
AMETHYST MINING IN BRAZIL

By David Stanley Epstein

Brazil is currently the leader in overall production of amethyst. This article describes the author's visits to three of Brazil's most important mining areas: Marabá, Pau d'Arco, and Rio Grande do Sul. Each represents a different geologic environment and, therefore, a variety of mining methods are used. In Marabá and Rio Grande do Sul, much of the amethyst is heat treated to become citrine.

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Because of its ready availability, modest cost, and attractive color, amethyst is currently one of the most popular colored gemstones (figure 1). Fine amethyst historically came from Russia's Ural Mountains and from the Idar-Oberstein area of West Germany, although both deposits are now largely exhausted. Today, economic quantities occur in Zambia, Mexico, and Uruguay, with lesser deposits in Australia, Sri Lanka, India, Madagascar, South-west Africa, and the United States (Webster, 1983). The major source, however, is Brazil. Hundreds of tons of various grades of amethyst are produced there annually (419 tons in 1985), of which a small but important percentage is of cutting quality.

Amethyst was discovered in Brazil early in the 19th century, by settlers from Idar-Oberstein (V. R. Sudback, pers. comm., 1987; Gonçalves, 1949); to date, mining claims have been filed in at least eight of Brazil's 27 states and territories. This article describes current mining of gem amethyst in three of the most important producing areas—Marabá (which currently is producing the most amethyst in Brazil), Pau d'Arco (which produces some of the finest material), and Rio Grande do Sul (which has the longest sustained production). These localities also provide good examples of the occurrence of amethyst in three different geologic settings: as large veins in quartzite, as a constituent of sedimentary alluvium, and as geodes in basalt.

This report is based primarily on the author's own observations made during a fall 1987 visit to these three areas, which involved travel of over 12,000 km, plus information obtained from numerous discussions with local miners, amethyst dealers, and government geologists. For each area, information is included on location and access, occurrence of the amethyst, history of the deposit, mining methods, production levels, and quality grades of the amethyst recovered (see table 1). Because almost all



Figure 1. This faceted 9-ct amethyst and the Rio Grande do Sul crystal cluster are representative of some of the fine material that has come from Brazil. Jewelry courtesy of Silverhorn, Santa Barbara, CA; photo © Tino Hammid.

citrine on the market today is produced by heat treating amethyst, the treatment procedures practiced at Marabá and Rio Grande do Sul are briefly described as well. Research done by Cassedanne (1988 a and b) indicates that there are no significant differences in the gemology of amethyst from different areas of Brazil; general properties are summarized in the accompanying box.

MARABÁ

Approximately 450 km south of Belém, the capital of the northern state of Pará, lies the municipality

and town of Marabá (figure 2). Although the most productive occurrence of faceting grade amethyst being mined in Brazil today is that of Alto Bonito, all of the material from this general region is commonly referred to by the name Marabá.

Marabá is easily reached from Belém by regularly scheduled airline. The hour-long flight is almost entirely over dense, tropical rainforest that is interrupted occasionally by small, grassy clearings and meandering rivers. From Marabá, one must take an air taxi southwest to the ranch (*fazenda*) on which the mine is located. A difficult

GEMOLOGICAL DESCRIPTION OF AMETHYST

Gemology

Amethyst is the purple to violet variety of crystalline quartz and is colored by an $O^{2-} \rightarrow Fe^{4+}$ charge-transfer process (Cox, 1977; Fritsch and Rossman, 1988). Aside from color, its properties are those of all crystalline quartz, regardless of locality: uniaxial positive with refractive indices of $o=1.544$ and $e=1.553 \pm 0.001$, and birefringence of 0.009. Since gem-quality specimens are essentially flawless, the specific gravity of 2.66 ± 0.01 can be regarded as almost constant, although mineral specimens and uncut crystals used in jewelry may be sufficiently included to expand the range of density. The most reliable and distinctive property, however, is the "bull's-eye" optic figure that is unique to quartz. With crossed Polaroids and a condensing lens, a uniaxial figure with an open center where the black cross fails to meet can usually be seen.

Separation of Natural from Synthetic Amethyst

None of these properties, however, will distinguish natural from synthetic amethyst. In addition, the absence of inclusions in the vast majority of faceted amethysts negates the potential diagnostic value of this characteristic. It was recently determined, however, that Brazil law twinning could be used to make the separation (Lind et al., 1983; Schmetzer, 1985, 1986). The author has found that this twinning can be observed in more than 50% of natural amethyst

simply with a diffused light source such as a light table. In more difficult cases, placing a single polarizing filter between the light source and the amethyst will usually make the twinning visible. Finally, observation with the stone between crossed Polaroids, possibly even with immersion, should resolve the most stubborn cases. Details of this technique are covered in Crowningshield et al., 1986. Brazil law twinning has not been observed in any synthetic amethyst studied to date.

The presence of Brazil law twinning in natural amethyst separates the natural stone from its synthetic counterpart. Photomicrograph by John I. Koivula; magnified 20 \times .



TABLE 1. Geologic and descriptive comparison of amethyst from Marabá, Pau d'Arco, and Rio Grande do Sul, Brazil.

Mining area	Occurrence	Condition and size of crystals	Color ^a	Treatment	Production
Marabá	Fracture fillings in quartzite	Generally good condition; some free-standing, some interlocked; individual crystals up to 15 kg in weight, 50 cm long	Maximum tone of 7 in best 19+ -ct stones, tone 8 in 50+ -ct stones	To citrine: buried in sand and heated by woodfire	Approximately 9.6 tons of gem-quality material produced in 1986
Pau d'Arco	Alluvial deposits	Partially eroded; from 300 grams to 40 kg	Maximum tone of 10 in 1-ct stones	To lighten color, heated in test tube; never turns to citrine	Approximately 7 tons of all qualities produced annually in 1985 and 1986
Rio Grande do Sul	Geodes inside basalt	Pyramidal crystals; up to 10 cm long	Maximum tone of 7 in 10-ct stones	To citrine: heated in oven	Approximately 19 tons of gem-quality amethyst and heat-treated citrine shipped legally through Rio Grande do Sul in 1986

^aBased on tone scale used by author in the field (see figure 5).

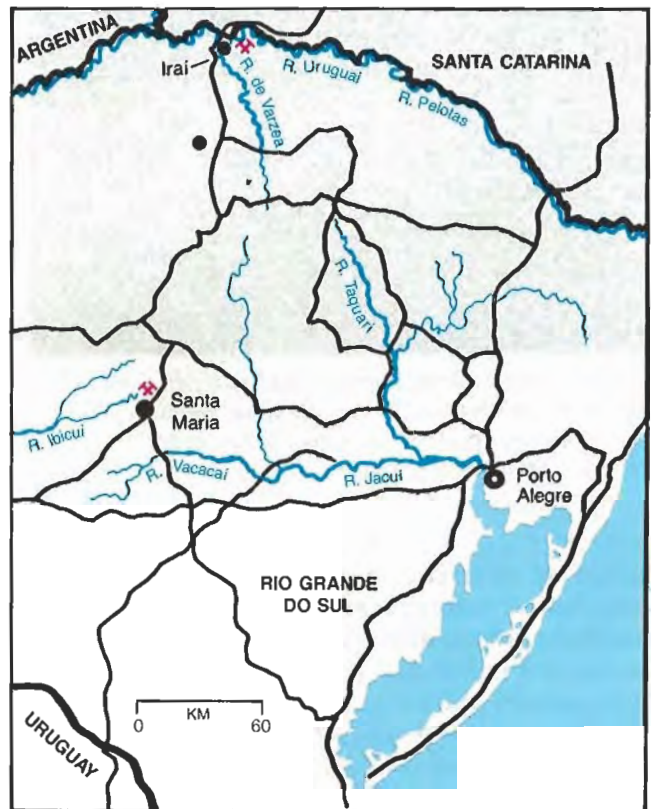
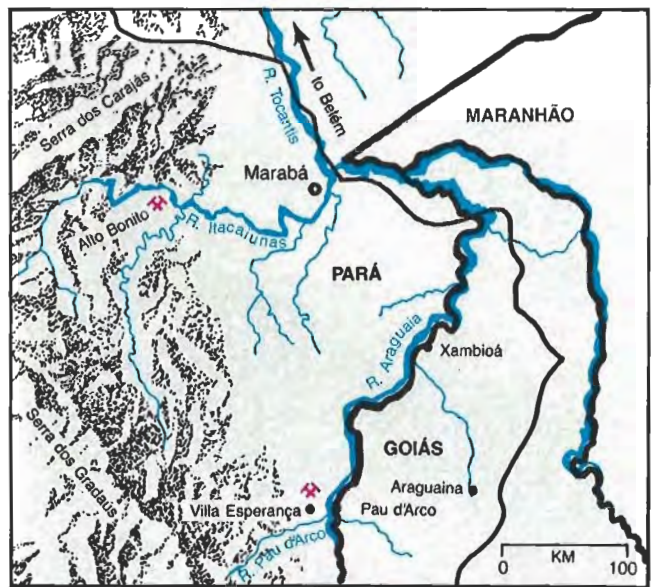


Figure 2. Brazil is now the most important source of amethyst in the world. This map shows the location of the Alto Bonito (Marabá) and Pau d'Arco amethyst deposits in the state of Pará, and the Irai and Santa Maria workings in the state of Rio Grande do Sul. Artwork by Peter Johnston.

one-hour drive by truck (a "taxi" service provided by the landowner) leads to the hillier region of Serra dos Carajás, where the amethyst is mined. The approximate geographic coordinates of the Alto Bonito amethyst deposit are 5°15' S and 50°30' W. Travel is advisable during the drier months, June to November, when temperatures range from 18° to 40°C (64° to 104°F).

Occurrence. Alto Bonito lies within the broad Carajás mineral province (Collyer and Mártires, 1986), which also includes the famous Serra Pelada gold deposit. The amethyst occurs in a series of sedimentary and extrusive volcanic rocks of lower Proterozoic age (approximately 1.7 to 2 billion years old). Specifically, it is distributed irregularly in veins and cavities in highly fractured and folded

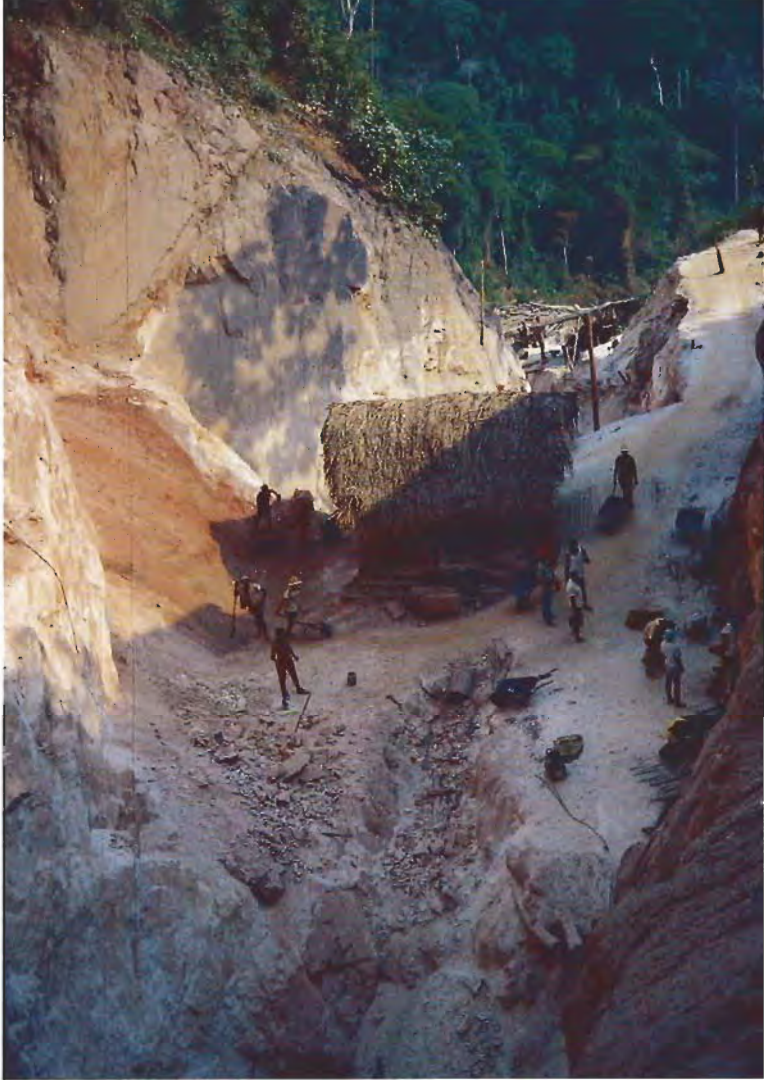


Figure 3. Both white quartzite and reddish quartzite are evident in this photo of an amethyst-mining operation at Alto Bonito, near Marabá, in the state of Pará.

layers of quartzite, a tough, siliceous, metamorphosed sedimentary rock. Two kinds of quartzite, which differ primarily in color, can be recognized in the field (figure 3). One is white or light colored, and the other is more reddish due to staining by hematite and other iron oxides. Collyer and Mártires (1986) report that amethyst occurs with greater frequency in the reddish quartzite.

The veins may reach a meter in thickness and vary greatly in length. The cavities are oval or elongate and may reach a diameter of several meters. In both the veins and cavities, the amethyst occurs as tightly packed crystals that range up to half a meter long.

History. In mid-1981, workers for the family of Pedro Miranda found fragments of amethyst crystals scattered on the ground at Alto Bonito. Be-

cause the fragments were of poor quality, and no one in the area had any knowledge of amethyst, this find remained unexploited for over a year until a prospector from Bahia, Manuel Xavier, saw the material and recognized its cutting potential. Xavier began the first amethyst diggings in the Marabá area.

These early workings were simple pits that reached a depth of only 2 to 3 m and were soon exhausted. Subsequently, José Miranda Cruz, the eldest of six Miranda sons, initiated a more organized exploration and recovery of amethyst. He built houses for the miners, and later a general store, school, and other facilities to sustain a community of several hundred persons. He also initiated the use of mechanized equipment so that the workings could be extended underground. At Alto Bonito there are currently 22 *barrancos* (shafts or tunnels) spread over an area of approximately 500 m². Each has numerous owners and partnerships, who pay 10% of the value of the recovered amethyst to the landowners for the opportunity to mine.

Mining Methods. The majority of the mining is done with picks, shovels, buckets, jackhammers, and occasionally small amounts of dynamite. Vertical shafts and horizontal tunnels are excavated to follow the veins of amethyst, and are reinforced with timbering taken from the surrounding forest. Electricity for lighting and ventilation systems are added as needed and as money is available. During my visit I was able to explore a number of these workings and experience some of the trauma and excitement of the amethyst miner firsthand.

To reach the first level of the Paulinho *barranco*, I was lowered by rope 20 m into almost total darkness. I then walked about 5 m along a tunnel to another opening, where two miners lowered me another 30 m. The lack of oxygen made breathing difficult, and the danger of the fragile walls collapsing was everpresent. At the bottom of this shaft were a few simple picks and a lantern. The tunnel followed a vein of amethyst that had been quite broad and of good color at the top, but here was very narrow and pale. The miners had been rewarded for their efforts at these depths, however, by the discovery of some richly colored amethyst in cavities—up to 1 m in diameter—embedded in the walls of the workings.

The next *barranco* I visited, known as the



Figure 5. In the field, the author uses an informal tone scale to grade amethyst. This photo represents tone values 2 (extremely pale pink) through 9 (deep purple) on the author's scale (tone value 0 would be colorless and tone value 10, black). On this scale, the amethyst must be a tone value of 4 or higher to be considered cutting quality. Stones courtesy of Samuel Goldowsky, Bob Bryan, and Simon Watt; photo © Tino Hammid.

Figure 6. In general, the amethyst from Marabá is less saturated than that from Pau d'Arco and Rio Grande do Sul. These fantasy cuts were fashioned by the author from Marabá amethyst. The largest stone is 28 ct. Photo © Tino Hammid.



make the amethyst from this area of great commercial importance. These include the uniformity of color (or regularity of color banding in banded material), the clarity and classic shape of the crystals, the unusually large size of unflawed sections, and the large production.

PAU D'ARCO

This area, which produces some of the best amethyst available today, is about 250 km south of Marabá, on the western bank of the Araguaia River (again, see figure 2). The approximate coordinates are 7°32' S and 49°23' W. It can be reached from Marabá by taking a rough paved road southeast and then a barge across the Araguaia River to the town of Xambioá. From here, one continues south-southeast through the city of Araguaia and then southwest by a new paved road for 100 km, and by dirt road for 65 km, to the town of Pau d'Arco. The actual mining village, Villa Esperança, is approximately 6 km south of Pau d'Arco on the west side of the river. This final leg of the journey requires recrossing the Araguaia River by a 7–9 passenger motorized rowboat at Pau d'Arco. Public transportation is available from Marabá, but is very primitive. A journey that might take eight hours by car could take 21 hours by public transport.

Villa Esperança, which has approximately 250 inhabitants, is situated at an elevation of about 200 m above sea level. As with Marabá, it is best to visit during the dry season, June to November. Malaria is common in this area.

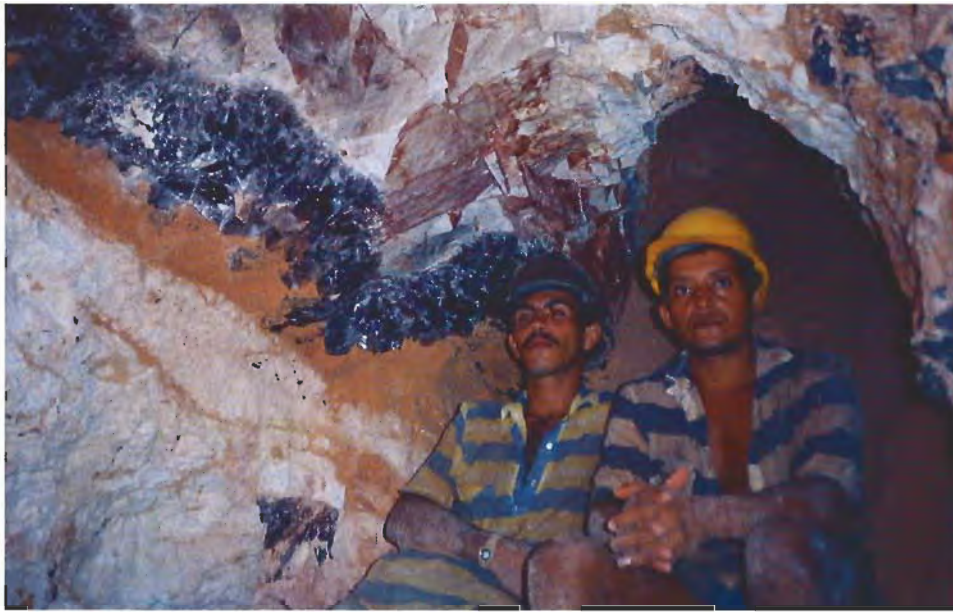


Figure 4. Veins of amethyst line the walls of this tunnel at Alto Bonito. Because the air is so thin, the miners operate in groups of three, with one man working while the other two rest.

Penhão, was about 200 m deep. It had been constructed into six different levels, each connected by vertical shafts. The descent into this system of workings seemed endless, until suddenly the shaft opened up into a large cavern, about 25 × 20 × 25 m. As in many of the tunnels, sections of large amethyst cavities and veins could be seen in the walls and ceiling of this natural cavern (figure 4). At this depth the air contains very little oxygen, and the ventilation equipment in these rudimentary mining operations is inadequate. Consequently, the miners work in shifts, with one man digging while two others rest.

The last tunnel I entered was that of Ze Liete. After walking several meters, I realized that I was standing inside the remains of a giant amethyst cavity. Such cavities may contain single crystals up to 15 kg, although these large crystals rarely contain much cuttable material.

Production. Buyers purchase amethyst directly from the various tunnel owners and cobb it (i.e., remove unwanted material from the crystal) either on site or at some distant location to produce gem rough. Table 2 provides some rough estimates of the quality and quantity of amethyst produced monthly at Alto Bonito in 1985 (Collyer and Mártires, 1986). Accurate estimates of the amethyst reserves at Alto Bonito are not available, but I observed material in place in the underground workings that would require one year's mining effort to recover. To date, there has been no systematic exploration of the surrounding area for additional occurrences of amethyst.

Description of the Amethyst. It is convenient to describe the color of gem amethyst from Brazil in terms of a tone scale (similar to that taught in the GIA colored stone grading course) that ranges from 0 (colorless) to 10 (black). Figure 5 provides a general idea of the range represented by tones 2 to 9 on this scale; cutting-quality amethyst generally has a tone value of 4 or greater. Although table 1 indicates that 5% of the monthly production at Alto Bonito is represented by good-quality, faceting-grade material, only 1% to 2% of the total production consists of pieces of amethyst that would yield a tone 7 in cut stones 19 ct or larger. Smaller cut stones rarely attain the darker tone values.

On average, the amethyst from Marabá is less saturated than that from the other localities discussed here (figure 6). Other factors, however,

TABLE 2. Estimated monthly production of amethyst at Alto Bonito, Pará, in 1985.^a

Type of amethyst	Average monthly production (kg)	% of total production
Good quality (facet grade)	300	5.00
Reasonable quality (facet grade)	500	8.33
Tailing (carving/tumbling grade)	3,800	63.33
Samples and collector pieces, druzes	1,400	23.33
TOTAL	6,000	100.00

^aAdapted from Collyer and Mártires, 1986.

Occurrence. In contrast to the primary deposits at Marabá, amethyst occurs at Pau d'Arco only in secondary, alluvial deposits (figure 7; Cassedanne, 1986). The crystals are unusually large: 20 kg pieces are not uncommon and crystals as large as 40 kg have been found. According to geologists who have studied this area (B. F. Filho, O. B. Ferreira, and R. A. C. Mártires, pers. comm., 1987), it is likely that the amethyst was transported from the same mountain range in which the Marabá amethyst is found. Recently, other amethyst deposits have been noted in this range (Cassedanne, 1988 a and b).

History. According to local miners, amethyst was first discovered at Pau d'Arco during a boar hunt sometime in 1979. In their efforts to capture a boar that had escaped into a narrow burrow, the hunters started digging to widen the opening. The boar ransomed its life when the hunters were diverted

by a large crystal of fine amethyst. The quality of the crystal was confirmed at Xambioá, itself a source of fine amethyst at that time, and miners began the rush to Pau d'Arco.

The first year or so of mining activity produced only a few of these large amethyst crystals. Then production picked up, until it reached its peak between 1982 and 1984 (B. P. de Alcontara, pers. comm., 1987). Throughout this period, most of the mining was by *garimpeiros*, independent miners, none of whom had registered their claims with the government. In December 1985, a company named Mineração Conceição Araguaia obtained the rights to explore the area and mine for amethyst. Local *garimpeiros* were furious, and violence followed. Eventually, an accord was reached whereby the local miners could continue to work on a portion of the property. The company brought in water cannons, heavy equipment, and professional geologists, but after much earth moving, the amount of

Figure 7. Mounds of gravel and other sediments mark the Pau d'Arco mining area, where loose crystals are found in secondary, alluvial deposits.





Figure 8. Picks and shovels are used at Pau d'Arco to remove the various layers of dirt and gravel that cover the amethyst-producing layer. The pits average 4 m wide \times 7 m long, and usually reach 2–3 m deep.

good quality amethyst recovered could not support costs and the project was halted (O. B. Ferreira, pers. comm., 1987). Currently, amethyst mining has reverted to simpler methods and a smaller scale, where individual miners or groups of miners will work a particular area. Most of the residents of Villa Esperança are involved in amethyst mining.

Mining Methods. Amethyst is currently recovered at Pau d'Arco from pits and tunnels. The pits (figure 8) average 4 \times 7 m and are only 2–3 m deep. Because the water table is so high, these pits may contain water much of the year. The pit miners recover the amethyst by digging downward with picks and shovels into the various layers of sediments until a productive one is reached, typically from 1 to 3 m below the surface. They then remove all of the rocks and sediments in this layer and subsequently wash them to reveal the amethyst.

In contrast, tunnels are excavated 3–5 m below the surface, where a thick, hard layer overlies the amethyst-bearing alluvium and provides support. The author saw no evidence of electrical generators during his visit; the tunnel miners work only by candlelight. They dig the material out with picks and shovels, hoist it to the surface, and then wash and sort it.

Each group of miners has its own prospect pit

or tunnel. Often several pits or tunnels are clustered in a single productive area called a *mansion*. The amethyst workings at Pau d'Arco currently cover an area that is approximately 1.5 km².

Production. Amethyst production at Pau d'Arco was relatively constant at about 7,000 kg per year in 1985 and 1986 (S. H. S. de Matos, pers. comm., 1987). There are no estimates available of potential reserves. All amethyst is sold as rough, not cobbled; production usually is brought into the village daily and sold to buyers from Minas Gerais. Except for a very small quantity that is sent to Japan, most of the amethyst is faceted in the Minas Gerais gem centers of Governador Valadares or Teófilo Otoni. It is difficult to estimate the percentage of amethyst recovered that is suitable for cutting. However, most of the stones that are faceted are less than 2 ct when finished, although larger stones—over 50 ct—have been cut.

The best amethyst from Pau d'Arco rivals the finest African amethyst in intensity and saturation (figure 9). However, the color in the rough may be quite unevenly distributed, and requires care in orientation by even an experienced cutter. Color zones of bluish and reddish purple can often be seen in the rough, even in the same piece, in a pattern that is quite different from the distinct spots or bands of color in African or other Brazilian amethyst. The tone of the Pau d'Arco amethyst can be so dark that even 1-ct stones may appear black.

Figure 9. Pau d'Arco produces some of the finest amethyst, in terms of hue and saturation, in the world. This 14-ct stone was cut by the author. Photo by Robert Weldon.



At its best color and when properly cut, the material has a velvety violet body color and projects red flashes from the pavilion facets. The smaller stones make fine calibrated goods.

RIO GRANDE DO SUL

Rio Grande do Sul, the southernmost state of Brazil, borders on Uruguay and Argentina. In fact, the Uruguayan amethyst deposits are continuous with these of Rio Grande do Sul. Within the Paraná basin, in the northern part of the state, is the longest continuously producing amethyst-mining region in Brazil. Paved roads are available from Porto Alegre to the mining areas. Amethyst is found in numerous places in the state, but these many occurrences are of similar geologic setting. In the following descriptions details will be given on two typical occurrences: Santa Maria (160 km west of Porto Alegre) and Iraí (375 km northwest of Porto Alegre).

Geology and Occurrence. About 130 million years ago, this region experienced extensive volcanic activity, which produced massive lava flows that are horizontal for the most part but do follow the topography (A. A. Muller, pers. comm., 1987). In some of these flows, now hardened to a black, fine-grained basalt, amethyst is found. The most productive basalt layer, 2 to 5 m thick, is located at an elevation of 300 to 350 m above sea level.

Amethyst occurs as crystals in geodes in the basalt (figure 10). The geodes probably represent pockets of gas that was released from, and trapped in, the lava as it cooled. They are distributed randomly within the host rock, commonly in the shape of elongate, rounded tubes. Typically these geodes are less than 1 m in diameter, but geodes exceeding 3 m have been found.

Almost invariably, the geodes exhibit an outer "skin" of celadonite, a green, micaceous, iron-silicate mineral; inside this is a layer of colorless quartz or agate. Amethyst is found clustered in the center of some geodes in crystals up to 10 cm long; other geodes are filled entirely with agate.

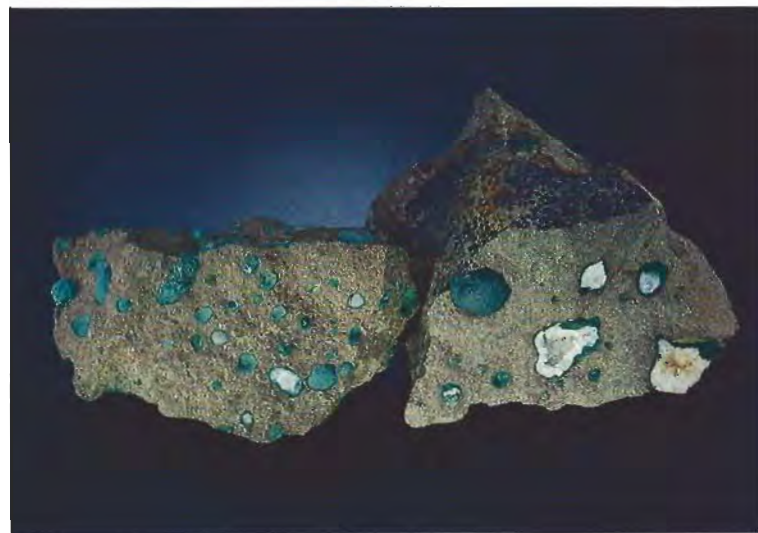
Miners at Rio Grande do Sul also use the presence of celadonite as an indicator of amethyst. Since celadonite is an iron-rich mineral, and the amethyst color requires iron, one expects to see amethyst in iron-rich zones. Nodules of solid celadonite 2–8 mm in diameter often precede small, 0.5–1.5 cm, geodes of crystalline quartz with celadonite rims and reddish (presumably



Figure 10. In Rio Grande do Sul, the amethyst occurs in vugs or geodes within basalt. As evident here, sometimes the amethyst completely fills the cavity; other times it simply lines the inner surface.

iron-rich) bands around the geode (figure 11). As the miners continue in the direction in which the quartz geodes occurred, the first indication of an amethyst geode is a rounded, green, celadonite-

Figure 11. At Rio Grande do Sul, small (2–8 mm in diameter) celadonite nodules often precede 0.5–1.5 cm geodes of crystalline quartz with celadonite rims. These small quartz geodes commonly lead miners to the larger, amethyst-filled geodes for which this locality is known. Photo by Robert Weldon.



coated knob of rock sticking out of the gray-black basalt. Those geodes that contain the thickest celadonite layers have been found to be richer in amethyst (A. A. Muller and H. M. Santos, pers. comm., 1987).

History. In about 1820, immigrants from the Hunsrück region near Idar-Oberstein, in what is now West Germany, arrived in Rio Grande do Sul and settled the area between the Taquari and Jacuí Rivers. When occurrences of amethyst and agate were found shortly thereafter, about 1825, these immigrants recognized the economic potential and began shipping the rough material to Idar-Oberstein (Gonçalves, 1949; V. R. Sudback and B. Munsteiner, pers. comm., 1987). Descendants of these early immigrants are the current landholders in this area of Rio Grande do Sul. Although some of the original landholdings were quite large, subdivision among family members over several generations has resulted in the current situation whereby most private parcels are less than 50 acres.

Figure 12. Before cutting-quality amethyst is sold on the open market, pale-colored or fractured sections are usually broken off with a small hammer in a procedure called "cobbing."



Although mine ownership in Rio Grande do Sul is similar to that in other areas of Brazil, there are some important differences. With the tacit approval of the government, small landowners usually retain the mineral rights without filing the necessary documents. Some families work the diggings themselves, and rent a bulldozer or jackhammer as necessary. More commonly, a landowner will arrange with a second party, often a gem merchant, to underwrite the costs of exploration and mining. The landowner usually receives 25% or more of the production profits, a higher percentage than in other parts of Brazil because the land is more valuable for cultivation. Often, the second party will buy out the original landowner to retain all of the profits.

Mining Methods. Amethyst mining in Rio Grande do Sul may be carried out with simple hand tools, or with heavy equipment and explosives. Open-pit mining is most common, although other methods are also used.

In 1969, a local miner at Iraí, Alberto Lemos de Moraes, decided to try recovering amethyst by underground mining of those portions of the massive basalt that were not broken by fractures and were still unweathered; here is where the greatest number of intact amethyst-lined cavities are encountered (A. Lemos de Moraes, pers. comm., 1987; again, see figure 10). Lemos de Moraes used explosives and power tools to remove the dense rock, eventually extending the tunnel to 60 m. Hand tools are used to chisel the amethyst geodes, intact if possible, out of the basalt. Because the basalt is so hard, removal of a large, intact amethyst geode may take as long as a week.

At some of the mines, the amethyst crystals are often sold before they are even removed from the ground. Once a geode is located, a small hole is punctured in the surface and a light is lowered into it. The potential buyer then attempts to assess the quality and value of the amethyst crystals, and a price is negotiated. The geode is then chiseled from the host rock in as intact a condition as possible, which gives the buyer the option of selling it as a mineral specimen or cobbing the individual crystals for cutting rough.

Cobbing of amethyst crystals to remove unwanted material is usually done off the mine site. The person doing the cobbing sits at a bench under a strong incandescent light, holds the crystal on a metal plate, and then strikes it with a small



Figure 13. Amethyst from Rio Grande do Sul is often of excellent color, though a bluish rather than reddish purple. Because the amethyst commonly occurs in vugs or geodes, it is also popular as mineral specimens. This radiated amethyst slab, with an agate center, is from Iraí. Photo © Harold & Erica Van Pelt.

hammer to break off fractured, poor-colored, or included sections (figure 12).

Production. In 1986, official government statistics indicate, 4,152 kg of cobbled amethyst, 14,752 kg of cobbled citrine (produced by heat treating amethyst), and 155,560 kg of mineral specimen material were exported from Rio Grande do Sul (A. A. Muller, pers. comm., 1987). Indeed, most of the amethyst specimens on the market today come from Rio Grande do Sul. The vast majority of the cobbled amethyst exported is shipped to Idar-Oberstein for cutting.

Faceted amethyst from this area can reach a tone 7 value (again, see figure 5) in stones of about 10 ct, and a tone 5 or 6 value in stones of 1–9 ct. Faceted amethysts from Rio Grande do Sul average 3–7 ct; that is, they are smaller than the average stones from Marabá but a bit larger than those from Pau d'Arco. The Rio Grande do Sul amethyst is often bluish rather than reddish (figure 13),

which may distinguish it from amethyst found in other areas. The color rarely has any brownish tinge, but it can be slightly grayish.

Santa Maria. One of the most interesting mining areas within Rio Grande do Sul is near Santa Maria, the state capital. Located in the center of Rio Grande do Sul, Santa Maria is a well-ordered town of some 200,000 inhabitants that is easily accessible by various modes of transportation.

In the early 1930s, German gem dealers visited this region looking for amethyst. They were surprised to find crystals scattered on the ground in several places. After negotiating agreements with local landowners, they began to mine using picks and shovels. Recovery of amethyst in this area has continued up to the present day (S. Klein and J. C. Moto, pers. comm., 1987).

We visited the mine of Siegfried Klein, about 20 km outside of Santa Maria, which had been worked for amethyst intermittently since the



Figure 14. At Iraí in Rio Grande do Sul, a tractor is used to remove much of the hill in which the amethyst-bearing basalt layer is found, 30 m below the original surface.

arrival of the German merchants over 50 years ago. One pit that four miners had recently opened with simple picks had yielded thousands of loose crystal sections of amethyst geodes. In fact, during the first week that this deposit was in production, about 1,000 kg of amethyst were recovered, of which about 200 kg were specimen or cobbing quality; these 200 kg might yield 5 to 10 kg after being cobbled. It was an unusually large find for the first week's production.

Amethyst Mining at Iraí. The town of Iraí is situated in the extreme northern part of Rio Grande do Sul, near the border with the state of Santa Catarina. The topography consists of gently rolling hills and the climate is quite mild, making this one of the loveliest regions in southern Brazil.

Amethyst was first found here in the 1920s.

Revolutionaries fleeing from the Brazilian army hid along the banks of the Rio Uruguai. While foraging, they came across occurrences of amethyst near the future site of the town of Iraí. At present, this area produces approximately 200 to 250 kg of cobbled amethyst and 700 to 800 kg of cobbled citrine (i.e., heat-treated amethyst) per month (V. R. Sudback and A. Bortoluzzi, pers. comm., 1987).

I visited the Bortoluzzi-Fischer mines on a small hill near the outskirts of Iraí. Mines in Rio Grande do Sul are often named in this fashion for both the mine owner and the landowner. Unlike the relatively simple mining observed at Iraí, here 20 miners use highly sophisticated open-pit methods to recover the amethyst from a layer of basalt that lies 30 m below the present surface (figure 14). These men had worked, with a bull-

dozer, for an entire year to remove the hundreds of tons of dirt that covered the productive layer. At the basalt level, jackhammers, some explosives, and hand tools were used to locate and remove the amethyst-lined geodes. Some of these geodes weighed up to 100 kg, but many of the crystals were very dark.

Most of the other mines in this area consist of underground tunnels that are excavated into the hillsides surrounding the town of Iraí, to reach the productive layer of basalt. The tunnels average about 2 m in height and may be up to 5 m wide. The miners use explosives and hand tools to dig through the hardened lava. The longest tunnel I observed was about 60 m.

CITRINE PRODUCED BY HEAT TREATING AMETHYST

Citrine rarely occurs naturally, although some has been reported in Brazil (Sauer, 1982; Webster, 1983). Essentially all the citrine on the market today is created by heat treating amethyst (Webster, 1983; figure 15), particularly because lighter colored amethyst frequently becomes a more desirable color as citrine. Several treatment methods are used. At Marabá, amethyst is embedded in sand in wheelbarrows and then heated over wood fires to turn the stones yellow (figure 16). Samples are extracted at various intervals to monitor the degree of change in color. In the course of my



Figure 15. Virtually all of the citrine sold in the gem market today is created by heat treating amethyst. This approximately 15 × 20 mm citrine is actually Marabá amethyst that has been heated. Photo © Tino Hammid.



Figure 16. The heat treatment of amethyst to produce citrine at Marabá is simple but dramatic. The amethyst crystals are buried in sand in wheelbarrows and then heated over a wood fire.

travels, I noted that the temperature for a complete color alteration could vary from as low as 235°C to as high as 550°C, depending on the origin of the amethyst. When choosing amethyst for heat treatment, miners look for the presence of one or more bands of color with a rusty appearance that seems to indicate a high iron content. If the stone is going to turn yellow, it will do so before reaching 550°C.

In Rio Grande do Sul, the stones are placed in airtight ovens, sometimes embedded in a firmly packed powder or sand, and heated at approximately 450°–550°C for 45 minutes to two hours. The oven is then allowed to cool to room temperature (several hours) before the stones are removed. Citrine produced by heating amethyst from this area is often given the misnomer Rio Grande do Sul "topaz," especially in Brazil. The darkest material may display a strong brownish red color and approach the color of some garnets. When heat treating amethyst from Rio Grande do Sul, the miners look for particular features (e.g., a grayish band) that they know from experience will produce the best citrine color. More than 15 tons of cobbled citrine was shipped from this state in 1986.

Miners at Iraí reported that finding natural citrine is a once-in-a-lifetime occurrence. Like the amethyst from Rio Grande do Sul, the citrine occurs in geodes; sometimes several citrine geodes may be found in a particular section of the basalt. The miners theorize that these sections have been "heated" in the earth. Government geologists re-

ported a recent find of natural citrine in the neighboring state of Santa Catarina.

Simple heating experiments with Pau d'Arco amethyst revealed that heating this material only lightens the color and may remove it altogether. Changes in color due to treatment are directly related to the chemical and physical properties of the individual piece of rough (Nassau, 1984). Within the same mine, however, pieces of rough with similar visible characteristics will usually react the same to treatment.

CONCLUSION

Several other localities in Brazil also actively produce amethyst. These include the states of Rio de Janeiro, Minas Gerais, Pernambuco, Ceará, Piauí, and Goiás (Cassedanne, 1988b). A number of workings can be found in Bahia.

The three Brazilian localities discussed in this article are among the three most active amethyst mining operations in the world today. Most of the Brazilian amethyst currently seen in the market is from these occurrences, with literally thousands of kilograms of specimen and faceting-quality amethyst produced annually. Significant amounts of this material are also heat treated to produce citrine.

Although formal estimates of amethyst reserves in Brazil are not currently available, it appears that significant quantities will be available for many years to come.

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