

Lastly, it was found that sinhalite could be easily separated from peridot. Sinhalite is not listed in table 1, but readings with the DiamondMaster show that it has an inertia about the same as topaz and much greater than peridot.

It is hoped that the preceding discussion will permit the practicing gemologist to make more effective use of these new thermal testing instruments. Unfortunately, at present, the state of knowledge of thermal properties of gem materials is quite limited. Advances in this knowledge for practical use in gem testing will probably first come through experience in the use of the instruments. Advances in the instrumentation, particularly directed toward improvements in the precision and reproducibility of readings, will also go far to making these devices important tools in gem testing.

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OPAL FROM QUERÉTARO, MEXICO: OCCURRENCE AND INCLUSIONS

By John I. Koivula, Chuck Fryer, and Peter C. Keller

The Querétaro area, 200 km northwest of Mexico City, has been producing fine, unusually transparent opal with vivid red and green play of color for over 100 years. These opals occur largely in gas cavities in pink to brick-red, thinly bedded rhyolitic lava flows and are mined in open-pit quarries. After examining thousands of opals from this area, the authors selected 20 specimens containing excellent examples of both common and rare inclusions that seemed to represent the variety of inclusions found in gem-quality opals from this locality. The opals and their inclusions were then subjected to a battery of tests to ascertain their nature. These tests revealed both two- and three-phase inclusions and a variety of different mineral species.

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Mexican opal has been known since the latter part of the 18th century, but the more familiar gem-quality material has been available to the world market only since the end of the last century. At times, the beauty of Mexican opal (figure 1) exceeds that found in opal from any of the world's better-known deposits, such as Australia; yet its somewhat undeserved reputation for instability has prevented it from taking a major role in the modern jewelry trade (Sinkankas, 1959). The most important opal deposits in Mexico are in the state of Querétaro, although there are other significant deposits in the states of Chihuahua, San Luis Potosí, Guerrero, Hidalgo, Jalisco, and Michoacán. However, Querétaro is the center of opal mining and cutting in Mexico, and it is the predominantly reddish-orange fire opal from the Querétaro deposits that is addressed in this study of the locality and internal features of this material.

Although most gemologists who have examined even a small number of opals from Querétaro with a microscope are familiar with at least two or three inclusions in this material, very few inclusions have as yet been conclusively identified. In addition, with the exception of some brief general descriptions of inclusions in opal that are scattered throughout the literature, virtually nothing has been written on this subject.

This article briefly describes the Querétaro deposits and the opal they have produced and, with this as background, presents the results of a study of about 3,000 opals from this locality that were examined for inclusions.

LOCATION AND ACCESS

The opal mining and cutting center of Querétaro is also the capital city of the state bearing the same name. Querétaro is located in central Mexico, on its high central plateau, approximately 200 km northwest of Mexico City. Access to the capital city is via Highway 57, a major toll



Figure 1. This 0.95-ct cabochon shows the reddish orange body color with red and green play of color that is typical of fine fire opal from Querétaro. Photo by Mike Havstad.

road from Mexico City. The principal productive area today is in the vicinity of the Iris mine, which is reached by taking the toll road from the city of Querétaro approximately 30 km back toward Mexico City to Highway 120, and then traveling east on Highway 120 toward Cadereyta for about 6 km until the open-pit mines can be seen from the highway along a series of low ridges (Burton, 1981).

HISTORY AND MINING

According to Webster (1975), fire opal was used extensively by the Aztecs (1200–1519 A.D.) in some of their ceremonial objects. Sinkankas (1959) states that the opal was known to the Aztecs as *vitziziltecpatl*, or "humming bird stone," an allusion to the similarity of the opal to the iridescent feathers of a humming bird. These early accounts of the Aztecs' use of opal are somewhat substantiated by one of the most famous Mexican opals in the world: the Aztec Sun God opal. Once

part of the famous Hope collection (which also contained the Hope diamond), it supposedly is of Aztec origin and was taken from a temple in the early 16th century (Kunz, 1907). After being sold from the Hope collection in 1886, this opal became part of the Tiffany gem collection of the Field Museum of Natural History, in Chicago, Illinois, where it still resides today.

With the conquest of the Aztecs, the location of the Querétaro opal deposits remained a mystery for several hundred years. It was not until 1855 that a servant of the Hacienda Esperanza re-discovered them (Ramirez, 1884), and it was another 15 years before Don José María Siurob of Querétaro located the Santa María Iris mine in Hacienda Esmeralda and began commercially working the opal deposits (Foshag, 1953). Bauer (1904) states that the gem was so common in the area that "specks of opal are often seen in the stones of buildings." It is interesting to note that the Santa María Iris mine remains the most productive and famous of the Querétaro opal mines today. Since Don José's initial commercial efforts at Hacienda Esmeralda, the region has experienced widespread development. Sinkankas (1976) notes that production from the Querétaro area reached an all-time high in 1969, a result of greatly increased demand from Europe and Japan. Sinkankas lists eight mines, in addition to the famous Iris mine, active in the Querétaro area. Perhaps the most notable of these is the Carbonera mine near Trinidad, not far from San Juan del Río.

All opal mining operations in the Querétaro area are very simple open-pit quarries, and the opal recovery methods have not changed significantly in the last 100 years (figure 2). These quarries may be quite large (figure 3); Burton (1981) reported that the original Iris open-pit mine now has walls over 60 m high. Recovery initially involves the dynamiting of the opal-bearing rock from the quarry wall. The loose boulders are then stacked in a pile to be broken down by hand—into pieces 5 cm or less to improve recovery of gem-quality material—under strict supervision. The rough opal is then sorted and taken to the city of Querétaro where it is fashioned into cabochons. Because of the unusually high transparency of the material and the play of color, these cabochons are usually cut with a high dome rather than the flat ovals common to opals from other regions of the world (Foshag, 1953).

The opal occurs in a series of thinly bedded



Figure 2. Using the same methods as their 19th-century predecessors, miners remove material from the newly reopened Mina El Buey. Mine owner Joaquín Ontiveros reported that Mina El Buey was last worked over 100 years ago.

rhyolite lava flows (Kunz, 1907). Locally these pink to brick-red rhyolites exhibit an abundance of irregular to oval lithophysal (gas) cavities common to rhyolitic lava flows. The opal occurs as a secondary filling in these cavities as well as in any other available spaces in the lava, including pumice fragments and fractures. The opal usually fills the cavities totally, but occasionally it is found as loose nodules in the open spaces. These loose nodules, which may be "as large as a hen's egg," are generally the highest quality material (Foshag, 1953). Figure 4 illustrates one of the finest matrix opal specimens found in Querétaro (Kunz, 1907).

GEMOLOGY OF THE QUERÉTARO OPAL

Opal from the Querétaro area typically has lower properties than the Australian material. The refractive index is usually around 1.42 to 1.43; the



Figure 3. View looking into the Mina La Simpática. This mine is typical of the simple open-pit quarries in Querétaro.

specific gravity is approximately 2.00 ± 0.05 . Querétaro opal is often distinguished from other opal by its unusually high degree of transparency and by its particularly vivid red and green play of color. Although the cabochon is the most common cutting style (again, see figure 1), the transparency of the Querétaro material occasionally allows it to be faceted (figure 5), a cutting style not generally considered for opal. A reddish orange body color is most commonly seen in fine opals from this area (responsible for the term *fire opal*), with predominantly green play of color that may be in broad spangles, small flecks, or even pinfire. Black opals have been reported (Mayers, 1947), but they are probably the result of heat treatment (Sinkankas, 1959).

GENESIS OF MEXICAN OPAL: MULTIPLE CYCLES OF GROWTH

After carefully studying several Mexican opals with included acicular crystals, the authors noted that in almost all cases there seemed to be a shell



Figure 4. Fire opal in matrix. Called one of the finest specimens of its kind by Kunz (1907), this 7.5 × 6.5 cm nodule was taken from the Iris mine in Querétaro and is now part of the Harvard University Collection.

of whitish to pale yellow material surrounding the needle-like crystals. This shell, or coating, often seemed to take on a somewhat bulbous, almost botryoidal, appearance that at first was attributed to a flow structure around the included crystals. It was not until the authors examined a sample of rhyolite matrix rock that contained several partially open gas cavities lined with numerous acicular crystals coated with a near-colorless transparent material (as shown in figure 6) that a full understanding of the nature of these coatings and their origins was learned.

X-ray diffraction on the near-colorless coating material proved it to be opal. This led the authors to theorize that if the cavities containing these already-coated crystals were later filled entirely with opal, an inclusion pattern similar to the one illustrated in figure 7 could be easily explained as resulting from at least two cycles of growth. One

such coated crystal included in an opal was cut through so that it could be studied in cross section. The result, as seen in figure 8, is reminiscent of tree rings and shows that several stages of deposition took place during the initial coating of the needle-like crystal and prior to its inclusion in the larger body of the orange-colored opal host.

It is not particularly surprising to have several cycles of deposition, similar to the tree-ring analogy, because studies of chalcedony in rhyolitic flows in Chihuahua, Mexico, showed similar phenomena. Keller (1977) studied agate in the Sierra Gallego area of Chihuahua and found that the nodules formed at near-surface temperatures and that their characteristically banded structure was probably the result of many years of deposition of silica due to annual fluctuations in the local water table from the wet to dry seasons. It is possible that some of the opal in the Querétaro area formed under similar conditions.

From the numerous layered and flow structures in Mexican opals, it is concluded that the silica initially introduced into the host igneous rock was in a somewhat gelatinous plastic state. Flow structures are seldom as prominent and easily observable as the one illustrated in figure 9 or the black streamers reported by Fryer et al. (1982). They are more often observed as faint, curving flow lines associated with included crystals or other pre-existing formations that tend to interfere with and/or block the flow of the opalizing gel. In a few rare cases, the flowing gel will actually break or twist extremely thin acicular crystals.

INCLUSIONS IN MEXICAN OPAL

Over 3,000 opals from Querétaro were examined with the microscope. The opals were either tumbled, polished, rough, or cut en cabochon. Many contained portions of their original rhyolite matrix. They ranged in hue from near colorless to pale yellow through orange to deep orange-brown, and the diaphaneity varied from transparent to translucent. The majority displayed at least some play of color. Those with some rhyolite matrix frequently proved the most exciting to the authors, as crystals of interest would be attached to the rhyolite and extend into the opal. Occasionally free-floating included crystals and crystal fragments were encountered in the opal.

From the original mass of opals, 20 specimens were chosen because of the size of their inclu-



Figure 5. Faceted fire opal, 3.10 ct.
Photo by Mike Havstad.

Figure 6. Acicular crystals coated with a near-colorless transparent material (found to be opal) inside partially open gas cavities. Magnified 6 \times .

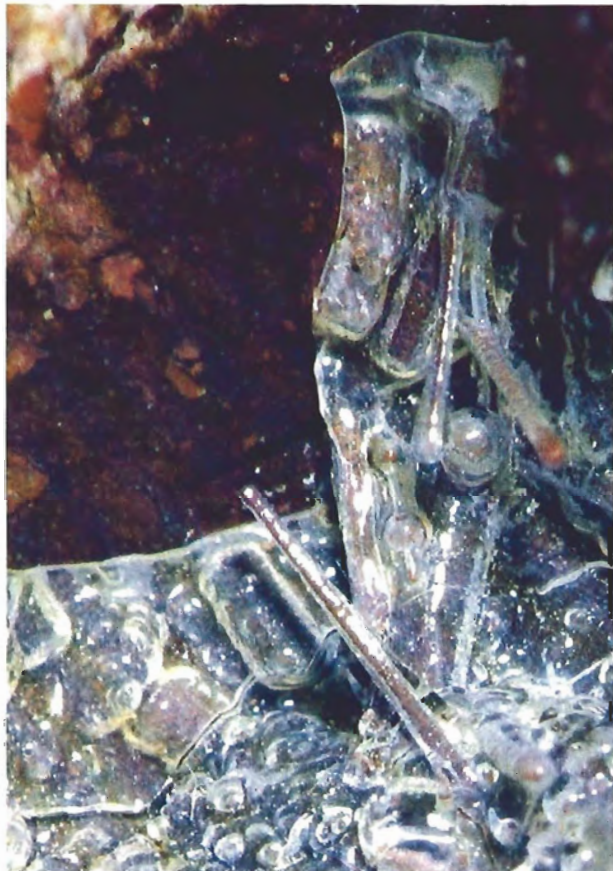


Figure 7. Opal-coated crystals included in opal. Magnified 45 \times .



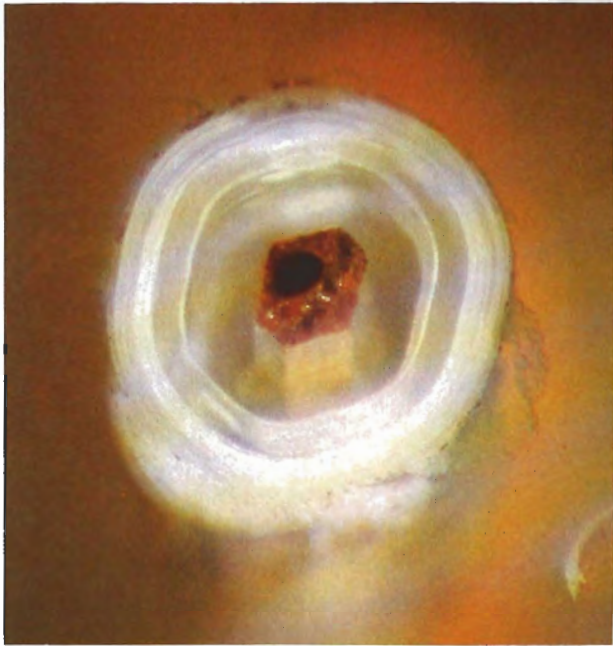


Figure 8. A cross section of a coated crystal (in this case, a partial limonite pseudomorph after hornblende) in Mexican opal. The rings indicate that several stages of deposition occurred during the initial coating of the needle-like crystal and prior to its inclusion in the opal host. Magnified 100 \times .

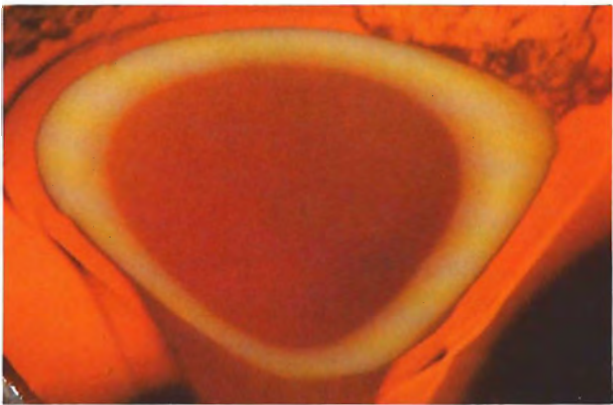


Figure 9. Flow structure in Mexican opal. Magnified 15 \times .

sions, the ease with which they might be analyzed, their photogenic nature, and in some cases because of their rarity and uniqueness. The following discussion reports the results of this investigation, which led to the definitive identification of a number of the included minerals and the revelation of some heretofore unreported inclusion phenomena in opals.

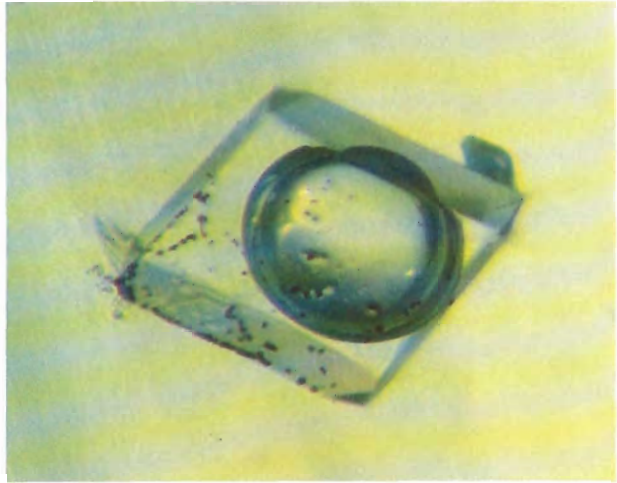


Figure 10. A three-phase inclusion in Mexican opal. Notice the tiny red solid phases attached to the surface of the void. Magnified 50 \times .

Three-Phase Inclusions. When we observe an inclusion that appears to be a negative crystal such as that illustrated in figure 10, one of the last gemstones to come to mind as a possible host is opal, because, by virtue of its amorphous nature, opal should not house negative crystals that contain the liquid, gas, and solid components of a three-phase fluid inclusion. Figure 10, however, illustrates just such a three-phase inclusion in a Mexican opal. The following explanation is offered for its existence. Perhaps during initial formation in its extrusive igneous host, the opal captured and included a euhedral crystal, a carbonate such as calcite or dolomite. If the opal's environment and the natural water it contains in its structure turned somewhat acidic, the rhombohedral carbonate crystal could be dissolved, leaving behind a rhombohedron-shaped cavity that would now be filled with a portion of the dissolving solution and an accompanying gas bubble. Any insoluble inclusions in the original carbonate crystal would be left behind as solids.

In addition, if the dissolving solution brought chemically suspended impurities with it, these, too, could be deposited in the void left by dissolution of the carbonate crystal in the opal host. Study of figure 10 immediately reveals the obvious liquid and gas phases present. A closer examination reveals numerous tiny red solid phases attached to the surface of the void which dent the gas bubble where they are trapped between it and the walls of the cavity, proving that they are inside the bubble with the liquid and gas phases.



Figure 11. This two-phase inclusion in Mexican opal consists of an acicular crystal of hornblende within a balloon-shaped void. Magnified 45 \times .

Two-Phase Inclusions. One of the opals studied contained an included acicular crystal of hornblende within the teardrop void shown in figure 11. It might be easily mistaken for an opal coating on a crystal such as the one shown in figure 7. The hornblende needle contained in the upper bulbous portion of the void was broken off and free to move about in the void, thus identifying it as a hollow space.

A void of this nature might be formed when the opalizing gel fills cavities in the host rock that contain the hornblende needles. As the gel covers the needles, gas bubbles might attach to the hornblende just as gas bubbles can be seen to coalesce on the surface of any object placed in a liquid such as water. The greater density of the gel would force the accumulating gas bubbles upward, forming a balloon-shaped tent around and over the end of the hornblende crystal. When the opal solidified, the gas would be trapped in the balloon-shaped void it had formed in the opal.

Hornblende. The crystal shown in figure 12 is typical of the black, needle-like crystals found in Mexican opals. It is also opaque and is of slightly distorted hexagonal cross section. Crystals of similar appearance that did not reach the surface of the opal host had rhombohedron-like termi-



Figure 12. Black, needle-like crystals are commonly seen in Mexican opal. This particular inclusion proved to be hornblende. Magnified 40 \times .

nations. These properties and the nature of the host rock suggested that these inclusions might be hornblende. An X-ray diffraction powder photograph of an exposed inclusion proved that the initial conclusion was correct. Note that the X-ray diffraction powder test caused no observable damage to either the hornblende inclusion or the host opal.

Limonite Pseudomorphs after Hornblende. Many of the acicular crystals and crystal groups of hornblende are completely, or at least partially, altered to limonite. Limonite is a general term used for hydrous ferric iron oxides such as goethite. Alteration products composed of limonite have a rusty brownish to yellow color with an earthy appearance. During the alteration process, some of the hornblende crystals became quite cavernous on their terminations. An excellent example of partial pseudomorphic replacement of hornblende by limonite is shown in figure 8. The cen-



Figure 13. Goethite inclusion in Mexican opal. Magnified 50 \times .

tral core of this crystal is still fresh black hornblende, while the outside has completely altered to limonite. Notice, too, that in the pseudomorph example, the external morphology of the original hornblende remains intact.

Goethite. Another inclusion observed and studied was a columnar mass of an earthy, red-brown color showing a circular cross section and a concentric radial structure (figure 13). A tentative visual identification of this and many similar inclusions suggested that the material was goethite, $\text{FeO}(\text{OH})$, a common alteration product of iron-bearing minerals such as hematite, pyrite, and hornblende.

As with the hornblende, X-ray diffraction proved the visual identification to be correct: the inclusion is indeed goethite.

Hematite. Intermixed and closely associated with goethite in Mexican opals is hematite. Close microscopic examination of goethite-containing areas in the opals will often reveal small amounts

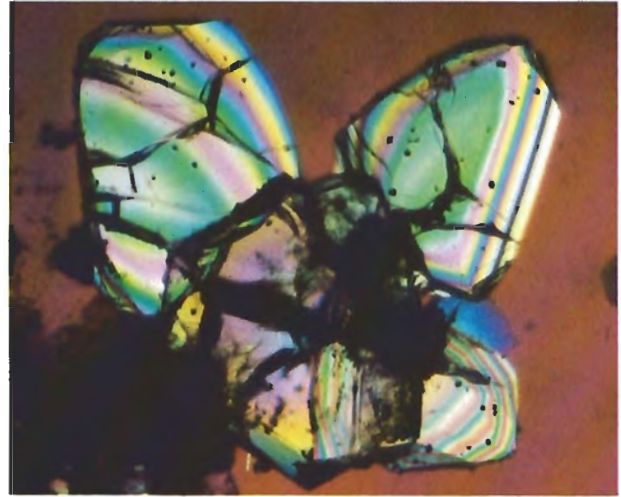


Figure 14. Euhedral prismatic crystals terminated by rhombohedral faces. Testing proved these inclusions to be quartz. Polarized light. Magnified 50 \times .

of a metallic-to-submetallic black material. An X-ray diffraction pattern (done for this study) showed that the black material is hematite. Scraping similar sections that reach the surface of the opals gives the characteristic browish red streak of hematite. Occasionally, single, tabular, somewhat distorted crystals are seen.

Fluorite. A few very small, transparent, near-colorless cubes with octahedrally modified corners were noticed by the authors. Polarized pinpoint illumination showed no evidence of double refraction. The cubes were in direct association with hematite. Two of the cubes are perched on the edge of a single tabular hematite crystal. As this opal is in a private collection, no further testing could be carried out. However, the habit, transparency, and single refraction of these inclusions strongly suggest fluorite.

Quartz. A small, tumble-polished sample of almost-colorless Mexican opal contained numerous small, essentially colorless, euhedral prismatic crystals apparently terminated by rhombohedral faces. Under polarized light with a first-order red compensator, the inclusions, as illustrated in figure 14, stood out vividly as doubly refractive solids in the singly refractive host opal. A Becke line test showed that the refractive index of the inclusions was higher than that of the opal. In transmitted light, little relief could be seen between the opal and the inclusions, suggesting that the R.I. of the inclusions was relatively close to that of the opal; but the double refraction of the in-



Figure 15. Cristobalite inclusion in Mexican opal. Magnified 110 \times .

clusions, their crystal habit, and their low relief suggested quartz. By grinding and polishing the specimen, we exposed one of the larger crystals. A stainless steel probe was used to extricate the crystal from the opal, and the crystal was then crushed. During crushing, no cleavage was observed. The randomly oriented fragments were then placed on a glass slide, and a small drop of clove oil, with a refractive index of approximately 1.53, was placed over the fragments which were then spread out in a thin layer. The tiny fragments of the inclusion virtually disappeared in the clove oil.

The Becke line test and the very low relief proved that the inclusion fragments were only slightly higher in refractive index than the clove oil. Under polarized light, the fragments again became readily visible. Using a tiny condensing lens, we checked the randomly oriented fragments for optic figures. One of the fragments displayed a uniaxial "bull's-eye" optic figure that positively identified the inclusion as quartz.

Cristobalite. Two opals—one a bright transparent orange and the other a near-colorless transparent specimen with attached rhyolite matrix—were found to contain translucent white crystal for-



Figure 16. X-ray diffraction analysis indicated that the dull, whitish, earthy masses illustrated here in association with an orangy brown prismatic crystal were kaolinite, a clay mineral. Magnified 40 \times .

mations such as the one illustrated in figure 15. Since the largest of the inclusions was in the orange sample, we decided to sacrifice this specimen. The same microscopic method of study employed on the quartz was used.

The intricate shape and platy nature of the inclusion eliminated the possibility of dislodging it from the opal host. A tiny cube containing the inclusion was cut from the opal and ground down on a diamond lap until it was about 2 mm in longest dimension. The sample was then crushed and placed on a glass slide. With a polarizing microscope, the inclusion fragments, which proved to be doubly refractive, were easily separated from the singly refractive opal matrix. A drop of clove oil (again, R.I. of 1.53) was then placed over a few isolated inclusion fragments, and a Becke line test showed that the inclusion had a lower index of refraction than the clove oil.

Next, a tiny drop of tetrachlorethane was placed over several of the inclusion fragments. The Becke line test showed that the inclusion fragments were very close to the refractive index, 1.48, of tetrachlorethane.

Cristobalite has refractive indices of 1.484–1.487 and is a known associate of opal in volcanic rocks such as rhyolite and trachyte.

Kaolinite. Dull, earthy masses and cloud-like globs of a white to yellowish-brown to brown material were noted on the surfaces of, and included in, several of the Mexican opals used in this study. These masses and globs could be found clinging

to included crystals, as in figure 16, or in direct contact with the matrix rock in the opals that contained matrix material. These masses showed no distinctive microscopically recognizable features.

The authors, therefore, depended entirely on X-ray diffraction for possible identification of these inclusions. Study of the X-ray diffraction pattern, obtained by scraping some of the whitish material from the surface of one of the opals, revealed that it was most probably kaolinite, a clay mineral.

Pyrite. Only one sample of Mexican opal was observed by the authors to contain very tiny, brassy-yellow, opaque modified cubes and what appeared to be pyritohedrons of pyrite. As the opal embracing the pyrite(?) crystals was in a private collection and could not be fully tested, this identification of pyrite in opal is only tentative.

CONCLUSION

The opal mines of Querétaro, Mexico, have been an important source of this unique gem material for over 100 years. The opal occurs in rhyolitic lava flows and is, for the most part, mined by hand just as it was in the 19th century. Even though the mining methods remain primitive, production is at an all-time high and the future in the world market appears bright.

The inclusions found in opals from this locality reflect their volcanic provenance. This study has conclusively identified five different mineral

species and tentatively identified four more, none of which was previously recorded in the literature as an inclusion in opal. Rutile, commonly noted as an acicular inclusion in Mexican opal, was not encountered in this study. In all probability, the hornblende noted here was previously misidentified as rutile. In addition, a three-phase inclusion, a two-phase inclusion, flow structures, and multiple cycles of growth have also been described and their origins suggested.

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NOTES • AND • NEW TECHNIQUES

THE NEWLY EXPANDED DEUTSCHES EDELSTEINMUSEUM OF IDAR-OBERSTEIN, GERMANY

By Peter C. Keller

With the opening of a new display area in 1982, this unique museum in the gem-cutting capital of Europe has not only doubled in size but has also established itself as one of the finest gemology exhibits in the world. This article describes both the new and old exhibit areas and discusses some of the organization and design techniques that have contributed to the success of the Deutsches Edelsteinmuseum.

In April 1982, the Deutsches Edelsteinmuseum (German Precious Stone Museum) of Idar-Oberstein, Germany, opened a new, second-floor exhibit area to the public. In addition, some of the original first-floor exhibits have been updated. The museum is now one of the best of its kind in the world.

The Deutsches Edelsteinmuseum is housed in the Diamant- und Edelsteinbörse which is the tallest building in Idar-Oberstein. The new ex-

hibit area was created both to accommodate the increasingly large volume of visitors and to expand the scope of the museum. People from all over the world come to Idar-Oberstein to purchase gems; yet no other public museum in the area adequately addresses all the various aspects of this unique field. Although the old agate mines and polishing mills are popular attractions, at the Deutsches Edelsteinmuseum visitors and Idar's gemological students have a chance to learn through seeing some of the finest examples of gems and gem workmanship available today.

THE FIRST-FLOOR EXHIBITS

Immediately upon entering the museum (see figure 1 for a detailed scheme of the two floors of exhibits), the visitor encounters a collection (approximately 30 pieces) of large gemstones, including a 12,555-ct blue topaz from Brazil and an 11,600-ct brilliant-cut rock crystal. According to Gerhard Becker, curator and a driving force in the museum*, this display of "gemstone giants" is meant to attract the visitor into the museum and entice him to explore deeper into the world of gemstones.

ABOUT THE AUTHOR

Dr. Keller is director of education at the Gemological Institute of America, Santa Monica, California. Formerly curator of gems and minerals at the Los Angeles County Museum of Natural History, Dr. Keller now serves on the Board of Trustees of that museum.

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**Mr. Becker is chairman of the volunteer committee that is in charge of the museum. The other members of the committee, each of whom is a specialist in a particular aspect of gemology, include: K. Arnold, Prof. Dr. H. Bank, R. Droeschel, D. Hahn, R. Hahn, and E. J. Petsch.*

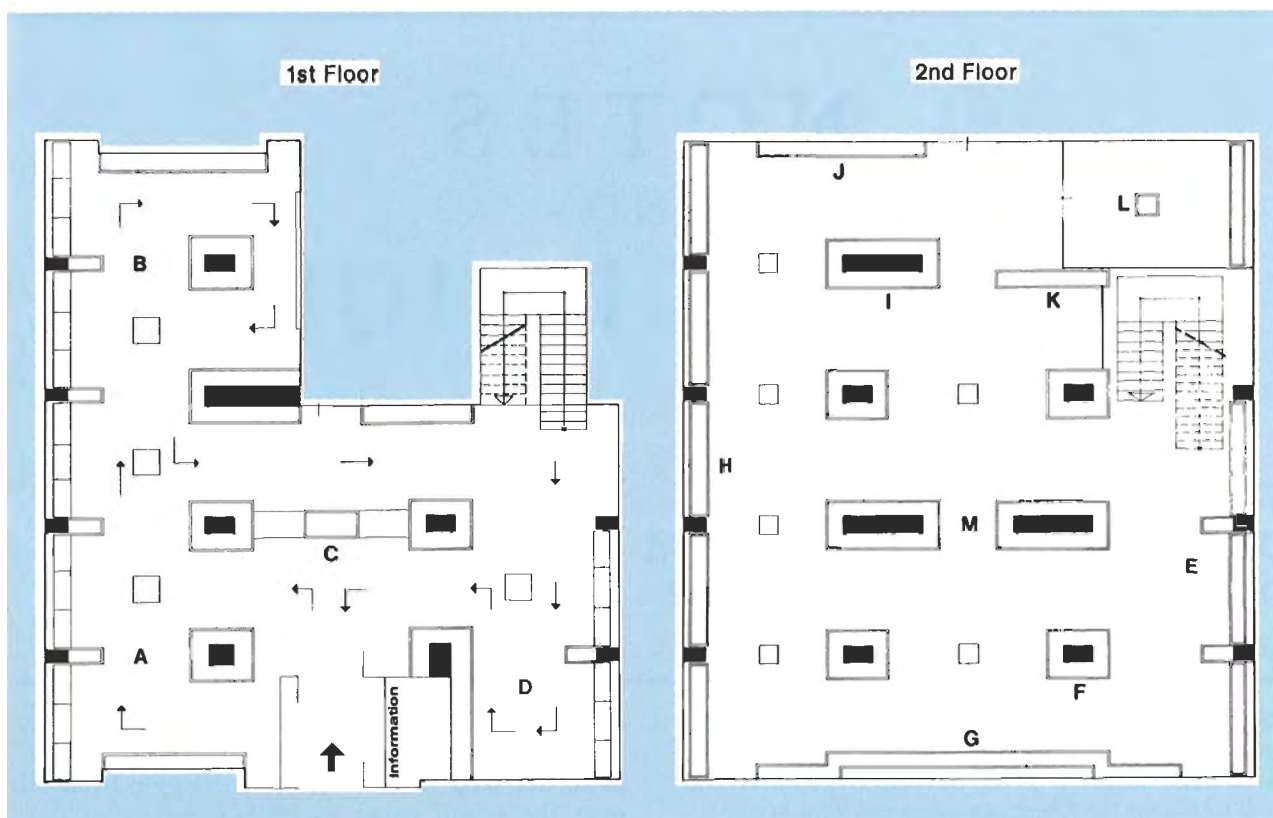


Figure 1. A floorplan of the Deutsches Edelsteinmuseum. The letters designate specific exhibit areas, as follows: A = the history of Idar-Oberstein's gem industry and items carved from Idar-Oberstein's own agate deposit; B = exhibits of both microcrystalline and macrocrystalline quartz varieties; C = unusually large faceted gems and fine carvings from Idar-Oberstein; D = the Glyptothek, an exhibit detailing the history of carving worldwide, with special emphasis on cameo carving in Idar; E = the systematic classification of gemstones along with particularly fine examples of amethyst and citrine; F = gemstones exhibiting asterism and chatoyancy; G = exhibits showing examples of all major gem species in both their rough and cut forms; H = ornamental gemstones as well as gemstones containing unusual inclusions; I = diamonds, both rough and cut; J = gemstones of the 20th century; K = synthetic gem materials; L = the gem vault, containing especially valuable gems that are on loan to the museum; M = rough and cut tourmaline and beryl.

Originally, the entire museum was devoted to the art of gem cutting and carving as it developed in Idar-Oberstein over the centuries. The main first-floor exhibit area is still arranged chronologically to show the evolution of the gem industry in Idar-Oberstein. To the left of the gemstone giants, one finds an exhibit explaining the origins and history of gem cutting in the area from 1375 to the present. This exhibit is accompanied by numerous early books documenting Idar-Oberstein's development.

With this history of gem cutting as a background, the visitor is next introduced to the distinctive agates found in the local Miocene-age basalt flows which gave birth to the gem industry

in Idar-Oberstein. These agates occur in a variety of colors but are predominantly brown and red. Beautiful specimens of amethyst have been recovered with the agates. These appear in the mining exhibits as well, for they also played a major role in the early development of Idar's gem industry.

By the end of the 19th century, however, the German craftsmen could no longer depend on the dwindling supply of agate from the local mines and began importing the stone from Brazil. It wasn't long before they brought in amethyst, rose quartz, and many other varieties of quartz as well. They also started dyeing the grayish Brazilian agate; first, they used black and red, and then they



Figure 2. This pair of rock crystal owls on a petrified wood base is typical of the contemporary animal carvings displayed in the museum. Each owl is approximately 8 cm high; the entire piece is approximately 18 cm.

slowly developed other colors such as greens and blues. The next exhibit shows both early and contemporary workmanship using all the varieties of quartz imported from Brazil; items included are carved bowls and various animals (figure 2).

In recognition of the role that agate and other varieties of quartz have played in stimulating and perpetuating the carving industry in Idar-Oberstein, fully half of the first floor of the museum has been devoted to quartz and its many gem varieties. Particularly interesting among the early carvings are the subtle brown, black, and black-and-white agate beads that were fashioned in Idar-Oberstein and subsequently used by many African tribes as currency. Also impressive are the

fine agate bowls with cameo-like carvings in their interiors, which may take up to a year to complete.

Separate from the main theme of the exhibit area on the first floor, and almost a museum within a museum, is an exhibit on the evolution of gem carving worldwide over the last 6,000 years. Called the *Glyptothek*, this unique display of carved gemstones contains approximately 250 objects. The entire exhibit was either collected or manufactured by Idar-Oberstein's foremost gem carver, Richard Hahn. If a piece was unobtainable, Hahn reproduced the carving in its original style. The exhibit beautifully illustrates the art of stone carving from early man, with his rough beads of



Figure 3. This fine Brazilian amethyst crystal is one of many "touch" specimens seen throughout the museum.

quartz; through the ancient Egyptians, with their scarabs and seals; the Romans, with their cameos and intaglios; and finishing with early European carvings, including those of Idar-Oberstein. The exhibit is particularly strong in cameos.

One of the more unusual aspects of the museum is the large number of high-quality specimens that can be touched by the public. Enjoyed by adults and children alike, the dozens of "touch" specimens scattered throughout the museum include a fine 1.2×0.6 m malachite slab from the USSR; a large, gemmy aquamarine crystal; a large sphere fashioned from lapis lazuli; and a superb amethyst crystal (figure 3).

At the base of the stairs that lead to the new second-floor exhibit area is a reproduction of a pegmatite pocket found in Madagascar (figure 4). This unusually large pocket contains enormous aquamarine and quartz crystals. The walls of the pocket are studded with mica and quartz as well as feldspar, which makes for a most convincing reproduction. The pocket was conceived and constructed by Gerhard Becker.



Figure 4. A two-meter-high reproduction of an aquamarine pegmatite pocket as found in Madagascar.

THE SECOND-FLOOR EXHIBITS

Mounted on the walls midway up the stairs to the new exhibit area are three large, dramatic photographs from different localities showing the most important types of gem deposits: alluvial mining for corundum in Sri Lanka, pegmatite mining for beryl and tourmaline in Madagascar, and open-pit mining for tourmaline in Brazil. These photos are appropriate to introduce the theme of the new, second-floor exhibit area: gemology. Every effort has been made to present a broad, well-rounded lesson in the field in a dramatic yet inviting atmosphere (figure 5). The walls, as well as the display bases, are covered with a dark, chocolate-brown carpet. Track spotlights also are used judiciously to give a feeling of warmth.

The first exhibit encountered explains how gemstones can be classified according to their chemical composition: from diamonds, as native elements, through the many silicates. Following this exhibit, we find a case of birthstones (cabochons); a display showing chatoyancy and asterism; and a presentation on inclusions in gems, such as rutilated quartz.

Most of the remaining portions of the new exhibit area are devoted to the major gem species and feature both rough specimens and cut stones. For the most part, the examples included—especially the rough crystals—are very fine. Particularly impressive are the large Brazilian gem crystals, including aquamarine, blue topaz, imperial topaz, kunzite, and tourmaline. The exhibit also contains some of the finest rough-and-cut tanzan-



Figure 5. The second-floor exhibit area stresses gemology in an atmosphere of elegance. Again, note the numerous "touch" specimens on the floor.

ite in existence today. Certainly the new exhibit in Idar-Oberstein must be considered one of the most extensive rough-and cut gemstone exhibits in the world.

The exhibit of phenomenal stones is also noteworthy. The stones show off their asterism and chatoyancy as well as any seen in major museums elsewhere (figure 6). The credit can be given to the unique lighting: the actual light source hangs from a long cord to within a few centimeters of the gem, so that a maximum amount of direct light hits the stone with minimal interference from ambient light. The exhibit itself contains some spectacular cat's-eye tourmaline and apatite, a star rose-quartz sphere, and a very interesting necklace of cat's-eye chrysoberyl beads.

Also on the second floor is an exhibit that displays virtually every important synthetic gemstone known today, including the products of such major manufacturers as Chatham, Kashan, Gilson, and Lechleitner. I know of no other exhibit of synthetics anywhere that matches this in scope.

Equally unique is the display of gemstones

new to the 20th century, in both their rough and cut forms. These include mineral species such as benitoite, sinhalite, brazilianite, ekanite, taaffeite, charoite, and sugilite, as well as species that

Figure 6. The fine exhibit on chatoyancy and asterism includes these cat's-eye tourmalines and star rose quartzes.





Figure 7. The new exhibit is particularly strong in diamonds, and the technique of displaying them on coal is but one example of the museum's innovativeness.

were not known as cut stones prior to the 20th century, such as cuprite and labradorite. Also featured are gems from localities that are new to the 20th century, such as Indian aquamarine, Pakistani topaz, Afghani tourmaline and kunzite, and Brazilian emerald.

The highlight of the new second-floor exhibit is a walk-in vault containing some of the finest gems in the museum. The centerpiece in the vault is a 2-ct diamond, displayed with several smaller diamonds. Elsewhere, diamonds are displayed in a unique manner on coal (figure 7). The cases along the far wall of the exhibit include exquisite tanzanites, emeralds, rubies, sapphires, imperial topaz, and some very fine cameos, one of which is of ancient Roman origin.

According to Gerhard Becker, the vault was built for two purposes. First, it enables the museum to present special exhibits from all over the

world with the assurance of adequate security. Second, the concept of a vault serves to underscore the great value of the materials housed therein.

The people of Idar-Oberstein can be justly proud. Their museum is indeed superb. I know of no other like it in Europe or, for that matter, anywhere else in the world. The Deutsches Edelsteinmuseum is in a unique position to present the subject of gemology and gem carving in that it is backed enthusiastically by the huge gem industry in Idar-Oberstein. Because of this gem industry, Idar-Oberstein receives a steady flow of new gem materials from the world over; the various companies select the best and most unusual from their inventories and loan it to the museum for display. This industrial backing guarantees that the museum will remain dynamic, constantly being changed and updated for the public.

PERIDOT FROM TANZANIA

By Carol M. Stockton and D. Vincent Manson

Peridot from a new locality, Tanzania, is described and compared with 13 other peridots from various localities in terms of color and chemical composition. The Tanzanian specimen is lower in iron content than all but the Norwegian peridots and is very similar to material from Zabargad, Egypt. A gem-quality enstatite that came from the same area in East Africa and with which Tanzanian peridot has been confused is also described.

In September 1982, Dr. Horst Krupp, of Idar-Oberstein, sent GIA's Department of Research a sample of peridot for study. The stone was from a parcel that supposedly contained enstatite purchased from the Tanzanian State Gem Corporation, the source of a previous lot of enstatite that Dr. Krupp had already cut and marketed. Material from the second parcel, however, exhibited no cleavage and, during reshaping, displayed hardness characteristics different from those noted in the first parcel of enstatite. Closer examination revealed refractive indices that corresponded more closely to those of peridot than enstatite. These stones reportedly came from alluvial gem deposits in the vicinity of the Usambara Mountains in the Uмба district near the Tanzania-Kenya border. While peridot from East Africa has been briefly reported (Bridges, 1982), there has as yet been no detailed documentation of the material in the gemological literature.

DESCRIPTION

The rough material examined by Dr. Manson consists of slightly worn-looking or partly corroded crystals. The crystal surfaces are characterized by varying degrees of frosting typical of alluvial transport. Still in evidence, however, are surficial solution and etch features, which suggest that the material was not carried far.

The 1.37-ct oval-cut stone now in GIA's permanent collection (GIA #13781) is exceptionally transparent and bright, with less yellow than is typical of most peridots. The refractive indices, measured from the table of the stone with a GEM

Duplex II refractometer and sodium light, approximate $\alpha = 1.650$, $\beta = 1.658$, and $\gamma = 1.684$, indicating a biaxial positive optic character. The specific gravity, measured hydrostatically, is approximately 3.25.

CHEMISTRY

The Tanzanian peridot was analyzed using a MAC electron microprobe at an operating voltage of 15 KeV and beam current of 0.05 μ A. The standards used were periclase for MgO, kyanite for Al_2O_3 , quartz for SiO_2 , wollastonite for CaO, rutile for TiO_2 , chromic oxide for Cr_2O_3 , almandine-spessartine garnet for MnO, fayalite for FeO, and nickel oxide for NiO. The data were corrected using the Ultimate correction program (Chodos et al., 1973).

For purposes of comparison, we also selected and analyzed peridots from major known localities: Egypt (Zabargad), Burma, Arizona, Norway, and Mexico (figure 1). The chemical compositions of these stones and the Tanzanian material are listed in table 1. Recent gemological and mineralogical literature on peridots from various localities provides additional information on comparable material (e.g., Burns, 1970; Wilson, 1976; Dunn, 1978; Gübelin, 1981; Steele et al., 1981; and Koivula, 1981).

RELATIONSHIP OF COLOR TO CHEMISTRY

The colors of the Tanzanian and 13 other peridots were determined with the GEM ColorMaster

ABOUT THE AUTHORS

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Figure 1. Seven of the peridots studied, representing the range of colors from various localities. These stones are (left to right) from: Tanzania, Burma, Burma, Arizona, Mexico, Egypt, and Norway.

(again, see table 1) and converted to CIE color coordinates. Figure 2 shows the positions of the stones on the relevant portion of the CIE diagram, from which it is evident that the hue of the Tanzanian peridot is closer to that of the Norwegian and Zabargad material than to the hues of the other peridots. Since the stones from Tanzania, Nor-

way, and Zabargad all contained less iron than the other peridots analyzed (see table 1), our first assumption was that the color would correlate simply with the amount of iron present. However, an examination of the stones when arranged according to Fe content (figure 3) indicates no such orderly relationship.

TABLE 1. Chemical composition (in weight %) and color of peridot specimens from various localities.^a

Chemical composition and color	Tanzania	Egypt (Zabargad)		Burma			Arizona		
	(13781)	(15)	(16)	(13034)	(13035)	(11447)	(12430A)	(12430B)	(12430C)
Composition ^b									
MgO	51.26	50.95	50.44	48.90	50.71	49.51	50.28	48.89	48.22
SiO ₂	40.62	41.03	41.07	40.25	40.75	40.81	40.80	40.55	40.77
CaO	* ^c	0.03	0.04	*	*	*	0.09	0.11	0.06
TiO ₂	*	*	*	*	*	*	*	*	*
Cr ₂ O ₃	*	*	*	*	*	*	*	*	*
MnO	0.12	0.13	0.11	0.15	0.07	0.09	0.10	0.12	0.17
FeO	7.74	7.95	8.14	10.16	8.58	10.06	8.25	9.73	9.68
NiO	0.39	0.41	0.38	0.31	0.39	0.33	0.35	0.37	0.39
Total	100.13	100.50	100.18	99.77	100.50	100.80	99.87	99.77	99.29
Ratio									
Mg/Mg+Fe	0.922	0.920	0.917	0.896	0.913	0.898	0.916	0.900	0.899
ColorMaster coordinates	A-29/80/04	A-21/57/02	B-36/100/01	B-29/36/01	B-48/46/01	A-26/63/03	— ^c	B-27/44/01	A-18/40/02
CIE x and y coordinates	0.399/0.501	0.406/0.515	0.422/0.540	0.505/0.451	0.542/0.427	0.414/0.494	— ^c	0.475/0.480	0.421/0.487

^aThe GIA catalog number for each stone is indicated in parentheses.

^bError is less than ±2 weight %.

^cAsterisk indicates less than 0.02 weight % throughout table.

^dColor coordinates for heat treated peridot:

	ColorMaster	CIE
Before heat treatment	A-27/63/03	0.418/0.491
After 12 hours at 700°C	B-54/99/04	0.458/0.474
After additional 12 hours at 750°C	D-18/83/04	0.506/0.469

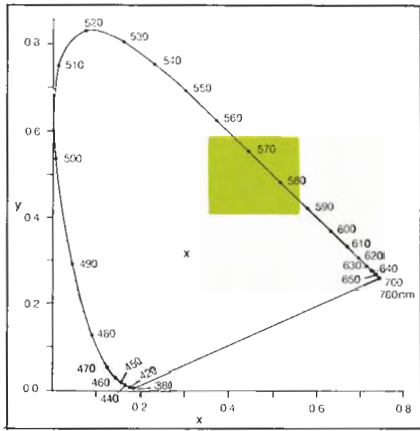
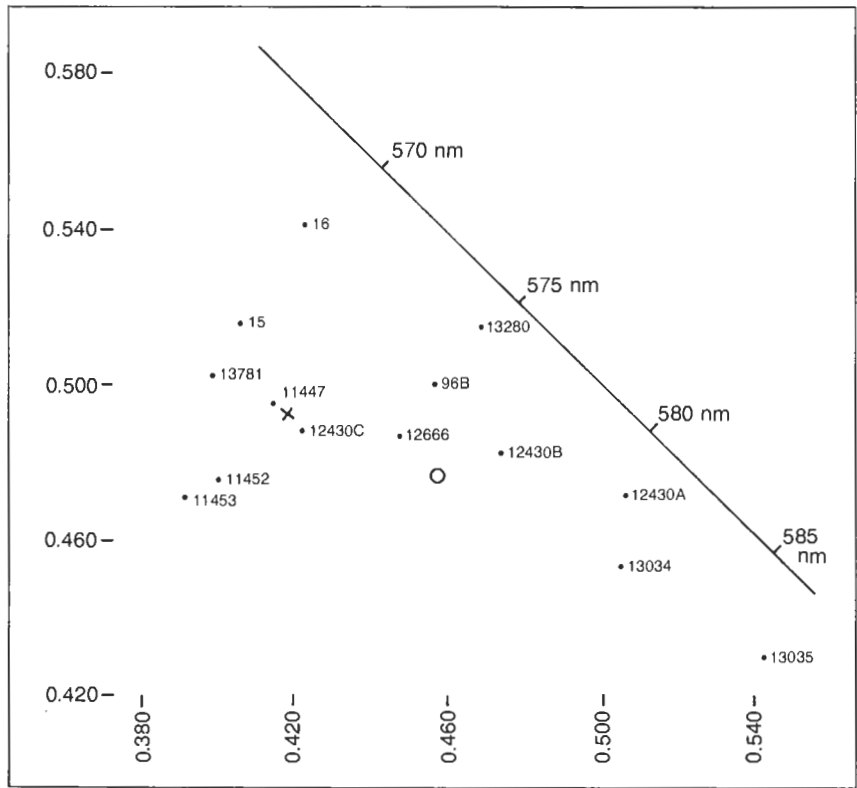


Figure 2. (A) CIE color graph; the shaded area is the region reproduced at right (B), on which coordinate points are plotted for the 14 peridots examined. (Note the GIA catalog numbers for cross-referencing with table 1.) Points x and o represent, respectively, the coordinates for stone 12430A before heat treatment and after 12 hours at 700°C. Enstatite 96B is also included on the diagram.



	Norway		Mexico
(13280)	(11452)	(11453)	(12666)
48.25	51.76	51.63	49.24
40.56	41.18	41.19	40.79
0.07	*	*	0.07
*	*	*	*
*	*	*	*
0.17	0.08	0.06	0.11
11.18	6.95	6.94	9.22
0.36	0.43	0.29	0.40
100.59	100.40	100.11	99.83
0.885	0.930	0.930	0.905
C-28/100/00	A-38/96/07	A-37/97/08	B-26/50/02
0.469/0.513	0.400/0.474	0.391/0.469	0.447/0.483

Next, we questioned whether the oxidation state of the iron present was affecting color. A study of diamond inclusions (Prinz et al., 1975) revealed that nearly colorless olivine inclusions oxidized to pale brown to red at the temperatures and times required to burn away the surrounding diamond (about 800°C for 6 to 24 hours). In order to confirm this effect, we selected for heat treatment one of the Arizona peridots already analyzed (GIA #12430A; see table 1). Exposure to 600°C for 4 hours yielded no visible effect, but after the stone had been subjected to a temperature of approximately 700°C for 12 hours, it turned noticeably darker and browner. An additional 12 hours of heating at 750°C produced the present color of the stone (figure 4). This suggests that the oxidation state of iron in peridot has a marked influence on the color. Further study of valence states and site locations of iron by means such as Mössbauer spectroscopy will provide a better understanding of the causes of color in peridots, but is beyond the scope of this article. It should be noted, though, that the times (several hours) and temperatures (over 500°C) required to oxidize peridot sufficiently to cause a change in color do not represent a risk for the jeweler/gemologist in terms of the color stability of a stone during repairs, in



Figure 3. A selection from the peridots studied that clearly refutes the idea that the amount of iron alone accounts for the variety of color observed among peridots. These stones are arranged (left to right) from lowest to highest proportion $Mg/Mg+Fe$ (i.e., from most to least FeO present).



Figure 4. The stone on the left is Arizona peridot GIA #12430A after heat treatment. Its original color was the same as that of the peridot shown on the right in this photo.

Figure 5. The stone on the left is an enstatite from East Africa (GIA #96B); the stone on the right is a peridot from Mexico (GIA #12666).

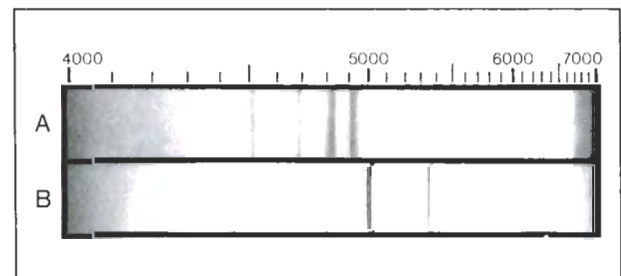


the cutting process, or during any kind of normal wear.

GEMOLOGICAL SEPARATION OF PERIDOT FROM ENSTATITE

We also examined an East African enstatite (GIA #96B) that we believe to be similar to the ones confused with the Tanzanian peridot. This stone at first appears to be quite like peridot (figure 5), and the refractive indices measured from the table of the stone—approximately $\alpha = 1.669$, $\beta = 1.672$, and $\gamma = 1.679$ (biaxial positive)—lie in the ranges of those for peridot, although the birefringence of enstatite is considerably lower than that of peridot (approximately 0.010 as compared to 0.036). The spectra of peridot and enstatite, however, provide an easy means of distinguishing

Figure 6. Optical absorption spectra of (A) enstatite from East Africa (GIA #96B), and (B) peridot from Mexico (GIA #12666).



the two stones. Although both have been thoroughly documented (Liddicoat, 1980), the spectra for the enstatite and peridot shown in figure 5 are reproduced here (figure 6) for immediate reference.

Chemical analysis of this same enstatite (see table 2; performed at the same time as the peridot analyses) revealed an MgO:FeO ratio similar to that of the Tanzanian peridot as well as a somewhat high aluminum content for enstatite (Dunn, 1975/76 and 1978; Schmetzer and Krupp, 1982). These compositional features are characteristic of enstatite formed in a high-temperature, high-pressure geologic environment in which peridot can also form (Deer et al., 1978).

SUMMARY

The dozen or so samples of cut peridot from Tanzania that we have seen are all exceptionally attractive gems with transparency and color comparable to that of material typical of Norway and to some of the stones from Zabargad. Although these East African peridots have been confused at times with enstatite, the characteristic spectra of the two materials provide an easy means of separation. The quantity of peridot available from Tanzania is as yet unknown and will determine the significance of this material to the gem market.

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TABLE 2. Chemical composition and color of the enstatite specimen from East Africa.

Composition ^a	Weight %
MgO	32.71
Al ₂ O ₃	7.10
SiO ₂	53.93
CaO	0.14
TiO ₂	0.09
Cr ₂ O ₃	0.09
MnO	1.12
FeO	4.49
Total	99.67
ColorMaster coordinates	B-26/50/01
CIE x and y coordinates	0.457/0.498

^aError is less than ±2 weight %.

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INVESTIGATION OF A CAT'S-EYE SCAPOLITE FROM SRI LANKA

By K. Schmetzer and H. Bank

A cut gemstone with intense chatoyancy that originated from Sri Lanka was determined to be a member of the scapolite solid-solution series. Indices of refraction and unit-cell dimensions were found as $\omega = 1.583$, $\epsilon = 1.553$ and $\underline{a} = 12.169$, $\underline{c} = 7.569 \text{ \AA}$, respectively; a meionite content of 69% was established by microprobe analysis. The chatoyancy is caused by needle-like inclusions with an orientation parallel to the c-axis of the scapolite host crystal. Microprobe analysis of these needles showed them to be pyrrhotite.

Natural scapolites are members of the solid-solution series marialite, $\text{Na}_8[(\text{Cl}_2, \text{SO}_4, \text{CO}_3)] | (\text{Al Si}_3\text{O}_8)_6$, and meionite, $\text{Ca}_8[(\text{Cl}_2, \text{SO}_4, \text{CO}_3)] | (\text{Al}_2 \text{Si}_2\text{O}_8)_6$. Scapolite crystals of gem quality occur colorless and in white, gray, yellow, pink, and violet. Cut gemstones are known from Burma, Brazil, Sri Lanka, Madagascar, Mozambique, Canada, Kenya, and Tanzania. Scapolites with chatoyancy, so-called cat's-eye scapolites, are known from Burma, Sri Lanka, Madagascar, and Tanzania. In general, the cat's-eye effect in this gem material is caused by needle- or rod-like inclusions running in a direction parallel to the optical axis of the tetragonal scapolite. These inclusions have been described in scapolites from Burma as rod-like cavities (Webster, 1975) or as needles of doubly refractive crystals (Eppler, 1973). In cat's-eye scapolites from Sri Lanka, parallel fibers or channels have been mentioned (Gübelin, 1968); samples from Madagascar contain hollow channels, liquid-filled channels, and needles of doubly refractive crystals (Eppler, 1958, 1973). The cat's-eye effect in scapolites from Tanzania is due to reddish brown inclusions of iron oxides or hydroxides; Tanzanian scapolites with asterism caused by two sets of parallel inclusions are known but are very rare (Schmetzer et al., 1977). By careful investigation of the mineral inclusions of two Tanzanian scapolites (chatoyancy not mentioned), the different mineral phases filling numerous growth tubes were determined to be lepidocrocite and Fe_2O_3 (maghemite or hematite).

Furthermore, hexagonal plates up to 0.4×0.4 mm in size with metallic luster were determined to be pyrrhotite in these samples (Graziani and Gübelin, 1981).

This article describes a scapolite crystal from Sri Lanka that was cut into a 1.68-ct cabochon (approximately 9 mm \times 5 mm) with particularly intense chatoyancy (figure 1). The ray of light crossing the surface of the cabochon is relatively broad compared to the sharpness of rays in other gemstones with chatoyancy or asterism, such as the more familiar cat's-eye chrysoberyls or asteriated corundum. The physical and chemical properties of this cat's-eye scapolite are presented, and the cause of the distinctive chatoyancy in this stone is explained.

PHYSICAL AND CHEMICAL PROPERTIES

A small facet was cut and polished on the bottom of the cabochon in order to determine the refractive indices. The crystal was optically uniaxial negative with $\omega = 1.583(1)$, $\epsilon = 1.553(1)$, $\Delta = 0.030$. Using common gemological determinative tables, we identified the stone as a member of the scapolite solid-solution series. This result was confirmed by the X-ray powder diffraction pattern of the sample (Debye-Scherrer camera, diameter 114.6 mm, $\text{FeK}\alpha$ -radiation). From the powder pattern, the unit-cell dimensions were calculated as $\underline{a} = 12.169(3)$, $\underline{c} = 7.569(2) \text{ \AA}$, $V = 1120.9 \text{ \AA}^3$.

Chemical data for the sample were determined by microprobe analysis (ARL-SEM-Q). A meionite content of the scapolite was calculated as 69 wt% using the formula:

$$\% \text{ meionite} = \text{Ca}/(\text{Na} + \text{K} + \text{Ca}) \times 100$$

The sulfate (SO_3) content of the sample was 0.46 wt%.

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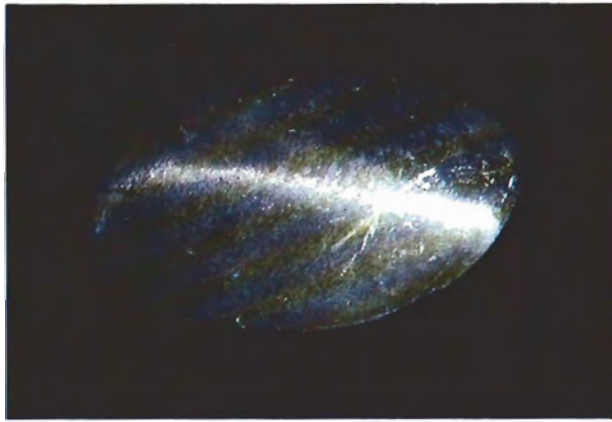


Figure 1. A 1.68-ct cat's-eye scapolite from Sri Lanka. Photo by E. Medenbach, Bochum.

In the scapolite solid-solution series, the unit-cell dimension a as well as both refractive indices ω and ϵ increase with the increasing meionite content of the sample, whereas the unit-cell dimension c remains more or less constant (Eugster et al., 1962; Deer et al., 1968; Tröger, 1971; Ulbrich, 1978). Comparing the physical data of the scapolite investigated here with the optical data and unit-cell dimensions of scapolites with similar chemical compositions, as given in the literature, we found a good congruence of all values. The meionite content of approximately 70%, as established by microprobe analysis, was confirmed. Several scapolites with a composition near 70% meionite have been described in the literature (Ingamells and Gittins, 1967; Evans et al., 1969; Ulbrich, 1973; Graziani and Lucchesi, 1982); though rarer, cut gem scapolites of similar composition have also been mentioned in various articles (Krupp and Schmetzer, 1975; Dunn et al., 1978; Graziani and Gübelin, 1981; see also, Zwaan and Arps, 1980).

THE CAUSE OF CHATOYANCY

The chatoyancy in the scapolite described in this article is caused by needle- or rod-like inclusions preferentially oriented parallel to the optical axis of the scapolite host crystal. Some of the needles, however, are also observed in an orientation different from this direction (as in figure 2). Identification of these needle-like inclusions was difficult because of their small size. Some of these inclusions ran in a direction perpendicular to the small facet that had been cut and polished for optical purposes; they were found to average 1 to 2 μm in diameter, with some even smaller. A qualitative microprobe analysis showed that the

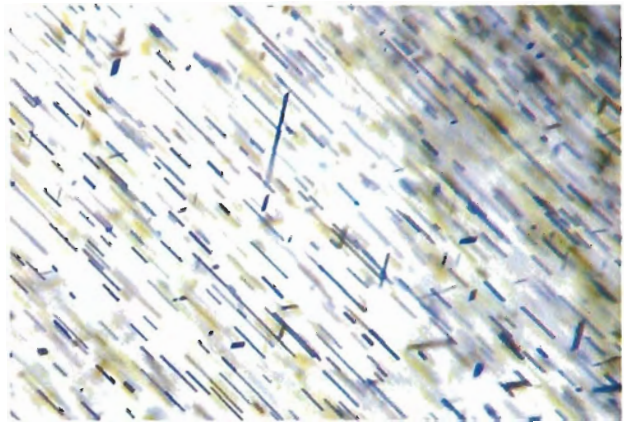


Figure 2. Needle-like inclusions of pyrrhotite in scapolite from Sri Lanka. Magnified 30 \times . Photomicrograph by Th. Lind, Heidelberg.

needles contained only iron and sulfur as the main elements. Quantitative analysis, however, was difficult. Because of the small diameter of the needles, only a quantitative analysis of both the inclusions and the scapolite host crystal could be done by the microprobe. Analyzing those needles of maximum diameter, we found iron contents of 22.4 to 31.8 wt%, and sulfur contents of 17.0 to 22.0 wt%. The atomic proportions of both elements calculated from these measurements, however, were found to be constant within the normal limits of error by microprobe analysis. Therefore, these data are thought to be useful for the determination of the inclusions. Ignoring the small analytical error caused by the 0.46% SO_3 content of the scapolite host crystal, we calculated the Fe/Fe+S atomic ratio to be in the range of 0.431 to 0.454. These values correspond to the ratio of these elements in pyrrhotite, Fe_{1-x}S (Craig and Scott, 1974). The determination of pyrrhotite plates in scapolites of similar chemical composition by Graziani and Gübelin (1981) is in agreement with this finding.

A distinct cat's-eye effect is caused in a gemstone cut with a curved surface (cabochon) by the scattering of light by parallel needle-like inclusions and the refractive effect of the surface of the cabochon (Weibel et al., 1980; Wüthrich and Weibel, 1981). Since some of the needle-like inclusions in this scapolite from Sri Lanka are oriented in directions other than parallel to the optical axis, a broad ray of light is formed on the cabochon's surface; this ray is less sharp than those commonly seen in cat's-eye chrysoberyls, in which only one distinct orientation of the needle-like inclusions is observed.

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Editorial Forum

"NEW" KUNZ MANUSCRIPT

Enclosed is a copy of an original manuscript which I recently acquired. New "finds" of original Kunz material are rare and this one surfaced through a non-gemological source—I therefore believe it to be new to gemological literature.

The inscription was located in a large and bulky "blank" book, being a collection of autographs, monographs, and inscriptions collected over an estimated twenty years by a U.S. ambassador's wife. He apparently served in a variety of positions and, as his wife, the collector assembled a huge number of inscriptions, principally from well-known political figures. The Kunz piece was the only one of gemological interest and prior to our discovery probably received little attention.

The two thoughts expressed by Kunz are interesting, if not informative, remembering that they are nearly a century old.

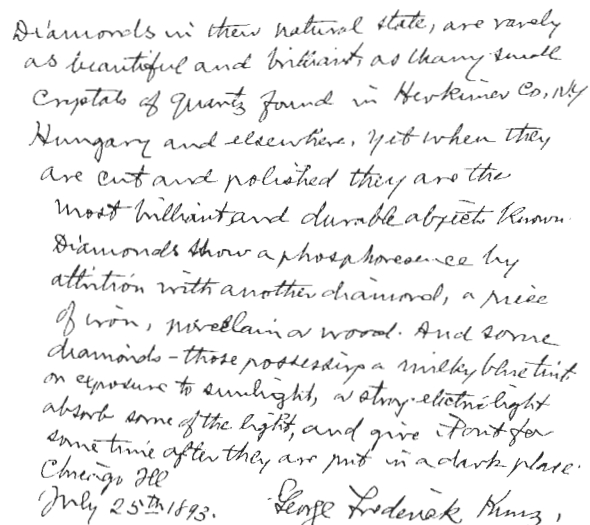
May I take one additional small bit of valuable space to express my thanks and appreciation for the excellence of *Gems & Gemology* in its new format. I am sure my colleagues join me unanimously in appreciation of the high standards of gemological excellence, editorial ethic and photographic achievement apparent in every issue.

Stuart J. Malkin
Olde World Gemstones
Sherman Oaks, California

PEARL MYSTERY SOLVED

The "Pearl Mysteries" in the Spring 1983 Lab Notes section of *Gems & Gemology* are undoubtedly the freshwater cultivated pearls coming out of China. They are the same kind we have been buying from the Pearl Branch of the China Arts and Crafts Corp. for the past four years.

The small baroques are quite unusual and very limited in quantity, and we can rarely find more than five or ten hanks at a time (ten 16" strands to the hank). The button pearls are delightful and we have done quite well by putting them into more elegant necklaces. The rice pearl shapes are much more prevalent and are



Diamonds in their natural state, are rarely as beautiful and brilliant as many small crystals of quartz found in Herkimer Co., N.Y. Hungary and elsewhere, yet when they are cut and polished they are the most brilliant and durable objects known. Diamonds show a phosphorescence by attrition with another diamond, a piece of iron, murexian or wood. And some diamonds—those possessing a milky blue tint on exposure to sunlight, a strong electric light absorb some of the light, and give it out for some time after they are put in a dark place.
Chicago Ill
July 25th 1893. George Lodovick Kunz,

available in a range of sizes and finishes. The larger semi-round (or partially baroque) are the prettiest and do best on 32" fashion ropes combined with other stone beads. All of them are available in a range of colors. We cherry-pick the peach nectar colors as well as shades of lavender, cinnamon, and some with a golden hue.

We visited the factory in Shanghai last year, where incidentally they were also cutting slabs of jade, as well as training a half-dozen apprentices in cutting diamonds. There was no evidence of bleaching or tinting of the pearls as they were being sorted. The drilling was done in two manners. The women, for the most part, were using old-style bamboo baskets, wedging the pearl and bow-stringing the drill. The men were using Japanese-style horizontal drills that looked like lathes.

Quantities have increased over the past four years, and we were even able to purchase a kilo of undrilled larger pearls, ranging in size from 6 to 10 mm, including quite a few exotic shapes and colors.

Frederick Fisher
Treasures by Frederick Fisher
Scottsdale, Arizona

Gem Trade LAB NOTES

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DIAMOND

Flights of Fancy

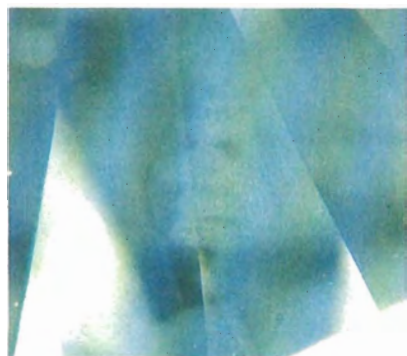
From time to time we encounter examples of some new creation or artistic achievement that is the product of someone's imagination. The "crusader" diamond illustrated in the Gem Trade Lab Notes column of the Winter 1982 issue of *Gems & Gemology* and the fish-shaped diamond pictured in the Spring 1983 column are examples of this. Occasionally we see inclusions in stones

that stimulate our own imagination, resulting in what might be called flights of fancy. Most of our readers have heard of Jonathan Livingston Seagull and his wonderful flights. In figure 1, taken in our New York laboratory, he appears to be coming in for a landing. Imagination has created something beautiful out of a feather (please pardon the pun) in a diamond. Another diamond, also seen in New York, has a cloud-like inclusion that very closely resembles a portrait of the third president of the United States, Thomas Jefferson (figure 2).



Figure 1. A flight of fancy. Magnified 25x.

Figure 2. Portrait in diamond. Magnified 53x.



Painted Pink Diamond: The Big Switch

During the presale viewing of gems and jewelry that were scheduled to be auctioned by Sotheby Parke Bernet galleries in April 1983, an attractive 9.58-ct fancy pink, potentially flawless emerald-cut diamond (figure 3) was replaced by a 10.88-ct light yellow emerald cut that had been painted quite evenly with pink nail polish (figure 4). The polish evidently did not prevent the diamond tester from giving a positive reaction for diamond when the stone was routinely checked prior to being returned to the display case.

The New York GIA Gem Trade Laboratory issued a report in late 1982 for the pink diamond. It measured 13.80 × 10.88 × 7.10 mm. In May 1983, we issued a report for the substitute diamond. After the nail polish was removed, it was found to be approximately U to V range in color and VS2 in clarity. It measured 14.84 × 11.83 × 7.32 mm.



Figure 3. A 9.58-ct fancy pink diamond stolen from Sotheby's in New York.

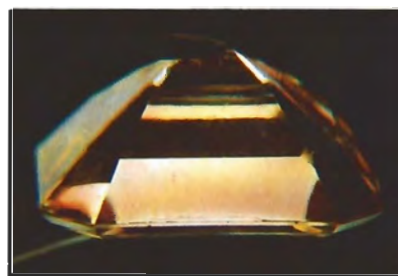


Figure 4. A 10.88-ct yellow diamond coated with pink nail polish that was substituted for the stone in figure 3. The pink band seen in the pavilion facet is representative of the color face-up.

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Sotheby's pre-auction estimate for the pink stone was in excess of \$500,000; the yellow substitute was valued by their appraisers at approximately \$12,000–\$15,000.

Rose Cuts

The rose cut originated in India over 400 years ago and was introduced into Europe by the Venetians very early in the 16th century. The early rose cuts were often fashioned from cleavage fragments of diamonds having trisoctahedral or hexoctahedral faces, thus yielding very shallow stones with natural facets. Rose cuts have a flat base, which usually corresponds to the plane of the original cleavage, and a shallow, dome-shaped crown covered with triangular facets terminating in a point at the center (see figure 5).

Although rose cuts do come into the lab from time to time, only infrequently do we see a large rose cut set over a concave metal base to simulate a heavier diamond. The ring shown in figure 6 was recently submitted to the Los Angeles laboratory for identification. The center diamond measures approximately 20 mm in diameter. The depth and weight could not be measured because of the nature of the mounting, but the stone was visually estimated to be only 2 or 3 mm deep. On the basis of these dimensions, the weight of the stone was estimated to be approximately 8–12 ct. A full-cut diamond of the same diameter would have weighed approximately 30 ct.

The thin rose cut was set in a closed-back mounting, over an engraved, concave metallic reflector that gave the illusion of a much larger diamond with greater depth and with pavilion facets. Between the stone and the reflector was a hollow space. Figure 7 illustrates the construction of this type of mounting, with a bottom view of the concave metal reflector (labeled A) on the left, and a top view—illustrating the stamped or engraved patterns that are intended to create an illusion of pavilion facets—on the right.

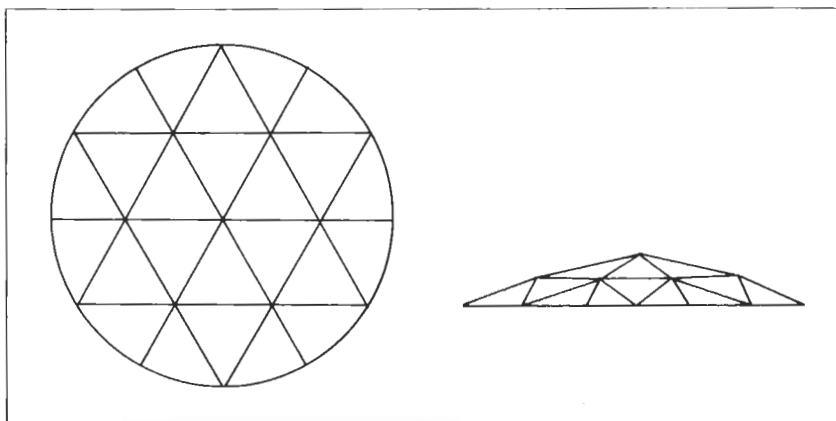


Figure 5. Diagrams of the crown (left) and profile (right) of a rose-cut diamond.



Figure 6. A rose-cut diamond, approximately 20 mm in diameter, set in a ring.

Some time after examining this ring we received an antique combination pin-pendant set with 24 rose-cut diamonds (see figure 8). These diamonds had the typical flat base but had much higher profiles than did the stone in the ring. Also, there was no engraved backing or hollow space behind the stones.

Simulants

In the past few months, the New York laboratory has received for diamond quality grading several brilliants that have turned out to be

Figure 7. Diagrams of bottom (left) and top (right) of the mounting illustrated in figure 6. A = the back of the metallic reflector. The stamped or engraved patterns on the front of the concave reflector are illustrated on the right.

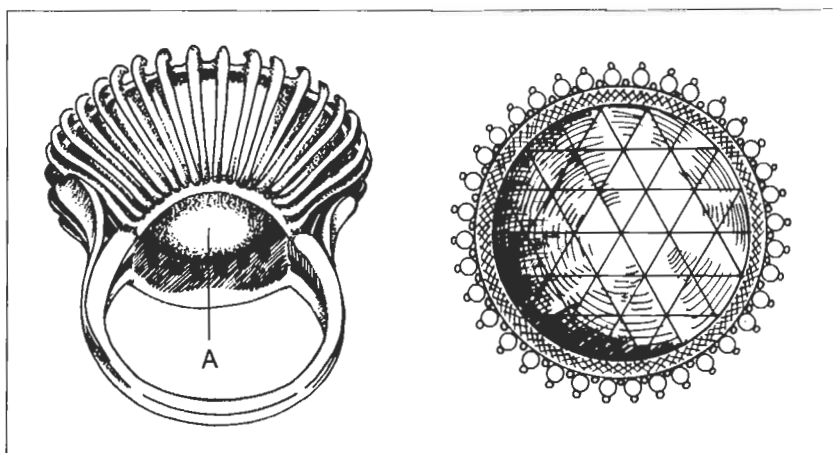




Figure 8. Rose-cut diamonds set in a combination pin pendant. The center stone measures approximately $11.8 \times 7.4 \times 2.5$ mm; the other 23 stones range from approximately 1.5 mm in diameter \times 0.8 mm deep to $6.5 \times 3.5 \times 1.1$ mm.

cubic zirconia. Perhaps the most convincing one was a very light yellow stone with obvious flaws (figure 9). It weighed more than 11 ct while appearing to have the size of a diamond of 6.5 to 7 ct. It was exceptionally well cut and polished, and with the "cape" color it must have been taken for a diamond many times before it became damaged. The staff surmised that the stone was probably damaged by heat during some repair work on its mounting. There is no question that cubic zirconia is the most serious diamond imposter yet to reach the market.

Treated Yellow Diamond

The Los Angeles laboratory recently received a yellow round brilliant diamond weighing slightly over 2.5 ct. The client explained that the diamond had an accompanying GIA Gem Trade Laboratory diamond grading report that stated the color grade as fancy light yellow, natural color. The client's suspicions were aroused because the color of this diamond was obviously more intense than fancy light yellow and would have been graded as fancy intense yellow.

The diamond and our grading report records were then examined.

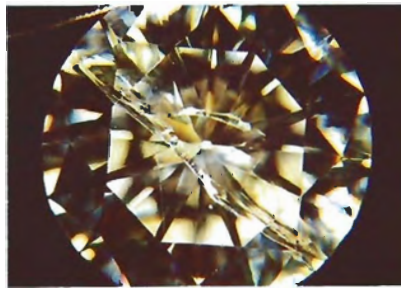


Figure 9. A yellow cubic zirconia submitted for diamond grading. Magnified 15 \times .

By comparing the measurements, weights, internal characteristics, and the like, we determined conclusively that this stone was the same diamond described on the report. Examination with the spectroscope, however, revealed that this diamond exhibited evidence of treatment in the form of a very strong line at 5920 Å, in addition to the moderate cape spectrum (lines at 4155, 4350, 4530, 4660, and 4780 Å). It was evident that this diamond had been treated to intensify the color after its original examination in the laboratory.

Even though the 5920 Å line was very easy to observe in this partic-

ular stone, it serves as a reminder that treated yellow diamonds may exhibit a cape series in addition to a line at 5920 Å (which may be easy or difficult to observe). This diamond also exemplifies the fact that treatment or damage can occur after a stone is examined by a laboratory.

EMERALD, Synthetic

Examples of a new synthetic emerald reportedly being manufactured in the USSR were seen in both the New York and Los Angeles labs at about the same time. All four stones submitted had quite obvious whitish seed plates, and two were color banded. Figure 10 shows one stone in which the seed plate was parallel to the culet. Spike-like inclusions pointing to the plate originate in the near-colorless zone at the culet. The stone shown in figure 11 has zoning of a different sort, unrelated to the seed plate. All the stones exhibited unusual crystal-growth disturbance, as illustrated in the lighted area of figure 12. The appearance of the stones in the microscope suggests

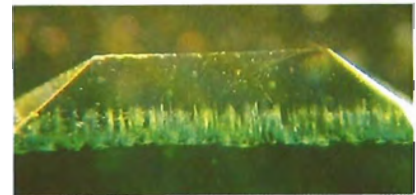
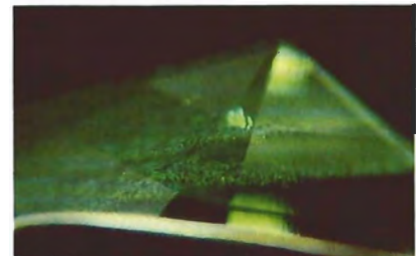


Figure 10. Colorless seed plate of a synthetic emerald immersed in methylene iodide. Magnified 63 \times .

Figure 11. Color zoning in a synthetic emerald. Magnified 63 \times .



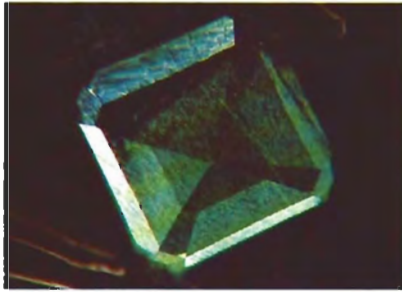


Figure 12. Growth disturbances visible in a synthetic emerald at 15 \times .

hydrothermal manufacture. However, unlike other hydrothermal synthetic emeralds with which we are familiar, these stones lack ultraviolet fluorescence and display very little red color with the color filter. The refractive indices average approximately 1.572–1.580. The birefringence, approximately 0.008, is high for any beryl, synthetic or natural. The specific gravity was determined to be slightly greater than 2.67.

JADE, Dyed Blue Jadeite

The Los Angeles laboratory was recently asked to identify the 8.98-ct translucent blue cabochon shown in figure 13. To the unaided eye, the interwoven structure typical of jadeite was apparent. A refractive index obtained by the "spot" method revealed a value of 1.66. Spectroscopic analysis was performed, revealing a sharp line at 4370 Å in the violet-blue region, and the characteristic dye band centered at 6500 Å in the orange-red region of the visible spectrum. This blue cabochon was therefore identified as jadeite jade, treated color. As with other materials that are frequently dyed, or stained, jadeite can be dyed virtually any color, but green is the one most commonly encountered.

OPAL, Black and White

A very unusual natural opal was brought to the Santa Monica labo-

ratory for identification. As shown in figure 14, this specimen consisted of an almost opaque black center area that was entirely surrounded by translucent, yellowish brown opal. The play of color was faint and definitely confined to the outer, translucent opal layer. Examination under the microscope revealed an irregular web-like structure visible only at the more translucent edge of the black center material and a botryoidal flow structure surrounding the black area.

The piece of rough material had one flat polished surface which gave a refractive index of 1.44; it measured approximately 23 \times 21 \times 4 mm. We were advised that this unusual piece had been found in Lightning Ridge, Australia.

PEARLS

Black Non-Nacreous Natural "Pearl"

One would almost think he were looking at a polished baroque stone when observing an item that was



Figure 13. An 8.98-ct dyed blue jadeite.

sent in for identification to our New York lab. However, as the "stone" was turned in the light under magnification, a peculiar beaver fur-like appearance somewhat resembling the flame structure of a conch "pearl" was observed (figure 15).

Figure 14. Unusual specimen of black and white opal, measuring approximately 23 \times 21 \times 4 mm thick.



Here and there were patches resembling clearings in a forest (figure 16). These took on an iridescent, almost opal-like quality when turned in the light. It was determined that the "pearl," which weighed in excess of 100 grams, was indeed a calcareous concretion with specific gravity the same as for natural pearls. We do not know what mollusc produced it.

Early Mabe?

Recently submitted to the New York laboratory for identification was a lattice-work pearl choker in which what appeared to be gold spacer bars were enameled white (figure 17). The necklace consisted of 76 "pearls," each approximately 8 mm in diameter, in four rows of 19 each. With a loupe, one could easily see that the "pearls" were assembled and probably mabes. The radiograph in figure 18 shows a peculiar rectangular insert as well as the hemispherical center, the drill hole, and the peg. The "pearls" did not fluoresce to X-rays, but we would not expect

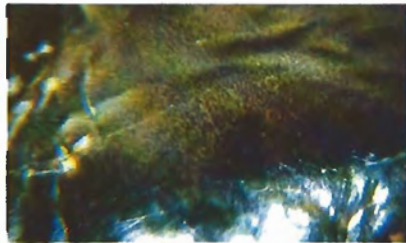


Figure 15. Surface characteristics shown by an unusual calcareous concretion. Magnified 20 \times .

Figure 16. "Bald" patch on the "pearl" illustrated in figure 15, taken at 45 \times .

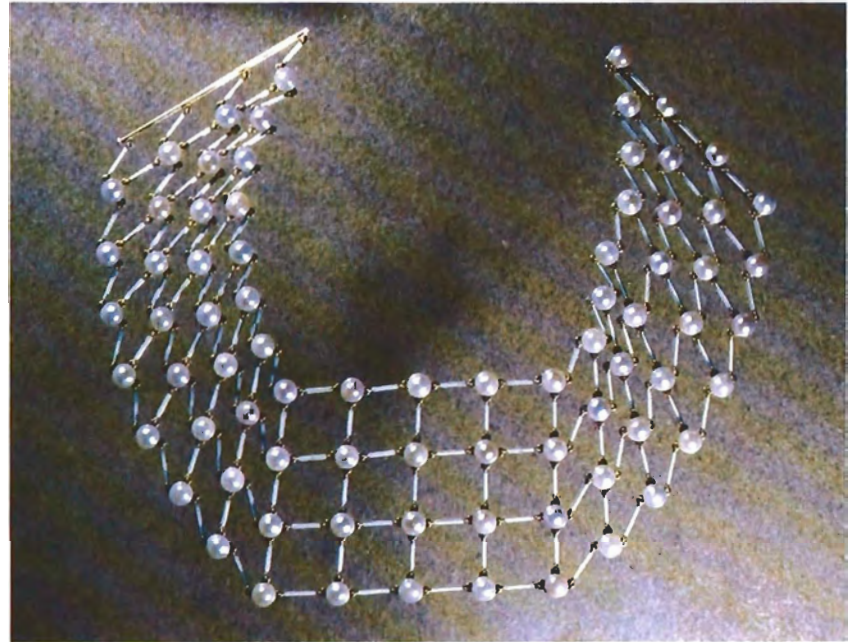
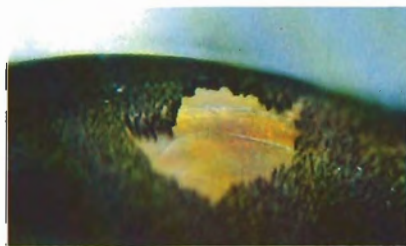


Figure 17. Mabe pearl necklace.

them to if saltwater shell had been used for the filler material.

In our attempts to determine if these might have been produced by Japanese technicians before they were able to grow whole cultured pearls, we learned that as early as 1890, up to 50,000 cultured blister pearls were being produced yearly. However, exactly how the blisters were prepared at that early time remains a mystery.



Figure 18. X-ray of one of the mabe pearls seen in figure 15.

QUARTZ, Green

Submitted to the Los Angeles laboratory for identification was the 9.19-ct green oval modified brilliant shown in figure 19. Microscopic examination revealed only a few cloudy areas of minute inclusions. The refractive indices were determined to be 1.544 and 1.553. A bull's-eye uniaxial interference figure was observed when the stone was examined in convergent, polarized light, thus proving it to be quartz.

Green quartz of this intensity has not been reported to occur in nature, but is known to be produced by the

heat treatment of some amethyst. This material is sometimes referred to as "greened" amethyst. Although this stone was fairly devoid of inclu-

Figure 19. A 9.19-ct "greened" amethyst.

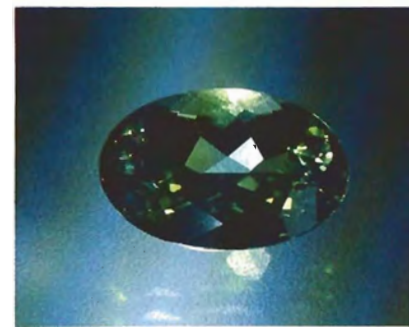




Figure 20. Two 1-ct taaffeites.

sions, the ones that were present suggested natural origin. It should be noted, however, that this color could possibly be produced in synthetic quartz by the heat treatment of synthetic amethyst.

SAPPHIRE, Color Restoration

Recently in New York we were shown a ring containing a natural colorless sapphire that the client said was a pleasant "Ceylon" yellow before a recent repair job. Dr. Kurt Nassau had suggested that the client bring the ring to us for the purpose of exposing it to X-rays. On two occasions in the past, Dr. Nassau had restored the color to red tourmaline that, thought to be ruby, had lost it through overheating. In these two cases the color, apparently permanent, was restored by the use of gamma rays.

To control our experiment with the colorless sapphire, we exposed the ring and another colorless sapphire from our own collection. When the two stones reached a medium dark brownish yellow, we put them both in a sunny window for about four hours. When removed, our loose stone was again colorless, but the ring stone was now a pleasant yellow, which the owner stated looked very much like her original stone. Evidently the natural color center is different from an induced center,

though heat can change them to colorless in both cases. We anticipate that the restored color will be permanent under normal conditions.

TAAFFEITE

Figure 20 illustrates two taaffeites, each weighing approximately 1 ct. Both stones were very "clean," with the typical color of taaffeite, and were submitted by the same client to our New York lab. The census of this rare material would probably show that only 45 or 50 of these gemstones have been reported thus far.

TURQUOISE, Imitation

Within a short period of time at the Santa Monica laboratory, we have seen two quite different kinds of imitation turquoise. One item was a drilled rondelle, measuring 8 mm in diameter by 3.3 mm thick, shown in figure 21. Note the uneven distribution of color and also the much lighter colored area around the drill hole. The material had a refractive index of approximately 1.58 or 1.59. The specific gravity, as determined by the hydrostatic method, was approximately 2.35. There was no absorption spectrum. The material was fairly soft; it could easily be scraped with a needle, thus exposing the underlying colorless material. An X-ray diffraction analysis of this material indicated that it was primarily gibbsite, a clay-like aluminum hydroxide, which had been dyed to simulate turquoise.

The other item we identified as imitation turquoise was a block of rough material measuring approximately 26 × 19 × 15 mm (figure 22). The properties of this material were as follows: refractive index, 1.57; specific gravity (hydrostatic method), 2.27; no absorption spectrum. Again,



Figure 21. Drilled bead of imitation turquoise, 8 mm in diameter.

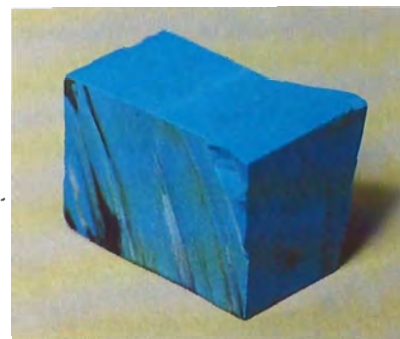


Figure 22. A block of imitation turquoise measuring 26 × 19 × 15 mm.

X-ray diffraction analysis was performed. The resulting pattern indicated a mixture of several materials, the main constituents being silicon dioxide and zinc oxide.

ACKNOWLEDGMENTS

Andrew Quinlan in our New York lab took the photos used in figures 1, 2, 4, 9-12, 15-18, and 20. Shane McClure, in Los Angeles, is responsible for figures 6, 8, 13, and 19. Mike Havstad, in Santa Monica, took the photos used for figures 14, 21, and 22. Susan Kingsbury, also from Santa Monica, supplied figures 5 and 7. Figure 3 was provided by Sotheby Parke Bernet, New York.

GEM NEWS

Stephanie Dillon, *Editor*

ANNOUNCEMENTS

The Cleveland Museum of Natural History—Wade Oval, University Circle, Cleveland, OH 44106. Telephone: (216) 231-4600. "Facets of Fire," the gem collection of the Cleveland Museum, comprises more than 1,000 specimens. It is now on display for the first time since 1958. There are additional temporary exhibits this summer: antique jewelry and watches will be displayed through July 31, and prerevolutionary Russian enamels will be shown August 1–28.

California Academy of Sciences—Golden Gate Park, San Francisco, CA 94118. Telephone: (415) 221-5100. The "Rainbow Gem Collection," consisting of 300 fancy-colored polished diamonds, highlights an exhibit from Antwerp, Belgium. The stones weigh approximately one carat each and represent the spectrum of colors in which diamonds are found. Also on display are specimens of diamond rough, tools used in diamond cutting, and a section of kimberlite host rock containing a 20-ct rough diamond. The exhibit runs through October 17.

Harvard University Mineralogical and Geological Museum—24 Oxford Street, Cambridge, MA 02138. Telephone: (617) 495-2356. More than 6,000 mineral specimens are

exhibited in the Mineralogical Museum, the oldest university mineral collection in the United States. The 1,000+ examples of gem material include carvings as well as faceted stones and cabochons. A 3,040-ct opaz and rubellite crystals from California pegmatites are among the featured displays. The Sidney Singer, Jr., collection of 38 faceted fluorites was acquired in 1982, and represents a variety of cutting styles as well as colors. In an adjacent gallery are hundreds of specimens of New England minerals, including amethyst from Rhode Island and tourmaline from Maine. Exhibits on meteorite cave formations and volcanoes, with panoramic photo-murals of Mount St. Helens before and after the recent eruption, are displayed in the recently renovated Geological Museum.

Winner of the 1983 George A. Schuetz Memorial Fund Jewelry Design Contest is Ms. Kyoko Kojima, of Tokyo, Japan. Ms. Kojima's design is for an 18K yellow-gold, platinum, and rose-gold man's belt buckle, set with diamonds (figure 1). The Schuetz contest is administered annually by GIA. Ms. Kojima was awarded a \$500 scholarship for jewelry-related study at an institution of her choice. Information on the 1984 Schuetz contest is available

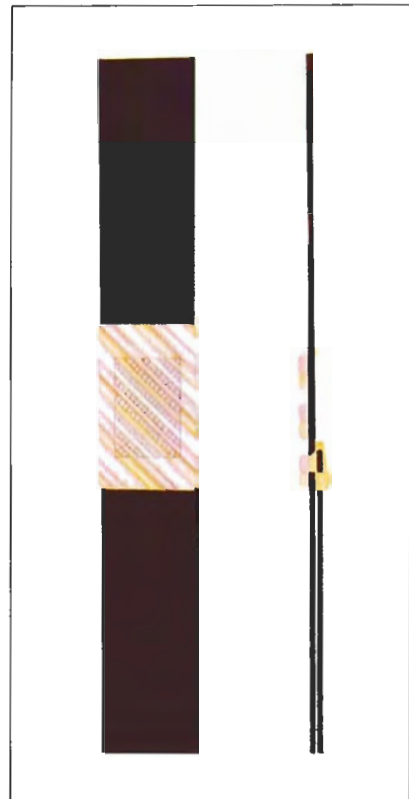


Figure 1. Schuetz award-winning design by Kyoko Kojima.

from The Scholarship Office, Gemological Institute of America, 1660 Stewart Street, Santa Monica, CA 90404.

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COLORED STONES AND ORGANIC MATERIALS

Estudio mineralógico y gemológico de los olivinos de Yaiza (Lanzarote) (Mineralogical and gemological study of the olivines of Yaiza). J. M. Bosch Figue-roa, C. de la Fuente Cullell, and M. Arbuniés Andreu, *Gemología*, Vol. 14, No. 49–50, 1981, pp. 5–18.

The volcanic island of Lanzarote, in the Canaries, underwent a series of eruptions between 1730 and 1736

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

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The reviewer of each article is identified by his or her initials at the end of each abstract. Guest reviewers are identified by their full names.

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which blanketed approximately one-quarter of the island's surface. The material, primarily basalt, emerged in the locality now known as the Montañas de Fuego, or Timanfaya, and covered an area of more than 200 square kilometers. Within the magmatic mass are embedded pyroclastic products, including volcanic bombs and aggregates of olivine crystals. A secondary type of olivine is found as coastal detritus, crystallized grains having been freed by the weathering away of encasing rocks.

Specimens from various parts of the island were studied. Those of greatest gemological interest were in the form of rounded crystals from the coastal fields. X-ray diffraction performed on crystals and associated rocks revealed the chief constituent to be forsterite (Mg_2SiO_4). The presence of chromite is evident in octahedral inclusions.

A good number of the olivines can be classified as peridot, not only for their transparency and green color, but also for their gemological properties: hardness, 6.05–6.40; S.G., 3.341–3.364; R.I., 1.650–1.694; birefringence, 0.035–0.038; optical sign, positive; absorption: widest band at 497 nm, narrower bands at 474 nm and 455 nm.

In addition to the mineralogical and gemological

data, there is also discussion of the use of the term *chrysolite* and the lore surrounding peridot. SLD

Euclase from Santa do Encoberto, Minas Gerais, Brazil.

G. Graziani and G. Guidi, *American Mineralogist*, Vol. 65, No. 1-2, 1980, pp. 183-187.

Transparent crystals of the gem mineral euclase [$\text{BeAlSiO}_4(\text{OH})$] have recently been found in a beryl-tourmaline pegmatite near Santa do Encoberto, São Sebastião do Maranhão, Minas Gerais, Brazil. Graziani and Guidi, noting the high birefringence and unusual inclusions, decided to investigate the euclase. This article describes the results of their study. The crystals, some several centimeters long, are well formed and exhibit a multitude of triangular etch pits on their prism faces. The mineral is biaxial (+), $2V = 60^\circ$, $\alpha = 1.651$, $\beta = 1.657$, $\gamma = 1.675$, and has a measured density of $3.065(5) \text{ g/cm}^3$. Absorption bands occur at 4680 \AA and 7050 \AA (doublet). Unit-cell parameters are: $a = 4.771(3) \text{ \AA}$, $b = 14.308(10) \text{ \AA}$, $c = 4.631(4) \text{ \AA}$, $\beta = 100.33(7)^\circ$, and $V = 311(1) \text{ \AA}^3$. Chemical analysis showed: $\text{SiO}_2 = 41.61\%$, $\text{Al}_2\text{O}_3 = 34.76\%$, $\text{FeO} = 0.28\%$, $\text{BeO} = 16.95\%$, and $\text{H}_2\text{O} = 5.95\%$. Trace elements detected in this material are Cu, Sn, Na, K, Pb, Ge, and F. Among the inclusions identified are apatite (hexagonal crystals), hematite (plates), rutile (needles), and zircon (rounded grains). A brief discussion is presented on the inferred conditions of euclase formation in this pegmatite.

JES

The heat treatment of some Norwegian aventurized feldspars. P. A. Copley and P. Gay, *Mineralogical Magazine*, Vol. 45, No. 337, 1982, pp. 107-110.

The variety of plagioclase feldspar known as aventurine is characterized by a fiery, reddish luster. This color is due to the reflection of light from small, disseminated mineral particles in the host feldspar. Chemical analysis of these plate-like inclusions indicates that they represent an iron oxide phase such as hematite. Previous work led to the belief that aventurine feldspar is formed by a compositional unmixing of an originally homogeneous solid solution of feldspar and hematite with falling temperature. This exsolution takes place in such a manner that thin hematite lamellae separate out along structural planes in the feldspar. The present article reports results from a survey investigation of the reaction to heat-treatment of 50 samples of aventurine feldspar.

In agreement with earlier work, the authors found the behavior of these feldspars on heating to be highly erratic: there was noticeable variation even between crystals from the same locality. Nevertheless, they were able to recognize a general pattern in heating behavior starting at 800°C . With increasing temperature up to 900°C , the inclusions begin to lighten progressively in color and disappear. This process of "homogenization" is virtually complete by 1000°C , and the

sample melts near 1050°C . Recrystallization of this melt gives a feldspar aggregate with no visible reprecipitated hematite inclusions.

Because their attempts to recrystallize feldspars with distinct hematite inclusions proved unsuccessful, the authors concluded that the formation of hematite inclusions by exsolution from an original Fe-rich feldspar seems unlikely. Rather, they favor the introduction of Fe-rich inclusions into "normal" feldspar from an external source. Further work is needed to answer this question. JES

Pehrmanite, a new beryllium mineral from Rosendal pegmatite, Kemiö Island, southwestern Finland.

E. A. J. Burke and W. J. Lustenhouwer, *Canadian Mineralogist*, Vol. 19, Part 2, 1981, pp. 311-314.

This article describes the new beryllium-bearing mineral pehrmanite [$(\text{Be}, \text{Zn}, \text{Mg})\text{Fe}^{2+}\text{Al}_4\text{O}_8$], which is found in a complex, internally zoned pegmatite near the village of Rosendal on Kemiö Island in Finland. While it occurs only as tiny grains (up to $250 \times 40 \mu\text{m}$) at this locality, this mineral would be of potential gemologic interest if larger crystals were found because it represents the iron analogue of the rare gem material taaffeite ($\text{BeMgAl}_4\text{O}_8$).

Pehrmanite is present in the wall zone of the Rosendal pegmatite along with quartz, plagioclase, sillimanite, muscovite, spessartine-almandine, and additional accessory phases. It is closely associated with, and replaces, the mineral nigerite. It occurs as small, subhedral, hexagonal-tabular crystals which have a light green color, a vitreous luster, and no cleavage. The mineral is very brittle, and has a calculated hardness of $8-8\frac{1}{2}$ and a calculated density of 4.07 g/cm^3 . Pehrmanite is uniaxial negative and is weakly to distinctly dichroic, with $\omega =$ pale green, and $\epsilon =$ pale grayish brown. The mean refractive index, calculated from reflectance data, is 1.79.

Following a detailed description of this new mineral, the authors conclude their article with a discussion of the origin of pehrmanite and the other Al-rich phases in the pegmatite. JES

Topaz rhyolites—distribution, origin, and significance for exploration. D. M. Burt, M. F. Sheridan, J. V. Bikun, and E. H. Christiansen, *Economic Geology*, Vol. 77, No. 8, 1982, pp. 1818-1836.

Besides granitic pegmatites, another important source of gem-quality topaz is a type of igneous rock known as rhyolite. Rhyolites are silica-rich, extrusive volcanic rocks composed of phenocrysts of quartz or alkali feldspar in a glassy or finely crystalline groundmass. They often contain gas cavities, and in the case of topaz rhyolites, they have relatively high concentrations of elements such as F, Be, U, Sn, W, and Ti. Crystals of topaz and other gem minerals (e.g., red beryl and red to black Mn-Fe garnet) are found in these gas cavities.

This article presents summary data on the characteristic features of these rocks, and focuses on their occurrence in the western United States and in Mexico. The tectonic setting and geochemistry of these topaz rhyolites suggests that they are extrusive equivalents of fluorine-rich granites. They originated from the partial melting of the continental crust followed by magmatic differentiation and crystallization. Topaz rhyolites represent only one of several genetically related types of mineral deposits that form in a volcanogenic environment. *JES*

Über die gemmologische Bedeutung des Gallium-Nachweises in Korunden (Concerning the gemological significance of the presence of gallium in corundum). H. A. Hänni and W. B. Stern, *Zeitschrift der Deutschen Gemmologischen Gesellschaft*, Vol. 31, No. 4, 1982, pp. 255-260.

It has become increasingly difficult to distinguish between certain synthetic and natural gemstones. One potential source of valuable information is to identify the trace elements in a gemstone, since they reflect the environment of its formation. This article reports trace-element data on the rare element gallium in a suite of 24 natural and eight synthetic corundums. Because of its atomic properties, gallium behaves chemically in a manner very similar to aluminum, and is concentrated in many aluminum-rich minerals in the earth's crust. However, it would not be expected in synthetic aluminum-rich materials grown in a chemically pure environment. These data on trace elements were collected using energy-dispersive X-ray fluorescence methods. According to the authors, all natural corundums in this suite contained gallium concentrations in excess of 200 p.p.m., whereas in various synthetic corundums (Verneuil, Chatham, Kashan, Knischka), gallium could not be detected. This article demonstrates why trace-element analysis will become an important tool in future gemological research. *JES*

DIAMONDS

Kimberlites: their relation to mantle hotspots. S. T. Crough, W. J. Morgan, and R. B. Hargraves, *Earth and Planetary Science Letters*, Vol. 50, 1980, pp. 260-274.

The origin of kimberlite, the host rock of diamonds, continues to be a matter of geologic inquiry. Available evidence indicates that kimberlites crystallize from magmas that are produced by partial melting in the earth's mantle at depths of 100 km or more. Using data for post-Triassic age kimberlites in North and South America and in Africa, the authors of this article suggest that the formation of many kimberlite magmas is related to "hotspot" activity in the mantle. Hotspots are areas in the upper mantle where there is a convective upwelling of magmatic material. By reconstructing

the relative motions of these three continents during the past 150 million years, the authors found that the places where kimberlite magmas were intruded into the crust fall very close to mantle hotspot locations. This correlation appears to cast some doubt on the competing hypothesis of kimberlite occurrence, which relates kimberlites to deep zones of structural weakness in the crust. *JES*

Maurice Tempelman's African connections. L. Kraar, *Fortune*, Vol. 106, No. 10, 1982, pp. 130-141.

Kraar presents a fascinating glimpse of "one of America's most active diamond traders," Maurice Tempelman. He traces Tempelman's history from his beginnings in his father's New York diamond brokerage firm to his development of a multi-million-dollar company with diverse holdings that range from gem diamonds to industrial diamond equipment.

The emphasis of this account is on Tempelman's skill at developing symbiotic working relationships with the leaders of Black African countries. His ability to couple his political expertise with his keen business sense is further illustrated in the discussion of his involvement in a number of projects. These include marketing diamonds in Zaire, prospecting for gold in Sierra Leone, establishing a diamond cutting and polishing plant in Sierra Leone, and mining uranium in Gabon. *DMD*

New data on the age of Yakutian kimberlites obtained by the uranium-lead method on zircons. G. L. Davis, N. V. Sobolev, and A. D. Khar'kiv, *Doklady Akademiyi Nauk, SSSR Geologiya*, Vol. 254, No. 1, 1982, pp. 53-57.

Applying the uranium-lead method of determining radiometric dates, Davis, Sobolev and Khar'kiv have refined the ages of 19 kimberlite pipes as well as alluvial deposits in six districts of Yakutia, USSR. The authors begin by explaining how recent modifications of the technique permit age determinations of the zircons that occur in these kimberlites.

From these new data the authors differentiate five stages of kimberlite volcanism in this area, reporting that as many as three stages occurred within one individual district. This volcanic activity extended over 300 million years, from the Ordovician period to the late Jurassic. The accuracy of these dates was verified by replicating the dates in other samples from the same deposit as well as by demonstrating the consistency of these dates with other geologic evidence such as stratigraphy and the fossil record. The authors conclude with a caution about another radiometric dating technique, the fission track method. Noting the discrepancies between the two sets of dates, they recommend using the uranium-lead method whenever possible. *DMD*

Mineral rims on diamonds from kimberlites. A. I. Ponomarenko and Z. V. Spetsius, *International Geology Review*, Vol. 24, No. 7, 1982, pp. 829–834.

When found in kimberlite, diamond crystals sometimes display a thin coating of other minerals resulting from secondary alteration. To better understand this alteration, the authors of this article carried out a mineralogical study of the coatings on several hundred diamonds.

The coatings ranged in thickness from tenths of a millimeter to about 2 mm. A variety of minerals were found comprising the coating material; the authors provide some compositional data on them. There is no indication that the diamond crystal itself participated in the alteration reactions that produced the coating.

From their study, the authors conclude that the formation of a coating on diamonds often accompanies and is related to the formation of fractures and veinlets in the surrounding kimberlite during hydrothermal alteration. These fractures allow for the movement of mineralizing solutions that deposit the coatings. Similar coatings found on other minerals in the kimberlite record the same alteration environment.

This study provides further information on the nature of kimberlite during both its formation and subsequent alteration. JES

The Southeast Asian strategy. J. Vollmer, *Goldsmith*, Vol. 162, No. 5, 1983, pp. 30–34, 70.

There is currently a move by De Beers to create a major cutting industry in Southeast Asia, specifically, in Bangkok, Thailand, and in Kota Bharu, Malaysia. The immediate reason for this new diamond-cutting industry is to handle the large De Beers stockpile of small rough and the anticipated large production of small stones from Australia and Botswana. Boasting low labor costs, a long tradition of colored-stone cutting, and a growing local diamond market, Southeast Asia seems a logical place for a "fifth" major diamond-cutting center (following Israel, India, Antwerp, and Hong Kong).

The author goes beyond these immediate reasons and presents other motivations as well. The other cutting centers for melee are in Israel and India, both often troublesome to De Beers. Israel, where the larger and better of the small stones are cut, has had a difficult time balancing its high labor costs with the depressed prices for faceted diamonds. India is an insatiable buyer of the cheaper small stones, but because of low yield it cannot handle the better rough profitably. De Beers feels that Thailand and Malaysia could correct this imbalance of demand between the better and lower quality melee. The increased competition would also supply them with valuable leverage.

The absence of any mention of the Soviet Union's pivotal cutting role is an important omission. Ms. Vollmer, nevertheless, has written an incisive article. Eight photographs accompany the text. FLG

GEM LOCALITIES

Brazilian gemstones. R. Ribeiro Franco, *Earth-Science Reviews*, Vol. 17, 1981, pp. 207–219.

This article gives a brief, but reasonably comprehensive, state-by-state review of Brazil's role as one of the most important gemstone producers in the world today. The author begins by addressing the question of defining precious vs. semiprecious and, fortunately, chooses not to use either term. He also discusses the definition of "gemological province" as a region where great varieties of gems may be found, and lists eight such provinces, in Burma, Sri Lanka, Vietnam-Thailand, Malagasy, California, Russia, India, and Brazil. Areas such as Colombia and Badakhshan, Afghanistan, are not considered gemological provinces because, according to the author, they produce only one gem species—emerald and lapis lazuli, respectively.

Following these discussions, the author briefly describes the diamond and colored stone sources in Brazil on a state-by-state basis. These include the agate deposits of Rio Grande do Sul and the pegmatite deposits in Minas Gerais, Espírito Santo, Bahia, and Goias. The discussion of the diamond occurrences in Brazil includes an interesting list of the 30 most important diamonds found in Brazil, which range in weight from 104.0 to 726.6 ct.

There are several states mentioned that show little history of gemstone production but have great future potential. One such example is the emerald occurrence at Santa Terezinha, in Goias, which has flourished since the writing of this article in 1981.

Peter C. Keller

The Colorado Quartz Mine, Mariposa County, California: A modern source of crystalized gold. A. R. Kampf and P. C. Keller, *Mineralogical Record*, Vol. 13, No. 6, 1982, pp. 347–354.

The first record of the Colorado Quartz Mine is a patent filed on February 1, 1875, by John A. Bataille, a merchant in the town of Colorado, Mariposa County, California. Since then the mine has changed ownership several times and is now the property of Colorado Gold, Inc., of Fallbrook, California. Kampf and Keller give a detailed account of the history of the mine and the occurrence of the fine specimens it has produced.

Located in the famous Mother Lode area of California, the Colorado Quartz Mine occurs in black slates of the Briceburg formation, probably of late Jurassic age, that have been intruded by greenstone dikes. The gold is found in pockets at the contact between the quartz veins of the dike and the slate wall rock. A chemical analysis of the crystallized gold showed a content of 93.3% gold and 6.7% silver. The general habit of the gold is octahedral and arborescent, which is illustrated in the photographs included in the 11 figures.

This excellent article is one of eight in an issue de-

voted to gold. Highly recommended to anyone interested in gold, the issue will undoubtedly become a classic because of the information presented and the outstanding color photographs
GSH

Rare-metal pegmatites with precious stones and conditions of their formation (Hindu Kush). L. N. Rossovskiy, *International Geology Review*, Vol. 23, No. 11, 1981, pp. 1312–1320.

In recent years, increasing amounts of gem material have come from granitic pegmatites in the Hindu Kush region of Afghanistan. In this article, Rossovskiy presents a summary of the geologic occurrence, mineralogy, and gem production of the numerous pegmatites in this area, which have many similarities to the pegmatite province of Southern California. Pegmatites in the Hindu Kush can vary greatly in size, shape, mineralogy, and internal structure, and occur as elongate veins in both granitic massifs and associated metamorphic rocks spread over a large area. Gem tourmaline, beryl (morganite, aquamarine), and spodumene (kunzite) are found as large crystals in pocket-bearing microcline pegmatites. From field evidence, these gem pegmatites appear to have crystallized at rather shallow depths in the earth's crust (3.5–6.5 km) and at relatively low temperatures (down to 200°C) in a geologically stable environment. The Hindu Kush represents one of the major pegmatite regions of the world; the present article is a valuable source of geologic information on this area, which until recently had not been carefully studied.
JES

GEM INSTRUMENTS AND TECHNIQUES

The influence of the internal structure of pearls on Lauégrams. H. A. Hänni, *Journal of Gemmology*, Vol. 18, No. 5, 1983, pp. 386–400.

Two X-ray methods are used to examine pearls: direct radiography and the Laué technique of X-ray diffraction. Although this article deals primarily with the Lauégrams produced by the Laué method, Hänni first reviews the features shown on a direct radiograph of a pearl. Then he turns to a detailed explanation of how the internal structure and the external shape of the pearl cause the various symmetry patterns observed on the Lauégrams of different pearls.

Line drawings and scanning electron microphotographs illustrate the arrangement of the aragonite layers that comprise a pearl's structure. These photos show the differences between the "brick wall" appearance of a cultured pearl nucleus and the overlapping platelets on the surface of a pearl.

Numerous Lauégrams illustrate the differences between the hexagonal symmetry of natural pearls and the two- or four-fold symmetry patterns of cultured pearls. Lauégrams also show the ambiguous patterns of abnormal pearls.

In conclusion, the author states that while a properly interpreted Lauégram may indicate a pearl's identity, it is probably not the most appropriate means for general pearl testing.
Chuck Fryer

A method for measuring the infrared spectra of faceted gems such as natural and synthetic amethysts. T. Lind and K. Schmetzer, *Journal of Gemmology*, Vol. 18, No. 5, 1983, pp. 411–420.

Techniques new to gemology continue to be introduced for the purpose of helping to identify and distinguish certain natural and synthetic gemstones. Infrared spectroscopy is one such technique that deals with the absorption or transmission of radiation by a material in the infrared region of the electromagnetic spectrum (>7000 Å). Radiation in this portion of the spectrum has frequencies that correspond to molecular or lattice vibrations in solids, and thus would indicate the presence of substances such as water in a gem material. From the position and intensity of the absorption bands, one can draw conclusions regarding the composition of a material.

As with other types of spectra, the recording of infrared absorption bands for gemstones is greatly influenced by factors such as the shape and size of the samples being tested. Using spectra from amethyst as an example, the authors of this article describe procedures for improving the recording of infrared spectra with the aid of a specially designed immersion cell. They illustrate how the new synthetic amethyst of Russian origin can be differentiated from natural amethyst by its distinctive infrared spectrum.
JES

Relación entre las proporciones de talla perfecta en es-tilo brillante del diamante (Comparison of proportions of brilliant cuts to ideal). A. Vilardell, *Gemología*, Vol. 15, No. 51–52, 1981, pp. 25–34.

The author discusses the use of data such as crown and pavilion angles and table depth percentages on five styles of brilliant-cut diamonds to construct a proportionscope. Diagrams of Johnson-Roesch, Tolkowsky, Tillander, Eppler, and Parker methods are provided. A graph of a properly cut diamond is based on these. The author illustrates the use of a simple mechanism for inserting a diamond into a slide projector for viewing against the image on the graph.
SLD

JEWELRY ARTS

The ABC's of brilliants. *Town & Country*, Vol. 136, No. 5031, 1982, pp. 198–202.

A is for aquamarine, B is for black pearl, C is for citrine . . . and so the staff of *Town & Country* presents a delightful collection of 26 color photographs by Cy Gross. Jewelry from the world's leading jewelry designers is superimposed on the erotic Art Nouveau alphabet created by artist-illustrator Erté in 1924. Unfortu-

nately, only two of the photographs are full page in size; the remaining 24 are condensed onto three pages. Thus, it is difficult to appreciate the beauty of the gemstones featured in each piece.

The short account that accompanies the photographs mentions that the letters will be available from Harry Winston, Inc., as monograms. Following this article is a two-page story on Erté as he celebrates his 90th birthday.

In case you were wondering, X is for xanthite, a yellowish brown idocrase from Amity, New York. *DMD*

Jewellery and other decorative arts in Thailand. C. Chongkol, *Arts of Asia*, Vol. 12, No. 6, 1982, pp. 82-91.

The decorative arts in Thailand date back to the Bronze Age, beginning approximately 1500-500 B.C., when the Ban Chiang culture in northeast Thailand produced designs on bronze ornaments similar to those of the Dongson culture in North Vietnam. With the increased Indianization of southeast Asia in the early centuries A.D., gold and silver ornaments using gemstones (especially rubies) contributed to the decorative arts. The kingdom of Sukhothai in the 13th century, followed by the Ayutthaya period (1350-1767), contributed objects that were unique and characteristically of Thai design.

Thai jewelry can be characterized as having great detail, stylized motifs, and a wide range of colors produced by the use of various gemstones and enamels. During the Bangkok period (since 1782), traditional Thai jewelry with fine craftsmanship and sophisticated designs was executed principally for monarchs, aristocrats, and the wealthy. Today, traditional styles of jewelry are largely found as antiques and used at times of ceremonial importance or on special occasions. New jewelry pieces may often be reproductions of the traditional styles.

This Bangkok Bicentennial issue contains other excellent, informative articles ranging from the "Sculpture of the Bangkok Period" to "Thai Votive Tables and Amulets." Even the editorial about the Buddhist art of Wat Benchamabopit is notable and makes this special issue, with its beautiful illustrations, necessary reading for anyone interested in the art of Thailand. *ERL*

Stylish but slightly shocking. V. Becker, *Connoisseur*, Vol. 213, No. 851, 1983, pp. 45-49.

It is always encouraging to find a magazine with the international reputation of *Connoisseur* giving space to the work of younger craftsmen who can enjoy the benefit of the publicity during their most productive years.

This article concerns the work of two London jewelry designers—David Courts and Bill Hackett—whose jewelry designs have become increasingly well known in the trendy world of rock stars as well as in such temples of conservatism as De Beers, Wartski, and the Vic-

toria & Albert Museum. One of their exotic bibelots has been purchased by the Headley-Whitney Museum, outstanding among American collections of jeweled objects.

The designs of Courts and Hackett will not please everyone. They are not meant to. They are bizarre, often macabre, with a sinister quality even though (possibly because) much of the inspiration comes from nature. In the pieces illustrating the article, there is something that suggests René Lalique designing the personal jewels of a witch: a horse spewing diamonds from its nostrils, an amber saber-toothed tiger about to spring, a winged snake's head carved in buffalo horn and set with diamonds and rubies, a snarling lion's head ring with opal eyes, a frog skeleton in pure gold. Everything is dead, exhausted, or about to strike. These pieces are definitely not for the collector who wishes to be soothed or reassured by the ownership of precious jewels.

They cannot fail, however, to interest anyone concerned with the meticulous execution of detail in the finest materials. And, as the author points out, they are more or less wearable. More important, they are extremely salable.

Whether these jewels are destined to be soon-forgotten or style setters of the future remains to be seen. After all, Cartier's Art Deco jewels were far from universally popular even when they were the most fashionable. Whatever happens in the case of Courts and Hackett, such provocative designers deserve careful watching. *Neil Letson*

The use of manipulation in Chinese rhinoceros horn cups. J. Chapman, *Arts of Asia*, Vol. 12, No. 4, 1982, pp. 101-105.

For over ten thousand years the carved rhinoceros horn has been a rare and treasured art form of the Chinese. Of the variety of articles shaped from the rhinoceros horn, the most numerous are the drinking cups. (The term *cup* is applied to any horn capable of containing liquid.) Chapman also discusses water droppers, bells, and rafts.

Because of the curved, conical shape of horns, they cannot balance on their own. The technique for making a full-tipped horn stand upright is called "manipulation." All of the types of manipulation described in this article require altering the shape of the cone. The ancient Chinese cleverly split and/or bent the rhinoceros horns into their desired forms, which made it possible to stand the cup on the ground without the aid of a supporting stand.

Rafts fashioned from the rhinoceros horn are rare. The side of the horn is shaped into the flat bottom, with the entire tip of the horn bent gently upwards to resemble the prow of a boat. All known rhinoceros-horn rafts are constructed so that Chang-ch'ien, the

ancient Chinese explorer, sits on the upper surface of the horn.

Of the fifteen hundred rhinoceros-horn cups Chapman has examined, only a small fraction are self-supporting, reshaped by the methods discussed in the article. Chapman includes nine photographs to illustrate these unique pieces. *KJW*

JEWELRY RETAILING

The great jewellers in France. B. Janot, *Diamant*, No. 252, September-October, 1981, pp. 29-36.

Starting with the French Revolution at the close of the 18th century, Janot discusses the rise of many important jewelry families in France. Dividing the time into six periods, he characterizes the popular jewelry, the major events in the jewelry trade, and the personalities in each group. Janot describes the dramatic change that occurred in such a relatively short time—from court jewelers who designed only for the aristocracy to independent jewelers designing for those outside the aristocracy. This is an interesting look at the beginnings of renowned French jewelers, from Nitot and Froment-Meurice to Boucheron and Cartier.

Noel P. Krieger

The pioneer jewelry makers of New England. *Executive Jeweler*, Vol. 2, No. 6, 1982, pp. 43-46.

In a rare look at the history of jewelry manufacturers in the New England region of the United States, the following 12 companies are featured: American Jewelry Chain, Armbrust Chain Company, Cheever, Tweedy & Co., A. T. Cross, Excell Manufacturing Co., A and Z Hayward Inc., Leach & Garner Company, LeStage Manufacturing Co., Marissa/Barrows, W. E. Richards Co., Howard H. Sweet & Son Inc., and Vennerbeck & Clase Company. Having immigrated from Europe, most of these pioneer jewelry makers founded companies at the turn of the century in Providence or Lincoln, Rhode Island, or in Attleboro, Massachusetts. Accompanying the short descriptions of each company are four black-and-white photographs of scenes from the early days of these manufacturers. *DMD*

SYNTHETICS AND SIMULANTS

Erkennungsmerkmale der neuen synthetischen Sapphire (Identifying characteristics of the new synthetic sapphires). E. Gübelin, *Goldschmiede Zeitung*, Vol. 80, No. 11, 1982, pp. 51-57.

In this article, Dr. Gübelin discusses the identifying characteristics of (a) the new Chatham synthetic blue sapphires, and (b) blue sapphires that have had their color enhanced by heat treatment or by a diffusion process.

The author briefly describes the crystal habits and

the physical and optical properties of the rough and faceted material produced by Chatham. In the detailed description of the typical inclusions that follows, the reader is cautioned that some of the inclusions closely resemble those found in natural stones. Twenty-three color photomicrographs adequately illustrate this part of the article. The remaining 15 photomicrographs show the characteristics of color-enhanced blue sapphires, including altered crystal inclusions with tension cracks, pock-marked girdle surfaces, pronounced color zoning, and color concentrations in surface cracks. Gübelin concludes this article with a list of 12 references. *KNH*

MISCELLANEOUS

Técnicas de crecimiento cristalino (Crystal-growing techniques). J. M. Nogués Carulla, *Gemología*, Vol. 15, No. 51-52, 1981, pp. 5-24.

The article first explains how crystals grow naturally in solution. It then lists the methods of synthetically producing crystals, first from vapor to solid, then liquid to solid, these methods being divided into those employing a smelter and those proceeding from a solution.

The processes described are: growth from vapor, Verneuil, Czochralski, Kyropoulos, Bridgman-Stockbarger, zonal growth, skull melt, growth from gel, hydrothermal growth, and flux fusion.

The explanations are accompanied by clear diagrams. *SLD*

Vug collecting. S. Frazier, *Gems & Minerals*, No. 537, 1982, pp. 16-20.

This article is divided into two parts. The first discusses the various definitions of vugs, and the second describes their occurrence. A vug is a cavity in a rock generally lined by a mineral with a composition different from that of the surrounding rock.

The author describes six basic occurrences of vugs. The first is the gem pockets in pegmatites where minerals such as tourmaline, topaz, and kunzite may be found. The second is amygdules, almond-shaped gas holes formed in basalt lavas. Some of the world's most beautiful agates and amethyst form in amygdules. The third is lithophysae, cavities with multiple concentric shells found in silica-rich volcanic rocks. Topaz and spessartine are examples of minerals formed in these vugs. The fourth type, vesicles, or gas cavities formed near the surface of lavas, are usually devoid of minerals but may contain beautiful microcrystals. Number five is the hydrothermal vein, where some of the finest classic mineral specimens have been found. The sixth is the solution cavity, which may form in sedimentary rocks such as limestone, where quartz crystals are found, or in the oxidized zones around sulfide ore deposits, where crystals such as malachite or azurite may be found. *GSH*

GEMS & GEMOLOGY is an international publication of original contributions (not previously published in English) concerning the study of gemstones and research in gemology and related fields. Topics covered include (but are not limited to) colored stones, diamonds, gem instruments, gem localities, gem substitutes (synthetics), gemstones for the collector, jewelry arts, and retail management. Manuscripts may be submitted as:

Original Contributions—full-length articles describing previously unpublished studies and laboratory or field research. Such articles should be no longer than 6,000 words (24 double-spaced, typewritten pages) plus tables and illustrations.

Gemology in Review—comprehensive reviews of topics in the field. A maximum of 8,000 words (32 double-spaced, typewritten pages) is recommended.

Notes & New Techniques—brief preliminary communications of recent discoveries or developments in gemology and related fields (e.g., new instruments and instrumentation techniques, gem minerals for the collector, and lapidary techniques or new uses for old techniques). Articles for this section should be about 1,000–3,000 words (4–12 double-spaced, typewritten pages).

MANUSCRIPT PREPARATION

All material, including tables, legends, and references, should be typed double spaced on 8½ × 11" (21 × 28 cm) sheets. The various components of the manuscript should be prepared and arranged as follows:

Title page. Page 1 should provide: (a) the article title; (b) the full name of each author with his or her affiliation (the institution, city, and state or country where he/she works); and (c) acknowledgments.

Abstract. The abstract (approximately 150 words for a feature article, 75 words for a note) should state the purpose of the article, what was done, and the main conclusions.

Text. Papers should follow a clear outline with appropriate heads. For example, for a research paper, the headings might be: Introduction,

Previous Studies, Methods, Results, Discussion, Conclusion. Other heads and subheads should be used as the subject warrants. For general style, see *A Manual of Style* (The University of Chicago Press, Chicago).

References. References should be used for any information that is taken directly from another publication, to document ideas and facts attributed to—or facts discovered by—another writer, and to refer the reader to other sources for additional information on a particular subject. Please cite references in the text by the last name of the author(s) and the year of publication—plus the specific page referred to, if appropriate—in parentheses (e.g., Liddicoat and Copeland, 1967, p. 10). The references listed at the end of the paper should be typed double spaced in alphabetical order by the last name of the senior author. Please list only those references actually cited in the text (or in the tables or figures).

Include the following information, in the order given here, for each reference: (a) all author names (surnames followed by initials); (b) the year of publication, in parentheses; (c) for a *journal*, the full title of the article or, for a *book*, the full title of the book cited; and (d) for a *journal*, the full title of the journal plus volume number and inclusive page numbers of the article cited or, for a *book*, the publisher of the book and the city of publication. Sample references are as follows:

Daragh P.J., Sanders J.V. (1976)
Opals. *Scientific American*, Vol. 234, pp. 84–95.

Liddicoat R.T. Jr., Copeland L.L.
(1967) *The Jewelers' Manual*, 2nd ed. Gemological Institute of America, Santa Monica, CA.

Tables. Tables can be very useful in presenting a large amount of detail in a relatively small space, and

should be considered whenever the bulk of information to be conveyed in a section threatens to overwhelm the text.

Figures. Please have line figures (graphs, charts, etc.) professionally drawn and photographed. High-contrast, glossy, black-and-white prints are preferred.

Submit black-and-white photographs and photomicrographs in the final desired size if possible.

Color photographs—35 mm slides or 4 × 5 transparencies—are encouraged.

All figure legends should be typed double spaced on a separate page. Where a magnification is appropriate and is not inserted on the photo, please include it in the legend.

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Please send three copies of each manuscript (and three sets of figures and labels) as well as material for all sections to the Editorial Office: *Gems & Gemology*, 1660 Stewart Street, Santa Monica, CA 90404.

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Suggestions for Authors

PRACTICAL GEMCUTTING

By Nance and Ron Perry, 95 pp., illus., published by Arco Publishing, New York, NY, 1982. US\$11.95*

The subtitle, "A Guide to Shaping and Polishing Gemstones," and comments in the introduction correctly present this book as a condensed but thorough description of all the various lapidary operations and techniques. It is primarily directed at the hobbyist or amateur lapidary.

All types of lapidary equipment (none commercial) are pictured and described. Complete operating principles as well as instructions for using all equipment are concisely but adequately presented.

A strong feature of this book is the "How to Build Your Own Equipment or Tools" coverage given where applicable. However, all measurements are given only in metrics, which is very inconvenient to those of us who have not converted to this system (which includes most Americans).

There is an appendix giving hardness, specific gravity, refractive index, as well as a set of recommended crown and pavilion elevation angles for a great many gemstone materials. A list of suppliers (gem and mineral shops) and an index conclude the book.

I highly recommend this book as a general guide to lapidary techniques.

WILLIAM C. KERR
Faceting Instructor, GIA

THE LIZZADRO COLLECTION

By Miriam Anderson Lytle, 124 pp., illus., published by John Racila Assoc., Chicago, IL, 1982. US\$39.00*

Congratulations to Miriam Lytle, John S. Lizzadro, and everyone involved in this project! This book is a fitting tribute to one of the finest collections of hardstone carvings in the U.S. After the preface by Paul Desautels and Ms. Lytle's introduction to the collection come photographs and descriptions of more than 60 masterpieces of lapidary art. There are a wide variety of carv-

BOOK REVIEWS

Michael Ross, Editor

ings—from teapots, buckles, and doctors' ladies to altar sets, stone chimes, and boulder carvings. Materials include nephrite, jadeite, rock crystal, agate, and lapis lazuli. The well-written text covers history, symbolism and folklore, artistic use of the material, and the techniques used in carving. Many pieces are exceptional—not only in design and execution, but also for the basic material. The blue jadeite pagoda censer is a prime example. Sixty-nine color photographs show full views and close-ups of carving details. A historical table with maps, a pronunciation guide, glossaries of motifs and gem materials, and a bibliography complete the work.

This is one of the finest collection books I have seen. The design and production are good; the text is enjoyable and educational; the photography is beautiful; the pieces are spectacular. Bravo!

MICHAEL ROSS
Course Revision Supervisor, GIA

JEWELRY CONCEPTS & TECHNOLOGY

By Oppi Untracht, 888 pp., illus., published by Doubleday, Garden City, NY, 1982. US\$60.00*

In this book, Oppi Untracht dissects and examines the art of creating jewelry and attempts to inspire the reader to a higher level of artistic awareness. The author has examined his subject thoroughly, and the results are impressive.

One can quickly get an idea of the care taken in producing this book by noting the quality of the color photographs and half-tone prints. Each piece of jewelry shown seems to have a sense of drama, no matter how simple or how intricate the design. Even the text type is of a style

that is easy on the eyes and pleasant to read.

The organization of material has a simple logic to it. The first chapter deals with a short basic history of jewelry and provides conceptual information about its relevance and importance. Chapter 2 describes the tools and equipment necessary for basic jewelry manufacture. The next 15 chapters discuss various techniques used to create jewelry. Mr. Untracht examines the different styles used for each technique and explains when and why each may be applicable. The processes vary from the most basic, which may be used by beginners, to those used by the largest manufacturers. The language is clear and understandable, even to those with a limited jewelry background, but the discussion is advanced enough to benefit jewelers with many years of experience. The line drawings are simple and well executed. There is enough detail to get the message across, but there is no excess. Mr. Untracht displays the same spirit whether he is examining common processes such as sawing and filing, or such exotic mediums as hand knitting and crocheting wire jewelry.

There is only one chapter that is a disappointment as far as depth of knowledge and credibility are concerned. Chapter 13, on "Stones and Their Setting," contains much good setting information, but some of the gemological information is incorrect, misleading, or incomplete. The explanation of color in gemstones assumes that all colored stones are allochromatic and fails to address coloring in idiochromatic stones. Refraction is described as "the ability of a polished transparent mineral to bend or deflect light from the entering direction to a new direction when it strikes a second or subsequent surface." This statement seems confusing. Notably absent in a table of gemstone characteristics are ranges of refractive index on many doubly refractive stones, including some for which birefringence is important in identification. The paragraphs dealing with synthetic stones are particularly weak. An example is the statement that

YAG has four times the dispersion of diamond and, therefore, greater brilliance.

The final two chapters are valuable additions to Mr. Untracht's epic work. The one contains tables of various useful information in one concise unit, and the other is a grouping of assorted jewelry-related glossaries.

The purpose of this tome is not to help create gemologists. It is written as an aid to aspiring artisans and jewelry technicians, and as such it does an excellent job. Oppi Untracht has put together what may well be the most useful and informative book on the market dealing with jewelry concepts and techniques. The book is well worth the price whether you are looking for a good technical reference, a complete and readable instruction book, or a source of inspiration.

JASEN KEIDAN
Silverberg @ Shaknis Jewelry Co.
Encino, CA.

VNR COLOR DICTIONARY OF MINERALS AND GEMSTONES

By Michael O'Donoghue, 159 pp., illus., published by Van Nostrand Reinhold, New York, NY, 1982. US\$12.95*

This attractive paperback volume presents a compendium of essential data on minerals and gemstones at a very reasonable price. It provides a handy, informative reference on the nature, properties, and occurrence of more than a thousand of the more important minerals.

Following a brief introduction, the majority of the book consists of concise descriptions of individual minerals. These indexed mineral entries are arranged by chemistry (i.e., elements, sulfides, oxides, etc.), as in most mineralogy texts. Within these broad categories, mineral species are further grouped by their major constituent elements, or in some instances by mineral families (e.g., feldspars, garnets).

Individual mineral descriptions include the following data: mineral name, chemical composition, general properties (crystal system, habit, color, luster, twinning, cleavage, hardness, specific gravity), nature of occurrence, and a brief summary of localities that have produced outstanding specimens. Although necessarily abbreviated, these entries contain the key information of interest to most mineral or gem collectors. Wherever possible, mineral descriptions are accompanied by color photographs illustrating typical modes of occurrence. Unfortunately, while most of these minerals appear to be hand specimens, bar scales to indicate the actual size of the specimens are not included within the photographs. Of particular interest to the gemologist in these descriptive entries are the details on how best to clean and preserve specimens and also the summary information on the fashioning of particular minerals into faceted gemstones or cabochons. The final section of the book includes 10 mineral identification tables, each organized around a particular diagnostic characteristic (color, hardness, crystal form, refractive index, specific gravity, etc.), and a summary bibliography of important reference works and scientific periodicals in geology, mineralogy, crystallography, and gemology.

On the whole, this book would be a welcome addition to a mineralogy or gemology library. The volume is well laid out and easy to read in a large, 8½" × 11½" format. For the most part, the photographs present accurate color renditions of the minerals illustrated. Considering the low price, this book would appear to be an excellent bargain for a person who desires to know something of the properties and appearance of different minerals.

JAMES E. SHIGLEY
Research Scientist, GIA

Editor's Note: The material in the VNR Color Dictionary of Minerals and Gemstones originally appeared

in the Encyclopedia of Minerals and Gemstones (G. P. Putnam's Sons, New York, 1976).

ANTIQUE AND TWENTIETH CENTURY JEWELLERY

By Vivienne Becker, 301 pp., illus., published by Van Nostrand Reinhold Co., New York, NY, 1982 (previously published by NAG Press in Great Britain in 1980). US\$24.95*

This is a fascinating study of both well-known and obscure 18th-, 19th-, and 20th-century jewelry styles and trends. The book is arranged by subject rather than chronologically, and covers such diverse topics as coral jewelry, pique, mourning jewelry, stick pins, cameos, mosaics in jewelry, Egyptian revival jewelry, signed jewelry of the 19th century, arts and crafts jewelry, and Edwardian jewelry. This arrangement provides quick and useful reference for the serious collector. In addition, the work is profusely illustrated—more than 250 black-and-white illustrations and a total of 55 color photographs.

Vivienne Becker is a leading authority on antique jewelry. Her articles on the subject appear regularly in such magazines as *The Antique Collector*, *Retail Jeweller*, *Connoisseur*, *Antiques World*, and *Art @ Antiques*.

The book's only shortcoming is the lack of a glossary. Ms. Becker mistakenly assumes that her readers are well versed in the vocabulary of antique jewelry and, in consequence, neglects to explain or define many key technical terms. Except for this failing, the work is an excellent examination of unusual and important fashions and developments in the history of jewelry.

JENNIFER PORRO
Freelance Writer
Los Angeles, CA

*This book is available for purchase at the GIA Bookstore, 1735 Stewart Street, Santa Monica, CA 90404