The Indaia Sapphire Deposits Of Minas Gerais, Brazil

By David S. Epstein, Warren Brennan, and Julio C. Mendes

The discovery of significant quantities of gem-quality sapphire in Minas Gerais could add corundum to the formidable list of gem species already commercially produced in Brazil. The presence of sapphire has been confirmed over a wide area within a 42-km² mining claim, and exploration has yielded over 500 ct of corundum per square meter from alluvium in a small section of the claim. Faceting-quality stones typically range from 0.5 to 2 ct; some are purple or violet, and many show a color change. Future production will depend primarily on the results of ongoing exploration and the feasibility of mechanizing an area of difficult access.

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Although minor occurrences of corundum in Brazil have been known for some time, production has been limited to industrial grades, some specimen pieces, very low-quality ruby cabochons, and extremely small amounts of gem sapphire, mostly under 0.5 ct. However, the recent discovery of blue (figure 1), fancy-color, and color-change sapphire in the Indaia (pronounced in-die-yuh) Creek region of Minas Gerais now raises the possibility of significant production of sapphire from Brazil.

Brazil was settled in large part as a result of the search for mineral wealth. Deposits of emerald, gold, and silver—found elsewhere in South America—encouraged exploration of the interior of Brazil. Ruby and sapphire were high on the list of desired items, but only small quantities were discovered in Ecuador and Colombia, with insignificant amounts found in Brazil. The first written reference to sapphire in South America seems to be by Codazzi in 1925. Considering the enormity of other mineral wealth and the discovery of industrial corundum and collection pieces (in places like Anage, in the state of Bahia), it seemed that geologic conditions were favorable for sapphire formation. Still, the gem deposits remained elusive.

The discovery of what appear to be significant quantities of sapphire at Indaia Creek has changed this situation. Two lots of this sapphire—25 kg and 50 kg—have been removed from two areas in this region since 1990. As sampling continues, the promise of increased production is encouraging.

HISTORY

Residents of the sparsely populated Indaia area say they have known about the unusual blue stones for many years; some stones had occasionally been found by chance during

Figure 1. These five sapphires, ranging from 0.19 ct to 0.86 ct, are representative of the gem-quality blue sapphires that have been recovered from Indaia. Courtesy of Brainin and Davenport; photo © GIA and Tino Hammid.

other activities but had never aroused much curiosity. The area is not near other well-known gemstone mines, and no *garimpeiros* (independent miners) lived nearby. Then, in the spring of 1984, a young boy playing near a stream close to his home happened upon a 3-gram blue sapphire (S. Davenport, pers. comm., 1991). A farmer, Osmar Filho Faustino, working near the same stream, later found another piece that he described to one of the authors (W.B.) as being about the size of a thumb (from the first joint to the tip) and of a clear, deep blue, more transparent than any previously seen. The farmer decided to show the stone to an acquaintance familiar with gems in the nearby city of Coronel Fabriciano. After being positively identified as sapphire, the stone was sold in the cutting center of Teófilo Otoni.

The identification and sale of this sapphire sparked the quest by several parties for a mineral-rights grant from the government. There had been other finds in Brazil; pieces that produced up to 2- to 3-ct cut stones had been coming from the Malacacheta region for over 25 years. Very small finds at Poxorey in Mato Grosso do Sul in 1984 and at Ipora in Goiás in 1985 also had been reported (R. Ribeiro, pers. comm., 1991). Over the last 10 years, one of the authors (D.E.) has seen 200- to 1,500-gram lots from unidentified locations, but few stones were of the size and quality described for the large piece from Indaia. The first government-recognized request for exploration rights was accepted in 1988, and several more requests by the same parties for additional land were accepted in 1989. The original exploration-rights request holders eventually sold their rights to Arysio Nunes dos Santos through an arrangement with the firm of Brainin and Davenport, which was appointed operator of the mine. Exploration rights were finally granted by

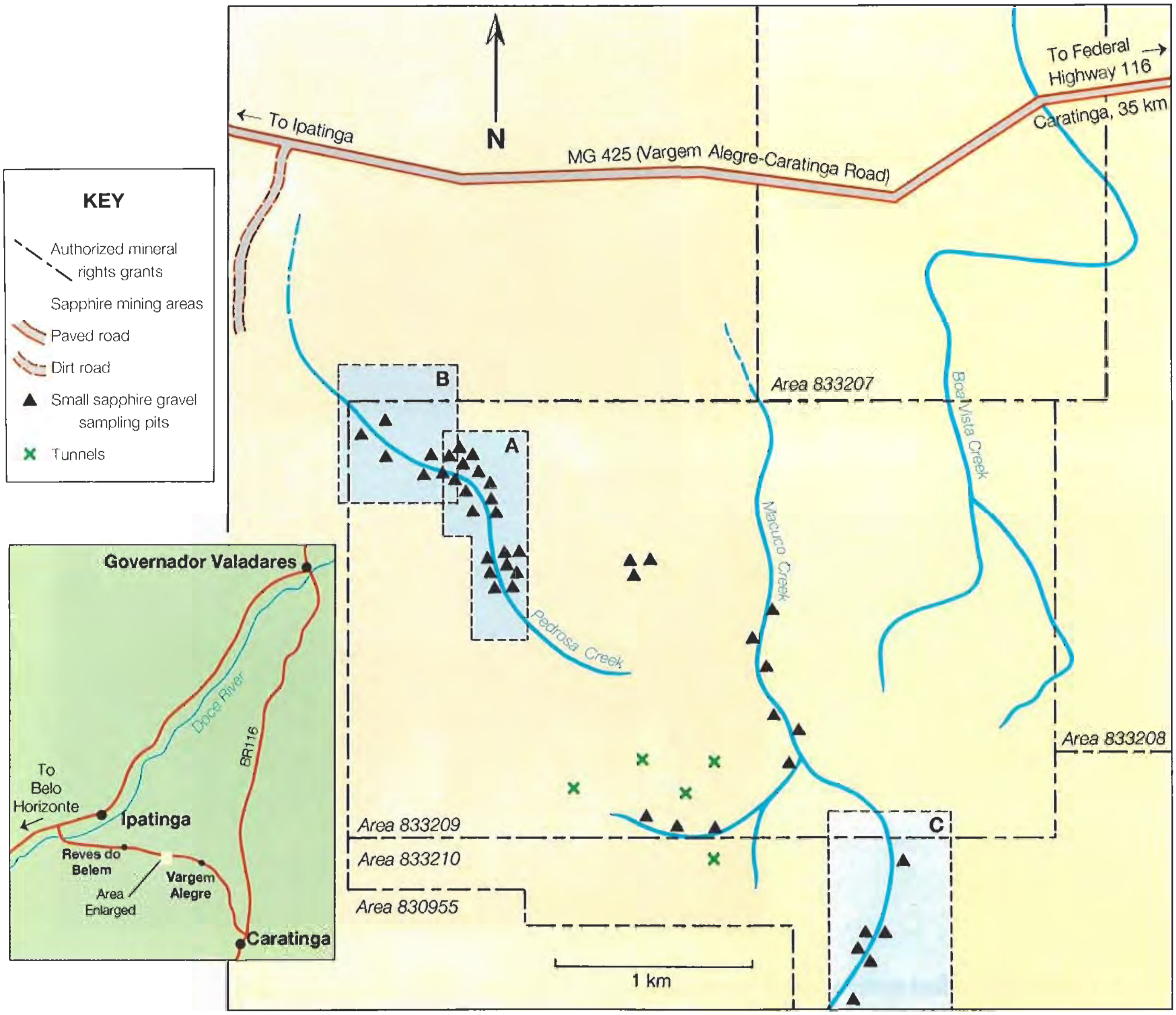


Figure 2. Thus far, three areas—A, B, and C—have been sampled and worked sporadically for sapphires in the Indaia region of Minas Gerais, Brazil.

the Brazilian National Department of Mineral Production (DNPM) to Mr. dos Santos, who intends to upgrade the grant status to the equivalent of a patented mining claim after exploration requirements have been fulfilled. This upgrade would allow the operators to start fully mechanized alluvial mining.

LOCATION AND ACCESS

The Indaia area of Minas Gerais is about 30 km by road southeast of the state's largest steel-milling city, Ipatinga (pop. 300,000; figure 2), which is just northeast of the famous "iron quadrangle" (Schorscher et al., 1982). One of the world's largest iron-ore areas, it is the type locality for the banded-iron formation known as itabirite and an important manganese- and gold-mining district.

The Indaia area is almost exclusively agricultural, producing cattle, corn, okra, rice, and an important eucalyptus crop used for cellulose pulp and paper production. The climate is subtropical, but temperatures rarely exceed 35°C (95°F). The rainy season is typically from October to March; annual rainfall averages between 150 and 200 cm (60–80 inches). Access may be impossible during the rainy season.

Areas A and B (again, see figure 2) are situated between two steep hills on either side of Pedrosa Creek (figure 3)—at 42°4' W, 19°6' S—about 700 m (2,310 feet) above sea level. There are two ways to reach these sites: From Ipatinga, travel 4 km east on BR 381 to a dirt road; turn south (right) and continue 14 km to Reves do Belem; then turn left (east) onto MG 425 (the Vargem Alegre–Caratinga Road indicated on the map) for an additional 10 km. A dirt road branches to the right, and may sometimes be traveled for 1 km by car, depending on conditions. It ends in a trail that can only be followed by foot or on horseback, up a steep and rocky mountain, for approximately 3 km. The climb to the top is treacherous during heavy rains.

The other access is from the city of Caratinga. Take BR 116 north 4 km to MG 425, turn west and continue past the town of Vargem Alegre; turn south onto the same dirt road noted above (on the left from this direction) after a total of 35 km from Caratinga. From here, follow the same directions given in the paragraph above.

Area C is accessible by four-wheel-drive vehicle via a dirt trail that runs roughly southwest from Vargem Alegre for 9 km to the site.

GEOLOGY

Although the precise origin of the Indaia sapphires is still under investigation, it is known that the general geology of the area is dominated by ancient Precambrian (older than 580 million years [My]) complexes of metamorphic basement rocks (DNPM, 1989), which outcrop over the entire area. In fact, the "iron quadrangle," just to the south of Indaia in Minas Gerais, is one of the world's classic areas of Precambrian geology.

These complexes include biotite gneisses, biotite hornblende garnet gneisses, and migmatites (banded rocks with both igneous and metamorphic portions). Radiometric dates for occurrences of these rock units in other areas are between 2.1 and 2.8 billion years old (Cordani, 1973; Hasui et al., 1976; Menezes Filho et al., 1977). Intrusive bodies, possibly associated with sapphire mineralization, have substantially younger ages: 550–600 My.

All presently known occurrences of sapphire here are alluvial (in recent gravels) or colluvial (on local hillsides). Even so, these Precambrian rocks are important, as they are the only likely source of the sapphire, either disseminated in the rocks themselves (in lenses or areas of variable composition within the unit) or associated with the intrusive bodies. In this respect, it is interesting that intrusive bodies of the "Granito Borrachudo" (Schorscher et al., 1982) were associated with gem mineralization in several other deposits within a 50-km radius, including the emerald deposit of Itabira (Souza, 1988), the Capoeirana emerald deposit (Epstein, 1989), and the Hematita alexandrite deposit (Proctor, 1989). It is not known whether one of the numerous intrusives that cross the region (Fontes, 1978) might be a factor in the mineralization of sapphire at Indaia. The intrusive granitoids of the region often resemble the ancient metamorphic rocks, with contacts between the two usually gradational and also weathered, making exact relations obscure. Note that any possible relation to intrusive activity in the Indaia area would be of a felsic-granitic type, unlike another known sapphire occurrence in South America—Mercaderes, Colombia (Keller et al., 1985)—which appears to have originated in alkaline basalts. Also note that the common accessory minerals normally found in alkaline basalts and/or heavy concentrates derived from them—such as at Mercaderes (black spinel, ilmenite, zircon, olivine, pyrope garnet, and augite)—are not present at Indaia. However, almandine garnet is, as are quartz gravels, white kaolinitic clay, very pale amethyst crystals, beryl, feldpsar, and muscovite.

Figure 3. At Indaia, sapphires are recovered from alluvium in the hills that line this narrow valley as well as along the creek.

It is possible that other ancient rocks, younger than the basement rocks and formerly overlying the

Figure 4. Nearly 2 m of clay-like material was removed with simple shovels to reach the sapphire-bearing gravels.

gneiss-migmatite complex, were the source of sapphires in the alluvium, but this is doubtful. The complex completely dominates the region, and any higher stratigraphic units that once existed have long since been eroded away, forming sedimentary beds older than and farther from the area of sapphire occurrence. The nature and occurrence of the sapphire indicates a closer source, which the mine operators hope to locate.

OCCURRENCE

The "diggings" are situated in an area of relatively high and very steep hills. Several small creeks merge to form streams, which run through the center of a narrow agricultural valley.

Although sapphires have been found on hillsides and in streambeds over more than 10 km^2, the first center of activity in 1990–1992 was an approximately 1-km stretch along Pedrosa Creek, extending as much as 50 m on either side of the stream (see area A on figure 2). The alluvium can be more than 5 m thick, but it averages 2–4 m (figure 4), with the gem-bearing gravel approximately 20–100 cm (8–40 inches) thick. There are two distinct gravel layers, usually separated by a horizon of predominantly white kaolinitic clay that grades into red and brown ferruginous clays. The upper layer is essentially barren, yielding only an occasional sapphire as the gravel is removed to reach the lower layer. Otherwise, the two layers are virtually the same, both composed of quartz gravels, white kaolinitic clay, and occasional small pieces of almandine garnet. The quartz, poorly sorted, varies from euhedral to subhedral and from sand size to fist size. Small, very pale amethyst crystals are frequently found. Other minerals found with the sapphires in sieve concentrates include beryl, feldspar, and muscovite.

Even when there is no kaolinitic horizon, the lower sapphire unit is easily recognized by the presence of sapphire itself, commonly numbering up to 200 small (0.5–2 ct) pieces per wheelbarrow load. The bottom of the sapphire unit is marked by a final layer of white clay, 20–30 cm (8–12 inches) thick, above the bedrock.

In late 1992 and early 1993, two new sites were identified at Indaia. Miners originally overlooked area B (see figure 2), adjacent to area A, apparently because the sapphire-bearing gravel layer is deeper (4–5 m). Initial efforts have produced slightly larger stones than at area A. Even more promising is area C, about 3 km to the southeast (see figure 2). Initial mining in this area has produced greater quantities of sapphires of a finer blue color and higher clarity than have been produced in either area A or B. Several fine, clear blue stones—weighing 5 to 7 ct—were recovered from a single prospect pit in area C. The occurrence of sapphire in these new areas appears to be the same as the occurrence in area A.

MINING

Several small "independent" operations have functioned sporadically in the past, but only Mr. dos Santos has a government-authorized exploration concession. This covers 42 km^2. Mineral rights are not in dispute, and access to areas A and B is limited by the 45-minute trail hike or mule ride over the mountain. The operators feel that these factors will inhibit large-scale unauthorized mining in the concession area.

In keeping with Brazilian law, the mine operators are working only at the "exploration level" of activity and they claim that they will continue at this level until the exploration concession can be upgraded to a mining concession (A. Nunes dos Santos, pers. comm., 1993). For this reason, the crew has been small—about five to 10 workers.

Even with the small crew, initial results have been promising, considering the primitive recovery methods. A washing system in area A includes a large (1 × 2 m) three-layer shaker screen and generator-operated electric water pumps. This is a significant improvement over the widely used circular hand screens, which are dipped in the nearest creek or water-filled pit. Miners use simple shovels to excavate down to the gem gravel layer (again, see figure 4). They then shovel the unsorted gem layer to the surface, cart it by wheelbarrow up a ramp, and dump it into the screening jig.

While one person directs water at the material from a pump-powered hose, another rocks the tilted top screen (which has a 2.5-cm [1-inch] mesh). Rocks and larger pebbles are discharged. The second screen (with a 1.25-cm mesh) catches the coarse gravel and pebble-size material. Fine gravel, and almost all sapphire, is retained by the third screen (0.3-cm mesh) and subsequently removed by hand (figure 5). Quality and quantity vary significantly from one pit to the next. Pits are widened or abandoned based on screening results.

Area C is worked using similar primitive mining and recovery methods. Unlike hard-to-access areas A and B, however, area C can be reached by a trail that is passable by four-wheel-drive vehicle. Although part of the approximately 9-km route from Vargem Alegre is tortuous and roundabout, the trail could be widened and improved.

PRODUCTION AND CUTTING

Production. Digging and washing operations are not conducted full-time at any of the specific areas, due to the emphasis on exploration and development of the entire mining claim. Nevertheless, at least some recovery operations take place regularly when the weather permits. According to the mine managers (A. Nunes dos Santos, pers. comm., 1993), area A has produced average weekly yields of 2–3 kg of corundum of a wide range of quality. Sapphire has been found scattered over area B, and sampling continues there. Almost every test pit in area C, each measuring about 2 × 2 m, has yielded sapphire. The yields of different pits range from a few hundred grams to about 2 kg. Total production of all grades of corundum from area C was about 50 kg in 1993.

The proportions of gem material appear to be about the same for all three mining areas. About 16% is cuttable and a marketable blue color; 4% is cuttable and purple to pink. Approximately 1%–3% of this cuttable material recovered to date is suitable for faceting, and the rest is suitable for carving or for cutting as cabochons and beads. Another 20% of the total is a nontransparent, "cloudy" blue that may be a candidate for heat treatment. The remaining 60% of the material is classified as "corundum gravel," which may also yield additional marketable sapphire with heat treatment. Experimentation with heat treatment is ongoing, and some color enhancement has been observed. Overall, however, the results remain inconclusive.

Particularly noteworthy is the high percentage—as much as 50% from some pits, and about 7% to 10% overall—of distinct color-change sapphire.

Given the small area being worked relative to the larger region over which sapphire has been confirmed, it would seem reasonable to expect that output will increase markedly when the government approves an upgrade to mining status, and the operators are ready to intensify efforts. Unknown factors affecting production include the quantity of sapphires present over the wider area and the feasibility of mechanizing an area of difficult access. Increasing the work force and retaining the hand methods currently in use is another option, and one that could be put into place quickly.

Figure 5. At Indaia, miners wash the sapphire-bearing gravels and then pick out the gems by hand.

Cutting. In general, cutting methods for Indaia sapphires are typical for corundum, but some of the rough requires special consideration for best results. Material with rounded color zoning must be cut so that the color is located in the culet of the gem and

Figure 6. The largest of these representative pieces of rough weighs 2.96 ct. Photo © GIA and Tino Hammid.

there is no window; the rounded color zone will then reflect off, and refract to, the pavilion facets. In most of the material, however, banding is slight and generally uniform in size and color throughout the stone. Most of the rough is broken pieces, which lend themselves more toward round shapes (melee) than toward the marquise and oval cuts commonly produced from well-formed crystals.

On lighter-toned goods, a brilliant cut is most effective, producing greater scintillation and making the tone sometimes a bit darker. In darker tones, the conventional mixed cut is recommended because the stepped pavilion facets move and divide the light less, minimizing any darkening effect. In overly dark stones, a window can be produced by cutting the pavilion facets below the critical angle.

DESCRIPTION OF THE MATERIAL

Materials and Methods. Twenty-seven rough Indaia sapphires, ranging in weight from 0.12 to 2.01 ct and in color from blue to purple and pink, were obtained at the locality. Using a Duplex II refractometer with a monochromatic sodium vapor light source, we determined refractive indices from two polished surfaces of sections cut from 19 of the rough samples. We determined specific gravity for 14 of the same sections with a 20-cm^3 pycnometer and an analytic balance. Twenty-four samples, each with at least one polished face, were examined with a Zeiss petrographic microscope. We also exposed the 27 rough specimens to standard long- and short-wave ultraviolet radiation. Three blue sapphires—0.12, 0.19, and 0.22 ct—were examined with a Beck prism spectroscope.

Visual Appearance. For the most part, the sapphires obtained at Indaia have been broken, subhedral pieces (figure 6), although we have seen some elongated hexagonal crystals. The predominant colors are medium to medium-dark tones of blue to violet- blue to purple. No hue approaching that of ruby has been found at the deposit to date, but there is an unusually high percentage of material showing color change—from a violet in day or fluorescent light to purple or saturated ("hot") pink in incandescent light.

It is interesting that a high percentage of sapphires with color change was also noted in the alluvial deposits of Mercaderes, Colombia (Keller et al., 1985). Color change also has been seen in some Australian (Coldham, 1985), Thai (Keller, 1982), Tanzanian (Dirlam et al., 1992), and Sri Lankan (Gübelin and Schmetzer, 1982) sapphires.

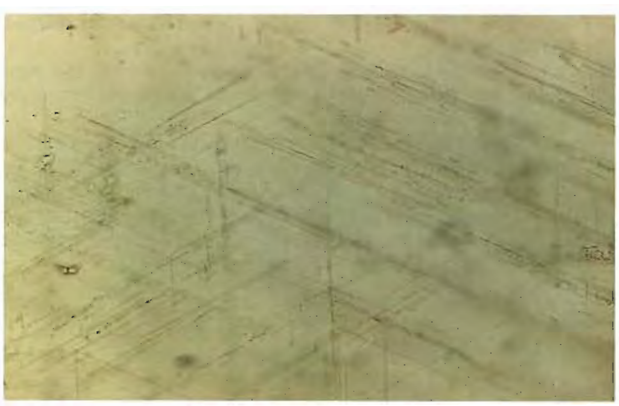
Refractive Index and Specific Gravity. We found that the refractive indices ranged from n_ε = 1.760 to 1.762 and n_ω = 1.768 to 1.772; birefringence was 0.008–0.010. Analysis of 14 of the polished "sections" gave a specific gravity between 4.00 and 4.02.

Ultraviolet Fluorescence. None of the sapphires showed a reaction to short-wave U.V. radiation. However, 16 of the 27 stones tested exhibited a moderate to strong bright red fluorescence to long-wave U.V. This long-wave fluorescence, somewhat similar to that noted in sapphires from Mercaderes (Keller et al., 1985), also resembles that seen in some rubies. The other 11 stones displayed very weak or no fluorescence to long-wave U.V. A distinct correlation between fluorescence, body color, and color change was noted: "Purer" blue and/or stones with only a weak color change generally exhibited a weaker or no fluorescence; more violet to purple stones and those with a stronger color change generally showed at least moderate fluorescence; pinkish purple and purple stones with a strong color change to pink generally showed strong fluorescence. Five grayish blue low-grade stones (corundum gravel) were essentially inert. Note that the correlation between long-wave U.V. fluorescence and color was not perfect: One fine blue stone showed medium-strong red fluorescence, one stone with strong color change from violet blue to pinkish purple did not fluoresce, and one pinkish stone showed no fluorescence. No phosphorescence was seen in any of the sapphires tested.

Spectroscopy. All three stones tested with a hand-held type of spectroscope showed a faint band at approximately 450 nm. This is consistent with the spectra for iron-rich sapphires from other localities.

Internal Characteristics. We observed several features in the 24 Indaia sapphires examined. Evidence of lamellar twinning (figure 7) and fine hexagonal growth zoning was clearly visible. High magnification revealed that fingerprint-like inclusions (healed fractures) formed a network of irregular liquid-filled channels (figure 8). The most frequently seen crystalline inclusion appeared as groups of tiny crystals (possibly zircon) surrounded by a brownish stain, and showing typical strain halos (figure 9). Fine needles (apparently rutile) on the growth planes were visible with high magnification. We noted small reddish brown crystals of mica, probably biotite, in almost all of the stones (figure 10). Although we observed two- and three-phase primary inclusions only rarely (figure 11), we saw secondary liquid inclusions in all stones examined. All of these inclusions have been reported in sapphires from other localities; none appears to be distinctive of Indaia.

Figure 7. Growth lamellae are typical of Indaia sapphire. Photomicrograph by J. C. Mendes; magnified 100×.



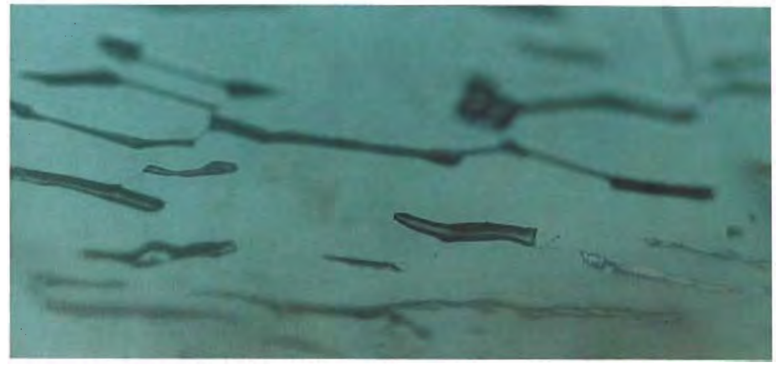


Figure 8. Most of the Indaia sapphires examined revealed networks of long, irregular liquid-filled channels, which are actually healed fractures. Photomicrograph by J. C. Mendes; magnified 200×.

Figure 9. This brown-stained inclusion looks like zircon. Note the tension halo associated with a healed fracture. Photomicrograph by J. C. Mendes; magnified 200×.

Figure 10. This reddish brown mica crystal, possibly biotite, shows strong pleochroism. Photomicrograph by J. C. Mendes; magnified 200×.

Figure 11. Only rarely were primary three-phase inclusions such as this observed in the Indaia sapphires. Photomicrograph by J. C. Mendes; magnified 200×.

CONCLUSION

The discovery of gem corundum in potentially commercial quantities is a significant development for Brazil. Also important is that a relatively large portion of the gem-quality material recovered to date shows color change. Although done at a very early stage, studies of recovery per square meter, and evaluation of quality and value of cut material, clearly show that some areas are potentially profitable, even with primitive mining methods. Yet to be determined, however, is how many areas can produce sapphire that matches or surpasses this quality and whether more sophisticated mining methods are practical and economical.

REFERENCES

Codazzi R.L. (1925). *Notas Mineralógicas y Petrográficas.* Bibliotéca del Museo Nacional, Bogotá, Colombia.

Coldham T. (1985) Sapphires from Australia. *Gems & Gemology,* Vol. 21, No. 3, pp. 130–146.

Cordani U.G. (1973) *Evolução Geologica Pre-Cambriana da Faixa Costeira do Brasil entre Salvador e Vitoria.* Instituto de Geociencias da U.S.P., São Paulo, Brazil.

DNPM [Departamento Nacional do Produção Mineral] (1989) *Research Grant Map of Area, Grant 27203-833.209/89.* Belo Horizonte, Minas Gerais, Brazil.

Dirlam D., Misiorowski E.B., Tozer R., Stark K.B., Bassett A.M. (1992) The gem wealth of Tanzania. *Gems & Gemology,* Vol. 28, No. 2, pp. 80–102.

Epstein D.S. (1989) The Capoeirana emerald deposit near Nova Era, Minas Gerais, Brazil. *Gems & Gemology,* Vol. 25, No. 3, pp. 150–158.

Fontes A.C.Q. (1978) *Projeto Jequitinhonha: Relatorio Final.* DNPM-CPRM, Belo Horizonte, Minas Gerais, Brazil.

Gübelin E., Schmetzer K. (1982) Gemstones with alexandrite effect. *Gems & Gemology,* Vol. 18, No. 4, pp. 197–203.

Hasui Y. et al. [sic] (1976) Geochronologia da regiao do Medio Rio Doce, MG. In *Resumo dos trabalhos, No Congresso Brasileiro de Geologia, 29,* Ouro Preto, Minas Gerais, Brazil, pp. 211–212.

Keller P.C. (1982) The Chanthaburi-Trat gem field, Thailand. *Gems & Gemology,* Vol. 18, No. 4, pp. 186–196.

Keller P.C., Koivula J.I., Jara G. (1985) Sapphire from the Mercaderes-Rio Mayo Area, Cauca, Colombia. *Gems & Gemology,* Vol. 21, No. 1, pp. 20–25.

Menezes Filho N.R. et al. [sic] (1977) *Projeto Tres Marias: Relatorio Final.* DNPM-CPRM, Belo Horizonte, Minas Gerais, Brazil.

Proctor K. (1989) Chrysoberyl and alexandrite from the pegmatite districts of Minas Gerais, Brazil. *Gems & Gemology,* Vol. 24, No. 1, pp. 16–32.

Schorscher H.D., Santana F.C., Polonia J.C., Moreira J.M.P. (1982) *Quadrilatero Ferrifero—Minas Gerais State: Excursions Anex.* ISAP, Belo Horizonte, Minas Gerais, Brazil.

Souza J.L. (1988) *Mineralogia e Geologia da Jazida de Itabira, Minas Gerais.* Dissertação de Mestrado, Instituto de Geociencias, Universidade de São Paulo, Brazil.