Boletín de la Sociedad Geológica Mexicana
Volumen 62, núm. 1, 2010, p. 123-140

The gemstone deposits of Brazil: occurrences, production and economic impact

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Abstract

This article gathers together data on the occurrence, production and economic importance of gem deposits in Brazil, including specific information on the major deposits. Of the 100 or so different types of gemstones found in the country, the most important in terms of production and/or originality are tourmalines, topaz, opals, varieties of quartz (agate, amethyst and citrine) and emeralds. Brazil is also one of the only producers in the world of imperial topaz and Paraíba tourmaline. The country also produces diamonds, rubies and sapphires on a smaller scale. Gem production in Brazil is, for the most part, carried out by prospectors and a handful of mining companies, reducing the capacity of the government to control the production and sale of gemstones. Another factor that tends to drive the industry to operate outside the law is the high tax burden, which is as high as 53% on the sale of jewelry and 25% on uncut or polished stones. Owing to the geographical distribution of gemstone deposits and the enormous size of the country, Brazil is divided into four gem-producing areas. In the Northeast there are primarily deposits of emerald, amethyst, citrine, hyaline quartz, elbaite, aquamarine, garnet, morganite and opal. The Central region is characterized primarily by emerald and diamond deposits, whereas in the South deposits and occurrences of amethyst, citrine, agate and diamond are found. The East is characterized mainly by the presence of gemstones associated with pegmatites and hydrothermal veins, Plio-Pleistocene sedimentary placer deposits and isolated concentrations of diamonds. Gem production in Brazil mainly occurs in the states of Minas Gerais, Bahia, Rio Grande do Sul, Mato Grosso and Goiás. The State of Minas Gerais is the largest producer and exporter of gemstones in the country and is responsible for 74% of the official production, which includes imperial topaz, beryl, tourmaline, spondumene and brazilianite. The State of Bahia produces mainly emeralds, amethyst and aquamarines and is the second largest producer of uncut colored stones after the State of Grande do Sul, which is one of the most important producers in the world of two of these: namely agate and amethyst. The State of Mato Grosso produces garnet, topaz, zircon, diopside, varieties of quartz and tourmaline on a smaller scale. The State of Goiás mainly produces emeralds, along with garnet, topaz, quartz (citrine and amethyst) and tourmalines. Natural diamond production is also significant in Goiás and Mato Grosso, where diamonds have been being unearthed by prospectors since the beginning of the 20th century. At present, the best prospects for diamond production in these states are to be found in kimberlites. Of the wide diversity of gems produced, some, such as the Paraíba tourmalines and the opal from Piauí, are renowned around the world for their originality and gemological properties.

Keywords: gemstones, gemological province, Brazil.

Resumen

El presente artículo reúne datos de localización, producción e importancia económica de los yacimientos de piedras preciosas en Brasil, así como información específica para los yacimientos de mayor relevancia económica. Entre los aproximadamente 100 diferentes tipos de gemas que se encuentran en el país, las más importantes en cuanto a producción y/u originalidad, son turmalina, *topacio, ópalos, las diversas variedades de cuarzo (ágata, amatista y citrino) y esmeralda. Además, Brasil es uno de los productores en el mundo de topacio imperial y turmalina Paraíba y produce diamante, rubí y zafiro a pequeña escala. La producción brasileña de piedras preciosas se realiza generalmente por mineros independientes y por unas pocas empresas mineras, por lo que el Estado ejerce un escaso control oficial efectivo sobre la producción y comercialización de gemas. Otro factor que contribuye a esta informalidad es la elevada carga fiscal en el medio, que alcanzó el 53% del valor de las ventas de joyería y el 25% de las ventas de piedras preciosas naturales o lapidadas. Debido a la extensa distribución geográfica de los depósitos de gemas en Brasil, por el gran tamaño del país, éste está dividido en cuatro sub-provincias gemológicas. En la provincia del Nordeste destacan los depósitos de esmeralda, amatista, citrino, cuarzo hialino, elbaíta, aguamarina, granates, morganita y ópalo. La provincia Central se caracteriza principalmente por la ocurrencia de esmeraldas y diamantes, mientras que en la del Sur predominan los depósitos y las ocurrencias de amatista, citrino, ágata y diamantes. La provincia del Este, por su parte, se caracteriza principalmente por sus mineralizaciones en pegmatitas y vetas hidrotermales y por depósitos sedimentarios del Plio-Pleistoceno de placeres de diamante. La producción de piedras preciosas en Brasil se concentra en los estados de Minas Gerais, Bahía, Río Grande do Sul, Mato Grosso y Goiás. Minas Gerais es el mayor productor y exportador de piedras preciosas en el país, lo que representa 74% de la producción oficial, incluyendo topacio imperial, berilo, turmalina, espodumena y brasilianita. El estado de Baía produce principalmente esmeralda, amatista y aguamarina, siendo considerado el segundo mayor productor de gemas brutas tras el estado del Río Grande do Sul, uno de los más importantes productores mundiales de ágata y amatista. El Estado de Mato Grosso produce, a pequeña escala, granate, topacio, zircón, diópsido y variedades de cuarzo y turmalina. En Goiás destaca la producción de esmeraldas y de granate, topacio, cuarzo (amatista y citrino) y turmalina. En cuanto a los diamantes en bruto también merecen mención los yacimientos de Goiás y Mato Grosso, que son producidos desde principios del siglo XX por mineros independientes. Hoy en día, las mejores perspectivas para la producción de diamantes en esos estados provienen de kimberlitas. Entre la variedad de gemas producidas en Brasil, por su originalidad y propiedades gemológicas, destacan en el mundo la turmalina Paraíba y el ópalo del Piauí..*

Palabras clave: gemas, provincia gemológica, Brasil.

1. Introduction

According to the Anuário Comércio Exterior [Foreign Trade Annual] (2006), in 2005, Brazil was first in the world ranking for the type and quantity of gems produced, with tourmaline, topaz and quartz (agate, amethyst and citrine) being worthy of special note, and was the second largest exporter of emeralds. Brazil is one of the few producers of imperial topaz and Paraíba tourmaline and also produces diamonds, rubies and sapphires on a smaller scale.

The Instituto Brasileiro de Gemas e Metais Preciosos [Brazilian Institute of Gems and Precious Metals] (IBGM, 2005a) estimates that, in 2005, Brazil was responsible for producing 1/3 of the total volume of gems in the world, excepting diamonds, rubies and sapphires, which have a low level of production in the country.

Brazil extracts around 100 different types of gems and production is carried out by thousands of prospectors and a few mining companies. This means that there is limited government control over the production of and trade in gemstones.

The official figure for gemstone production in Brazil in 2005 was, according to the Departamento Nacional de Produção Mineral [National Department of Mineral Production] (DNPM, 2006), only US$47 million (Table 1), US$36 million in diamonds and US$11 million in other gems, while the official figures for exports are as high as US$135 million (Table 2). On the other hand, exports of gems in 2005, according to the Foreign Trade Annual (2006), amounted to US$168 million or, according to the IBGM (2005a), US$129.9 million. It can be seen therefore that official exports of gems in 2005 were at least 2.7 times higher than the official figure for production, showing that it is practically impossible to calculate the true level of production of gems in Brazil, given the high degree of informality and smuggling in this sector. This informality is the result of the heavy tax burden that falls on the sale of gems and jewels on the domestic market. In 2004, for example (IBGM, 2005a), Brazil had the highest level of taxation world-wide for this industry, standing at 53% (on the value of production), more than three times higher than

Table 1. Brazilian production of colored gems and diamonds in the year 2005, in US dollars.

State	Colored Gems Uncut	Colored Gems Processed	Diamonds Processed	Total	Total (%)
Minas Gerais	467,165	6,449,607	28,066,408	34,983,181	73.8
Mato Grosso			4,444,940	4,444,940	9.4
Rio Grande do Sul	3,025,816			3,025,816	6.4
Góias		275,851	2,311,642	2,587,493	5.5
Bahia	942,460			942,460	2
Others	35,979	247,955	1,136,354	1,420,288	3
TOTAL	4,471,421	6,973,413	35,959,344	47,404,178	100

Source: DNPM (2006) - Anuário Mineral Brasileiro [Brazilian Mining Annual]. 1 US dollar = 2.40 Brazilian reais.

Table 2. Brazilian exports of gems in 2005, in US dollars.

Uncut colored gems	42,380,000
Processed colored gems	73,279,000
Uncut and processed diamonds	19,052,767
TOTAL	134,711,767

Source: DNPM (2006) - Anuário Mineral Brasileiro [Brazilian Mining Annual]. 1 US dollar = 2.40 Brazilian reais.

the world average, which is estimated at 15%. It should be pointed out that the tax burden in Brazil is in general much higher than that of other countries, such as Italy (20%), Spain (16%) and the United States (7%).

According to the Agência Brasileira de Promoção de Exportação e Investimentos [Brazilian Agency for Promotion of Exports and Investment] (IBGM-APEX BRASIL, 2006a, 2006b, 2006c), the current tax burden continues to be 53% on the sale value for the jewelry trade and approximately 25% for sales of uncut or polished gems in all parts of the country. The tax payable on exports of Brazilian gems and jewels, however, ranges from 7 to 10%.

Gem production in Brazil is widely spread across the country (Figure 1), but is especially heavily concentrated in the states of Minas Gerais, Mato Grosso, Goiás, Rio Grande do Sul and Bahia (Table 1). These five states account for 97% of the official production of gems (DNPM, 2006). The IBGM (2005a) estimates that, in 2004, around 80% of the gems went for export.

In 2005, the main destinations for exports of gems (DNPM, 2006), in terms of monetary value, were the United States (25.8%), Hong Kong (16.4%), Germany (9.3%), Taiwan (8.9%), India (7.1 %), China (5.9%), Japan (4.9%) and Thailand (4.5%), while official exports of rough diamonds amounted to 280,000 carats, generating a revenue of US$19 million (DNPM, 2007).

The chain of production for gems in Brazil ranges from the extraction process (carried out by prospectors and mining companies), industrialization (cutting and polishing, jewelers, trinkets and stone handicrafts), trade, and export. In 2006, this chain of production involved around 1,500 companies, of which 93% were small or very small businesses, and which supplied 350,000 direct jobs, 120,000 in the prospecting and the mining industry, 40,000 in the industrial production of jewels and related products, and 190,000 in trade and retail sales (IBGM 2005a).

In 2005, the Brazilian government's Ministry for the Development of Industry and Foreign Trade and the Ministry of Energy and Mines set up the Competitivity Forum for the Chain of Production of Gems, Jewels and Related Products, which identified the Local Productive Arrangements for Gems [APL Gems], for the purpose of providing support and managing small-scale mining operations, industrial production and trade.

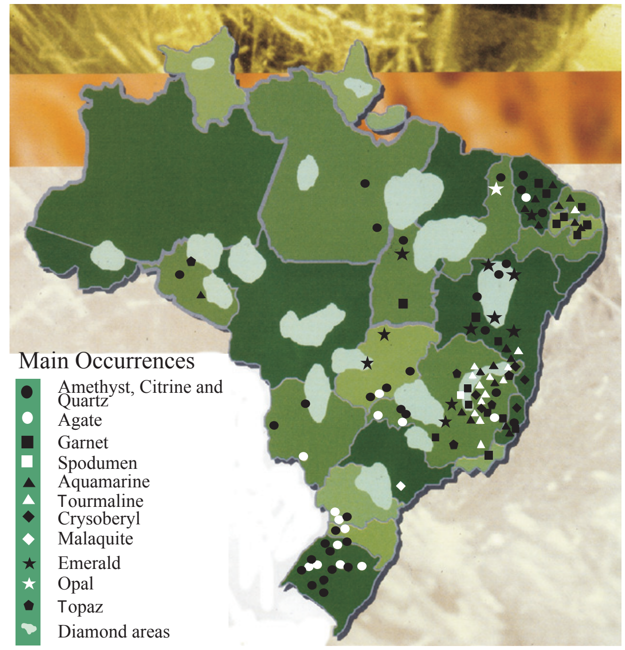

Figure 1. Gemological map of Brazil showing the main occurrences of colored gems and diamonds (IBGM, 2005b).

2. The occurrence of gems in Brazil

The geographical distribution of the occurrence of gems in Brazil, combined with the vast extent of the country's territory, enables us to categorize Brazil as a large gemological province. Limaverde (1980) has divided this province into four sub-provinces (Figure 2):

- The Northeast Sub-province is further sub-divided into two areas: the southern area, including the mining district of the State of Bahia (for emerald, amethyst, citrine, hyaline quartz, and others) and the northern area, which covers the pegmatite mineralization of the Borborema plateau and of the State of Ceará (for elbaite, aquamarine, garnet and morganite). The northern area also includes the only deposit of opal at Pedro II, in Piauí, encased in sandstones of the Maranhão sedimentary basin.

- The Central Sub-province covers areas in the States of Goiás, Mato Grosso and Pará, and is characterized primarily by occurrences of emeralds and diamonds, but also possesses gems associated with pegmatites and amethyst veins.

- The South Sub-province is subdivided into the southern part, which covers areas in the states of Rio Grande do Sul and Santa Catarina where beds and occurrences of amethyst, citrine and agate are associated with basalt, and the northern part, which occupies part of Mato Grosso do Sul (amethyst), Paraná (diamond) and São Paulo (pegmatite minerals).

- The East Sub-province covers primarily the states of Minas Gerais and Espírito Santo, and a small part of the State of Rio de Janeiro and is characterized mainly by

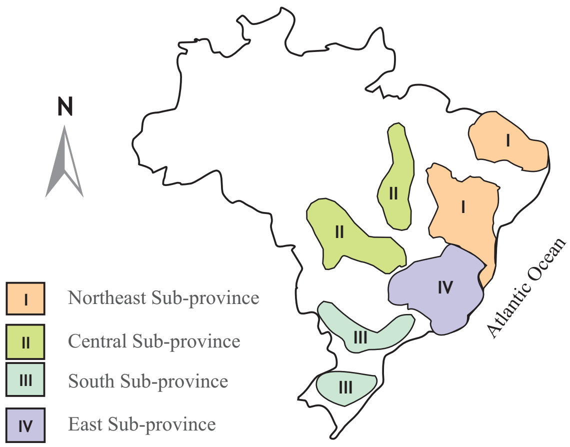

Figure 2. Gemological sub-provinces in Brazil (Limaverde, 1980).

the presence of gems associated with (i) pegmatites and hydrothermal veins, (ii) secondary deposits associated with alluvium, colluvium and Plio-Pleistocene paleo-alluvium and (iii) areas where diamonds are concentrated.

3. The main gem-producing states in Brazil

3.1. Minas Gerais

The State of Minas Gerais is a major producer and exporter of gems in the country, and is responsible for 74% of the official production of colored gems and diamonds (Table 1) and 92% of the exports. In 2000, the state was host to around 100 companies extracting gems, more than 300 cutting and polishing companies, around 200 jewelry businesses, with a network of around 13,000 retail stores and 600 wholesale companies, which as a whole were responsible for generating 150,000 direct jobs (Castañeda *et al*., 2001).

The main gemological districts of Minas Gerais (Figure 3) produce beryl (emerald, aquamarine, heliodor, goshenite and morganite), tourmalines of the schorlite-elbaite series, topaz (blue, colorless and imperial), chrysoberyl (chrysoberyl, cat's eye and alexandrite) and quartz (amethyst, citrine, morion and smoky).

Most of these gems are related, principally, to granitic rocks and associated pegmatites and hydrothermal deposits cutting the quartz sequences. On rare occasions imperial topaz is found in the products, resulting from the alteration of dolomitic rocks of the Itabira and Piracicaba groups, Minas Supergroup, in the Ouro Preto region, Minas Gerais. In this paper we use the term "imperial topaz" to refer the topaz extracted in this region.

Other gems encountered in Minas Gerais are: spodumene (kunzite and hiddenite), garnet, euclase, phenacite, titanite, scapolite, brazilianite, petalite, amblygonite and herderite, in addition to diamonds and low-quality corundum.

3.2. Bahia

The State of Bahia is the second largest producer of *uncut colored gemstones* in Brazil, after Rio Grande do Sul, which is reflected in the production valor of US$942,460 (Table 1).

In this state, Couto (2000) catalogued the presence of 700 occurrences and/or beds of gems (Figure 4), with especially large quantities of amethyst, diamonds, aquamarine and malachite. The main gems produced in Bahia in recent decades are emerald, amethyst and aquamarine, although dumortierite, quartz (pink, citrine and rock crystal), corundum and sodalite, also deserve mention, despite low levels of production and productivity. Other gems from Bahia with significant potential include: alexandrite, amazonite, apatite, chrysoberyl, fluorite, jasper, rutilated quartz, tourmaline and turquoise.

In the 19th century, diamonds were widely mined by prospectors in the Chapa Diamantina region (Lençóis, Andaraí, Palmeiras and Mucugê), along the alluvial plains of the Paraguaçu River basin. These mines were closed down in 1996 as the result of action taken by government bodies to preserve the environment of the Chapada Diamantina National Park. At present, diamond production in Bahia is minimal and of no economic significance (Couto, 2000).

Despite the good level of production of uncut gems, the cutting and polishing and stone handicrafts industry in Bahia is still rudimentary, being concentrated in the city of Salvador and some gem-producing regions, such as Campo Formoso. As a result, most gems produced are exported to other states or overseas. The sale of precious stones and jewels in the state is also concentrated in Salvador, where there are around 350 points of sale (IBGM, 2005a).

Couto (2000) grouped the gem deposits of Bahia into three categories: 1) secondary deposits from the Cenozoic era, where the gems (aquamarine, amethyst, corundum, diamond, emerald, malachite, pink quartz and turquoise) are concentrated in alluvium, paleo-alluvium, colluvium and eluvium; (2) deposits from the Archean eon, represented principally by beds of corundum, associated with regional metamorphism over clayey aluminous sediments, generating mineralized schist; and (3) beds associated with pegmatites and hydrothermal veins of quartz from the Proterozoic era, mainly consisting of aquamarine, but also containing chrysoberyl, topaz, morganite, andalusite, zircon, quartz, amazonite, fluorite and tourmaline.

3.3. Rio Grande do Sul

The State of Rio Grande do Sul is the largest producer of uncut colored stones in Brazil and one of the most important producers in the world for two of these: agate and amethyst. It also exports citrine, which results from heating of amethyst caused by the oxidation of iron and consequent

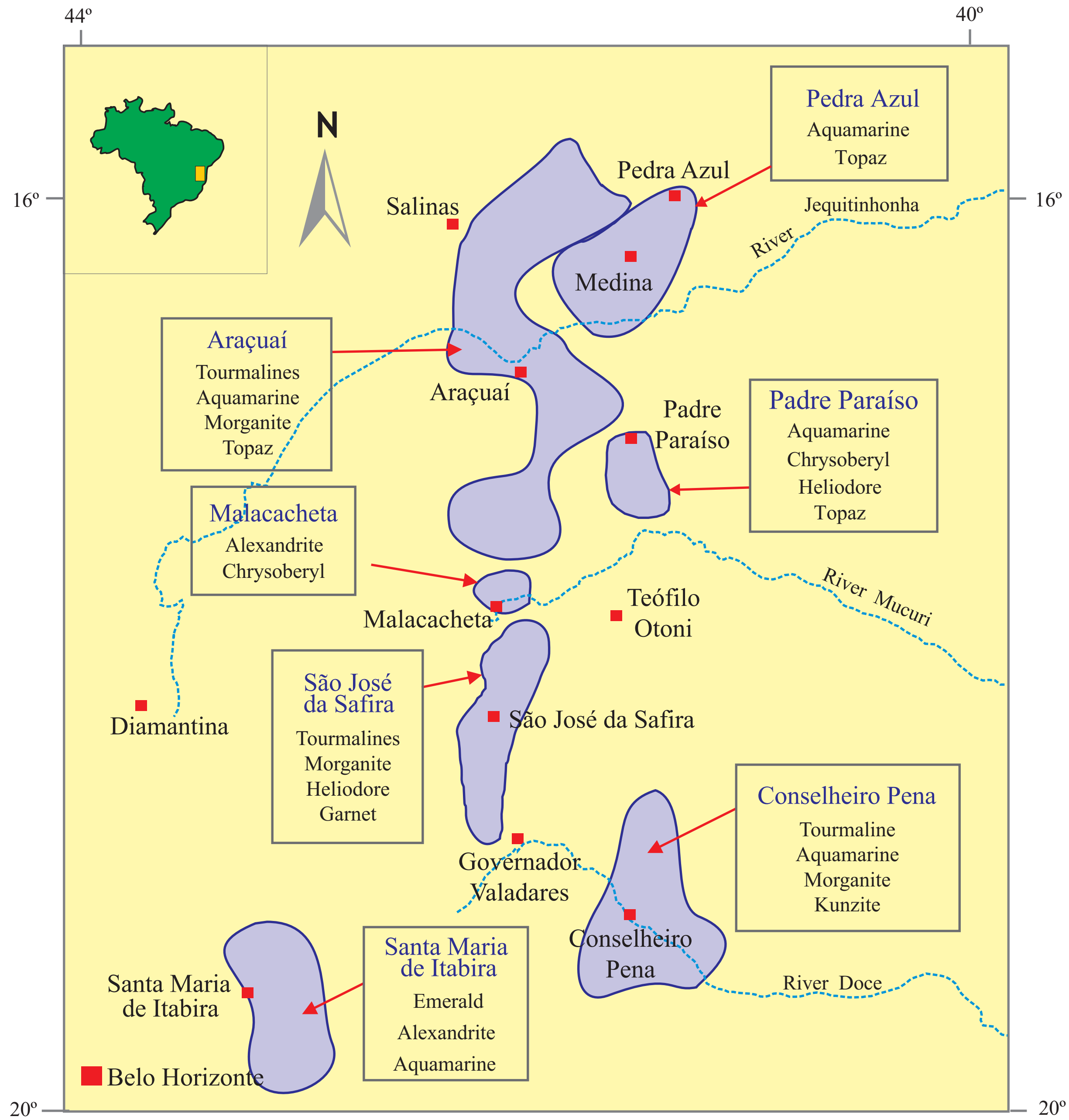

Figure 3. Main gemological districts in Minas Gerais (Castañeda *et al*, 2001).

change in color.

The map of gemstone deposits in Rio Grande do Sul (Branco and Gil, 2002a) registers 329 gem deposits, ranging from mere indications to actively operating mines and prospection sites, and 32 beds that produce minerals for collection (Figure 5).

Agate and amethyst account for more than 95% of the total value of gem production in Rio Grande do Sul. On a smaller scale, there is also production of rock crystal, citrine, fossilized wood, chalcedony, serpentinite and jasper. Minerals for collection, apart from amethyst, agate and rock crystal, include calcite in geodes, some of which are as large as 120 kg, selenite and minerals from the zeolite groups (heulandite, scolecite and stilbite) (Branco and Gil, 2002a).

The main areas for exploitation of agate and amethyst are to be found in Cretaceous rocks and are associated with the extensive basaltic ridges of the Paraná River basin. These gems generally occur in oval-shaped geodes of varying sizes within altered basalt. There are also reports of druses and geodes of up to 3,000 kg in weight and 3 m in length, with pieces weighing from 200 to 300 kg frequently found (Branco and Gil, 2002b). Concentrations of geodes can also

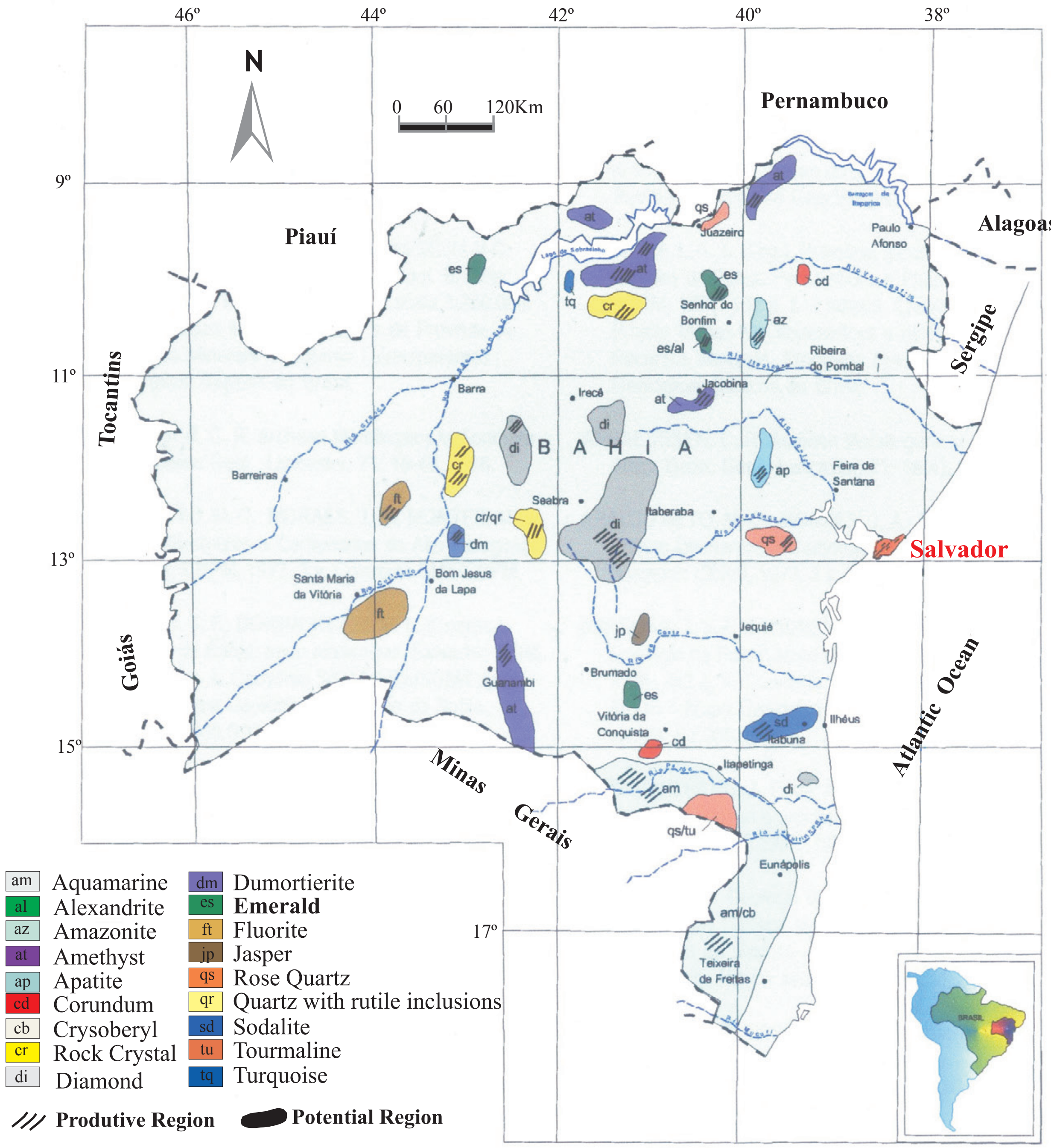

Figure 4. Gemological map of Bahia, showing producers/potential producers of gems (Couto, 2000).

be found in Cenozoic alluvium and eluvium resulting from the break up of basalt.

The map of gemstone deposits of the State of Rio Grande do Sul contains three clusters of gem production (Figure 5). (1) The first, situated on the border between Rio Grande do Sul and Santa Catarina, contains the largest beds of amethyst (Lamachia, 2006) and is located in the Alto Uruguai region, with 350 prospection sites, mostly in the municipalities of Ametista do Sul, Planalto, Iraí and Frederico Westphalen. This cluster is the largest producer of amethyst in the world. (2) The second, in the central region of the state, around the municipality of Salto do Jacuí, is responsible for 80 to 90% of the state's agate production. In this municipality, on the banks of the Jacuí River, the largest beds of highest quality agate in the world are to be found (Lamachia, 2006). (3) The third cluster, located on the border between Rio Grande do Sul and Uruguay around the municipality of Quaraí, is made up of numerous occurrences of amethyst and agate,

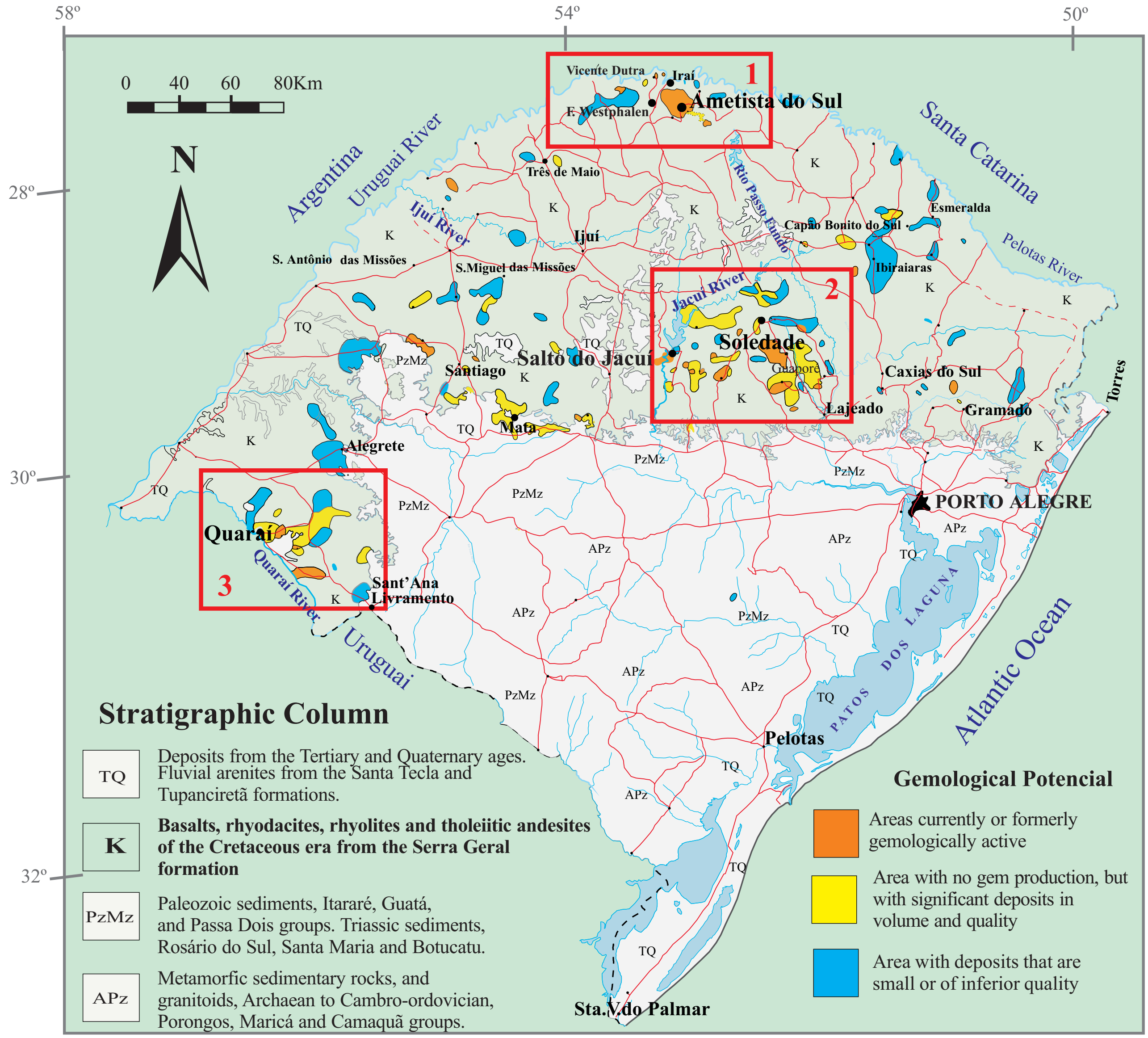

Figure 5. Gemological map of the State of Rio Grande do Sul (Branco and Gil, 2002a).

although production is relatively low in comparison with the other clusters.

According to the IBGM (2005a), Rio Grande do Sul has a group of cutting and polishing and jewelry industries, which in 2004 included more than 600 small firms that were responsible for 20% of Brazilian exports of gems and jewels, and worth US$47 million.

The municipality of Soledade is the main center for the gem trade in the State of Rio Grande do Sul and it is in this region that the University of Passo Fundo and the National Vocational Training Service (SENAI) provide technical support for small businesses in the sector. Two other important cutting and polishing centers are to be found in Lajeado, where there are 250 small businesses, and in Guaporé, with 120 small and medium-sized businesses processing mainly agate and amethyst.

3.4. Goiás and Mato Grosso

The State of Mato Grosso produces, on a small scale, garnet, zircon, diopside, quartz (amethyst, rock crystal, morion, pink and agate) and tourmaline.

The principal gem in the state is the emerald, with occurrences located in the northern region, near the municipality of Campos Verdes, which is also a small-scale producer of garnet, topaz, quartz (citrine and amethyst) and tourmaline.

The emerald deposit in Campos Verdes, located on the “Prospection Reserve of Santa Terezinha de Goiás”, was discovered in 1981 and had officially produced 534.11 tons of emeralds by the year 2000 (AGIM, 2002). The peak of production occurred in 1988, when 24.79 tons of uncut stones were extracted and sold for US$9 million. Since then, the quality of the emeralds has declined significantly. In 2000, despite prospectors extracting 25 tons of emeralds, the gross production value was only US$898,000.

The Campos Verdes emeralds are concentrated in talc schists and biotite schists, encased in carbonate-chlorite-quartz schists, which constitute a sequence of basic Precambrian metavolcanic rocks affected by greenschist facies metamorphism and by a subsequent process of hydrothermal alteration that enabled the formation of veins and seams of quartz and pegmatites, mineralized in beryls and emeralds (Biondi, 1990).

Diamonds are also worth mentioning in connection with the states of Goiás and Mato Grosso. Rough diamond production in these two states began in the early 20th century. In Goiás, it developed primarily through the work of prospecting on the alluvium of the Parnaíba River. In Mato Grosso, the main production area is to be found in the prospection sites located in the municipality of Poxoréu. It would seem that the main diamond reserves in the region are located on the Roosevelt Reserve for Indigenous People, lying between the states of Mato Grosso and Rondônia, where mining activity is prohibited by the Brazilian government (IBGM-APEX BRASIL, 2006b).

At present, the best prospects for diamond production in Goiás and Mato Grosso involve kimberlites. The Diagen International Resource Corporation is mining an altered kimberlite in Juína (NW Mato Grosso). Hundreds of potentially mineralized kimberlitic bodies have already been discovered in Mato Grosso, Minas Gerais and Rondônia

Compared with the rest of Brazil, Goiás and Mato Grosso are only statistically significant for diamond production (Table 1). According to the DNPM (2006), in 2005, the official value of processed diamond production was US$4.4 million in Mato Grosso and approximately US$2.5 million in Goiás. However, the true level of production in these states cannot reliably be calculated and some specialists claim that 98% of diamonds produced leave the country illegally and do not therefore appear in the DMPM's official records.

4. Case studies

Brazil produces a wide diversity of gemstones. Some of these are notable for their uniqueness, their history or the volume of production, even by international standards. Among the stones that are notable for their uniqueness, the imperial topaz of Minas Gerais/Ouro Preto and Paraíba tourmaline are the most important, along with the opal from Pedro II, in Piauí State. Historically, the gemstones with the highest economic value in Brazil are undoubtedly diamonds, since the country was one of the largest producers in the world for almost 150 years, up to 1866. At present, the Brazilian diamond industry is of little significance compared with production worldwide. In 2006, Brazilian diamonds represented, according to the DNPM (2007), 0.11%, 0.003% and 0.02%, respectively, of world production, importation and exportation of this gemstone. The Brazilian colored gemstones that are most worthy of note internationally, owing to their quality and the volume of production, include emerald, aquamarine, amethyst and agate.

It is impossible in this article to provide full details of more than a few of these gemstones, which are described below.

4.1. The imperial topaz of Minas Gerais

The main occurrences of Minas Gerais imperial topaz are to be found in a 200 km^2 area around the city of Ouro Preto (Figure 6), where two mining companies are responsible for almost all production of this gemstone: Mineração Vermelhão, which works the Saramenha mine, and Topázio Imperial Mineração, Comércio e Indústria Ltda., which is working on the Capão do Lana mine. Other deposits are being worked by prospectors, but production is on a very small scale.

In primary beds, imperial topaz occurs principally in centimeter-thick, strongly weathered, discontinuous channeled veins encased in heavily decomposed carbonate rocks (carbonatic phyllites, dolomites and impure marbles), dark-brown in color and clayey textured, in the Precambrian Minas Supergroup. As host rocks and veins with topaz mineralization are heavily decomposed, mining is open-cast and, in the principal mines, is carried out using hydraulic extraction, followed by collection of the extracted material with the aid of a dragline-type excavators, washing, sieving, jigging and, finally, the crystals are picked out by hand from a conveyor belt. In prospection areas, the altered material is extracted by hand and the mineral recovered is sieved and carefully washed, and the imperial topaz picked out manually (Figure 7a and 7b).

At the Capão do Lana mine, around 400 m^3 of altered material is extracted per working day, using two draglines. For every 100 m^3 of this clayey material, there is 1 m^3 of unaltered rock and free minerals, from which 1 kg of topaz is extracted. Of all the topaz processed, only around 1% (10 g) are gemstones (Gandini, 1994).

Topaz generally occurs in the form prismatic crystals, biterminated examples being rare. Normally, these crystals appear clumped together and fragmented, with a predominance of idiomorphic forms made up of two vertical rhombic prisms terminating in a rhombic bi-pyramid. Sizes vary from a few millimeters to around 20 cm, with most being from 1 to 4 cm. The color, which is one of the more noteworthy features of this gem, varies from golden-yellow to cognac-red, with varying intermediate hues between these two types. Chemical analysis of colored topazes using electronic microprobe suggest that Cr^{3+}, V^{3+} and Fe^{3+} are probably the chromophores for this kind of mineral

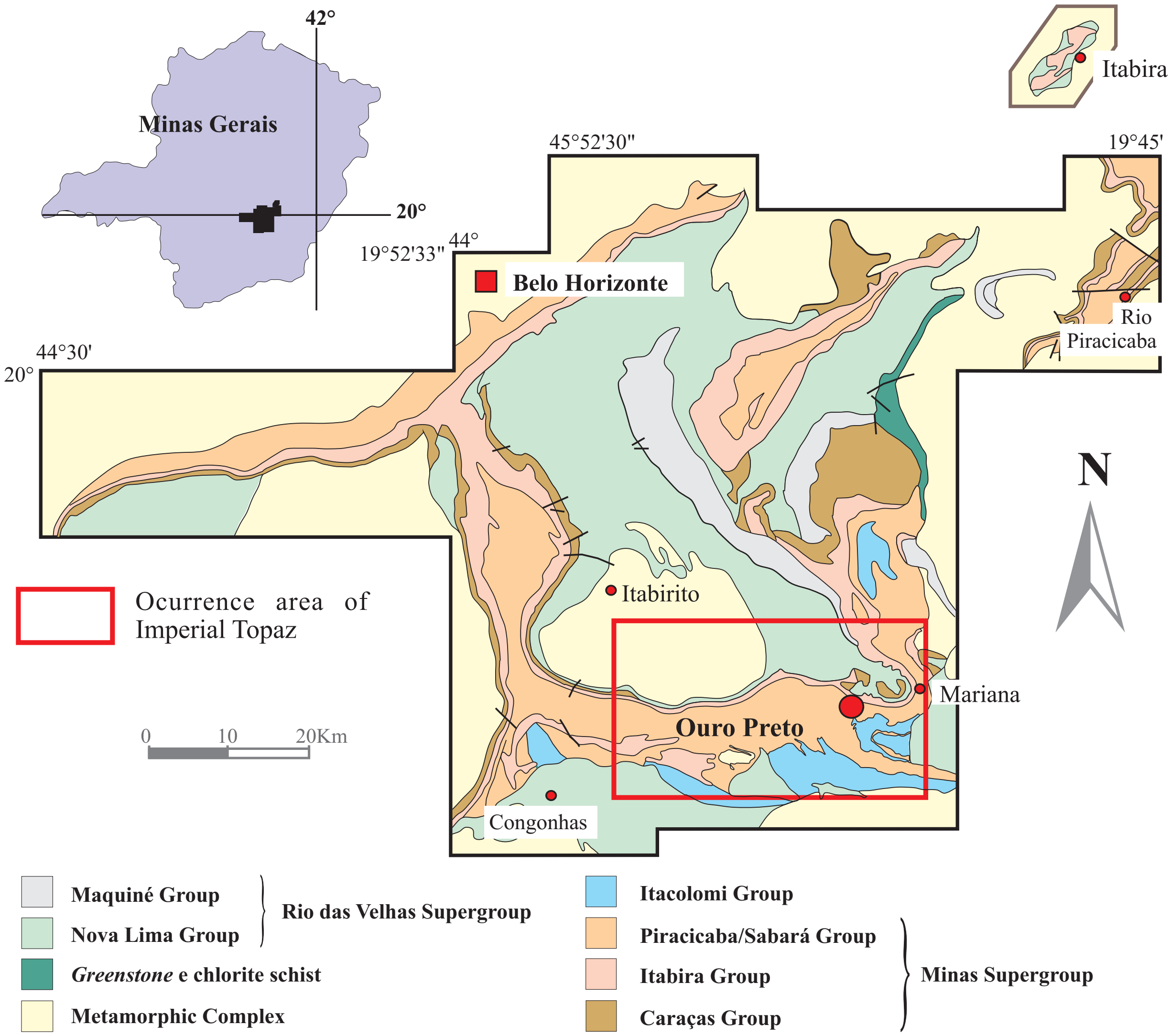

Figure 6. Map of area where topaz occurs in the Ouro Preto region in the State of Minas Gerais (Gandini, 1994).

(Gandini, 1994).

The crystalline inclusions, studied primarily using X-ray diffraction and scanning electron microscope, are represented by carbonates, topaz, hematite, ilmenite, mica, rutile, quartz, tremolite, euclase, chloritoid and apatite. These appear in much fewer numbers than fluid inclusions, which are both more frequent and more abundant. These fluid inclusions have been studied using various methods (heating/freezing stage mounted on a microscope, infrared spectroscopy and micro-Raman spectroscopy), which allows for identification of their composition, density, salinity and T and P trapping conditions. Table 3 correlates the data for temperature and pressure found in different beds in the region. These data suggest that the origin of imperial topaz in the Ouro Preto region is associated with hydrothermal processes and that the fluids have a metamorphic origin, probably resulting from decarbonatization reactions and dehydration of regional rocks, during some recurrent tectono-thermal episode (Gandini 1994; Almeida, 2004; Endo *et al*., 2007).

4.2. The emeralds of Bahia

Word of emeralds existing in the State of Bahia first came out in mid-1963, in the municipality of Pindobaçu, which went on to become the Carnaíba prospection site. Twenty years later, the Socotó prospection site was discovered in the municipality of Campo Formoso, which, in its first five years of existence, outproduced Carnaíba in terms of the gross production value. These two prospection sites areas are around 50 km apart and are genetically correlated (Couto, 2000).

The area around the Carnaíba prospection site forms an anticline with basement gneisses and Archaean migmatites

Photos: Arol Josué Rojas (2007)

Figure 7. (a) Panoramic view of the imperial topaz prospecting site in Antônio Pereira. (b) Detail of Front View of Excavation of Altered Material.

Table 3. Temperature and pressure of fluid inclusions in topaz from the Ouro Preto region.

Uncut colored gems	42,380,000
Processed colored gems	73,279,000
Uncut and processed diamonds	19,052,767
TOTAL	134,711,767

Source: Gandini (1994).

exposed in the center, surrounded by orthoquartzites of the Jacobina Group containing concordant intercalations of serpentinites associated with phlogopite-biotite-talc schists, which break down into phlogopitites. Granites and Palaeoproterozoic pegmatites cut through this sequence and are responsible for the metamorphism/metasomatism of the basic and ultrabasic rocks, which generated emeralds (Figure 8). Some of the emeralds in this region appear in seams of quartz and/or pegmatites encased in serpentinites. There are two main types of seams: one related to fractures cutting through the serpentinites and/or schists, and the other associated with contact veins between serpentinites and quartzites. These seams are called “clefts” and “track veins” (*veios de esteira*), respectively, by the prospectors. Most of the emeralds are, therefore, distributed and concentrated in the phlogopite schists within serpentinites.

The Carnaíba emerald reserves are estimated to contain 2,040 tons (Santana and Moreira, 1980). However, the Companhia Bahiana de Pesquisa Mineral [Bahia Mineral Research Company] (CBPM), which takes as its basis the historical data from prospection sites, suggests an average of productivity of 1.11 kg of (gem-quality and non-gem-quality emeralds per ton of biotite schist extracted and thus estimates that reserves total around 7,000 tons of gem-quality emeralds and 13.4 tons of non-gem-quality emeralds.

At the Socotó prospection site, gemstones are found in enclaves of ultrabasic rocks in intrusive granites responsible for the metasomatism that generated the emeralds (Figure 9). These xenoliths are composed basically of serpentinites, amphibolites and biotite schists.

Mining at these two sites is generally carried out underground and involves digging shafts to reach the phlogopitites, serpentinites, schists or potentially mineralized veins. Then, galleries are opened up from which larger crystals of beryl and emerald are extracted, the rest being sent to the surface where it is carefully washed and the gems picked out.

Schwarz (1987), on studying emeralds from the Carnaíba and Socotó region under a microscope, observed that, in samples from Carnaíba, the inclusions are characterized by the presence of flecks (stars; Figure 10a), signs of growth and the presence of few mineral inclusions, of which only the micas are significant, in addition to growth tubes and biphasic inclusions. The emeralds from Socotó, in turn, exhibit an extraordinary variety of growth tubes. They are characterized by growth phenomena marked by different types of color zoning (Figure 10b). The mica inclusions and the frequency of inclusions of other minerals (hematite and goethite/limonite flecks) (Figure 10c), apart from being biphasic inclusions, differ from those described in the emeralds from Carnaíba. The more interesting mineral inclusions, from a gemological point of view, among the samples from Socotó are the well-developed emerald crystals.

4.3. The opals of Piauí

Brazil is the second largest producer in the world of opal and more than 30 occurrences of this gemstone exist in the municipality of Pedro II, in the northeastern portion of the State of Piauí (Figure 11), near the eastern edge of

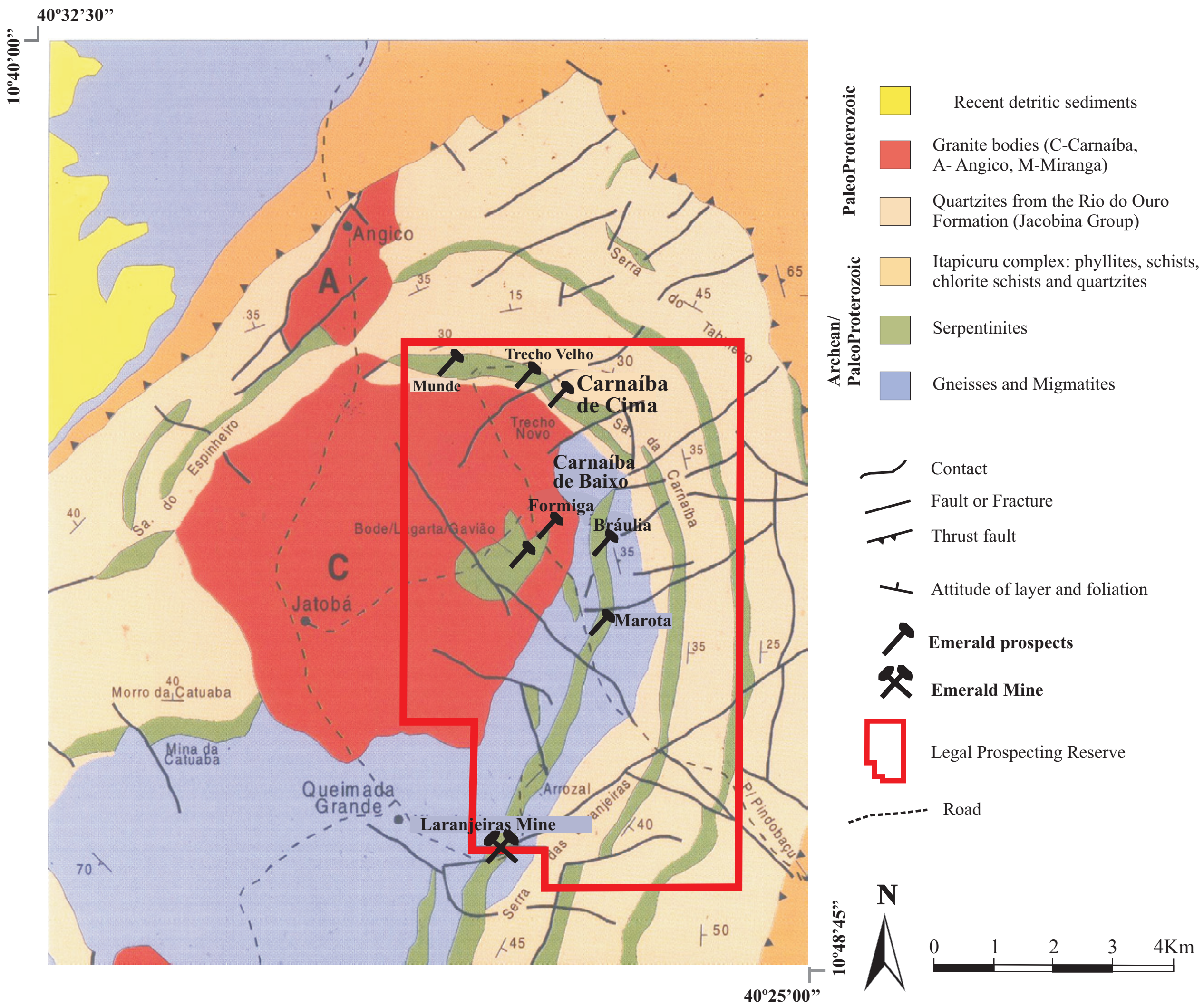

Figure 8. Simplified geological map of the Carnaíba region of the State of Bahia (modified from Couto, 2000 – CPRM).

the Maranhão sedimentary basin (Oliveira, 1998).

The strip of land exploited for the production of opal is located in the region that is made up essentially of subhorizontal sandstones of the Cabeças formation of the Paleozoic Era, intercalated and/or cut with sills and dikes of diabase and Triassic basalt.

The opals occur in three different ways (Oliveira, 1998): (1) in alluvium and colluvium resulting from the breaking up of the rock source; (2) in veins, filling fractures in the diabase and in the sandstone, principally in areas where these two kinds of rock come into contact; and (3) near the upper contact zone of diabase sills with sandstone, in a mineralized layer. Chalcedony and opal developed in this layer, which sometimes is made up of clayey material resulting from the alteration of the diabase/sandstone mixture, sometimes is formed of strongly silicified sandstones, and sometimes appears as a highly fractured siltite. At the base of this mineralized layer is microbrecciated shale with manifestations of opal in the fractures.

Type (1) opals are found in the alluvium of various rivers in the region, principally, the Corrente River and the tributaries of the Dos Matos River. The main prospection sites for this type of deposit are at Pirapora and Barra, located 500 m and 1,000 meters, respectively, to the south of the town of Pedro II. The extraction of alluvial opal is carried out by prospectors who open up wells that are 3 to 4 meters long and 1.5 to 2 meters wide to remove the sterile clayey layer. On reaching different sizes of shingle, the rounded sandstone and diabase/basalt pebbles are also excluded and the clay and sand are carefully washed in order to pick out any opals present by hand. In colluvial deposits, the sterile cover is removed, the material with argillic alteration is processed and the opals recovered by means of careful washing. In 2000, a new colluvial deposit was discovered and the prospection site, called Chã do Lambedor, subsequently came to employ 100 workers.

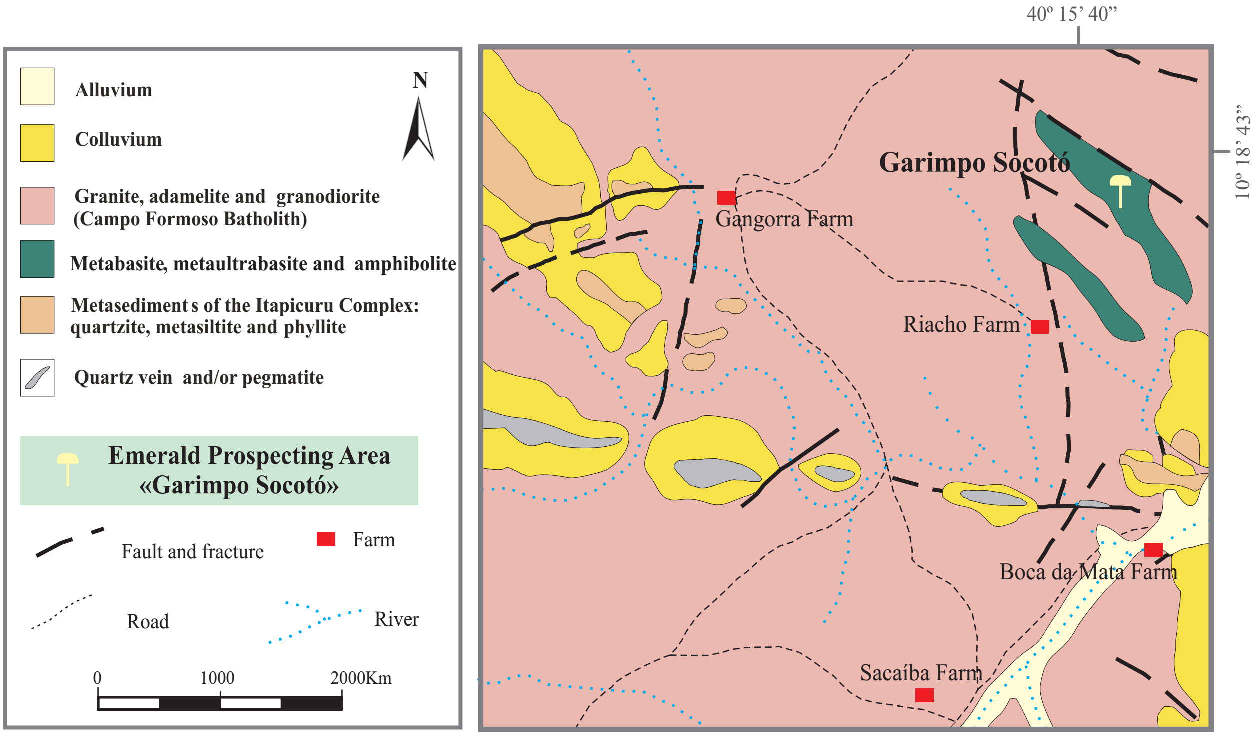

Figure 9. Gemological map of the State of Piauí (Oliveira, 1998 – CPRM).

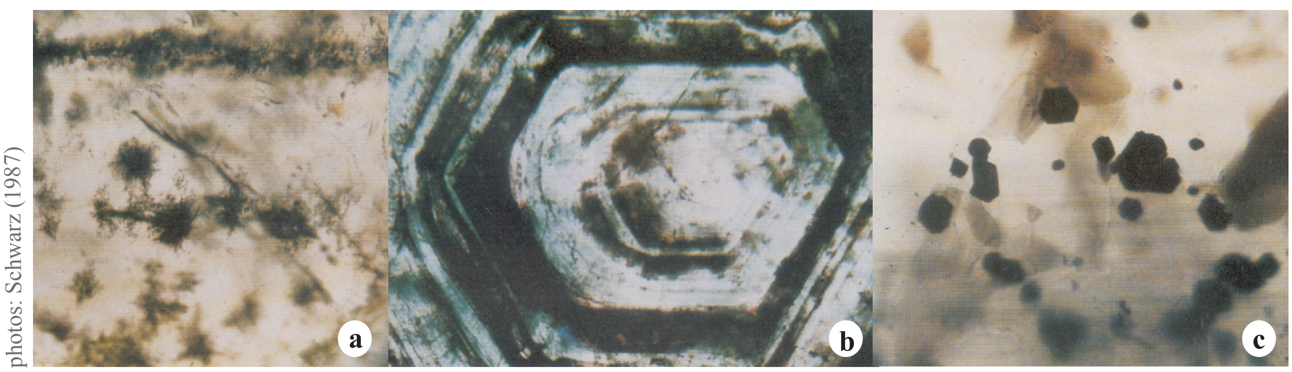

Figure 10. (a) Emeralds from Carnaíba: inclusions in the form of "flecks" or "stars". Emeralds from Socotó: (b) concentric zonal striation and (c) mica and hematite inclusions (hexagonal plates).

These opals are basically white in color, with a range of greenish oranges, reddish oranges and multiple colors, mainly of the flashfire, broad flashfire and pinfire varieties (Gomes and Costa, 2001).

Type (2) opals, from the upper contact of diabase with Cabeças sandstone, are undoubtedly the most important occurrences at Pedro II and represent more than 95% of the total quantity of opal traded in the region. The Boi Morto mine, discovered around 1940, is now the main bed in the municipality. The mine in Boi Morto was initially sunk by means of open longitudinal galleries above the contact of the unaltered diabase, which served as a solid floor. The clayey material recovered from the gallery was washed and the opal picked out by hand. This mining process is still used, but exploitation of the area has come to be principally open-cast, removing the sandstone with the aid of tractors and dragline, until reaching the potentially mineralized level made up of hard sandstone or of smectitic clay levels. On reaching the hard sandstone, the tractor carefully breaks up the mineral with the aid of scarifiers, exposing their fractures and making it possible to recover manually the gems found in the fractures and veins. In the zones with clays, removal is carried out slowly and the stones are picked out by hand or washed out from the clay. Other important beds of opal of this kind are those of Roça, Mamoeiro and Pajeú, situated from 5 – 7 km to the southwest of Pedro II.

Many mines of type (3) opals, which are associated with a sterile covering over a mineralized strip at the top of diabase bodies, have been closed by the public authorities because the cover has reached a thickness of 60 m, causing environmental damage and posing a hazard to mine-workers.

The opals of Pedro II are very hard and highly resistant to changes in temperature as a consequence of their low water content: around 5.7%, compared with a world average for opals of between 6 and 10% (Lamachia, 2006).

Oliveira (1998) has classified the opals of Pedro II, taking into consideration the mass-tone (*potch*), distribution of colors and quality. As for mass-tone, the main types found are: *white opal*, which has a milky background and is more frequent; *black opal*, which has a black mass and is extremely rare; *gray opal*, whose mass tones are variations on gray; and *semi-black opal*, with dark gray background. With regard to the range of colors, the types most frequently found at Pedro II are: *rolling flash*, which shows frequent and constant changes in color, like oscillating waves; *broad flash*, where a single wave rapidly crosses the stone; *exploding flash*, where the colors are shocking; *mackerel sky*, when a formation of thin parallel nebulous colors occurs; *flame* or *flash-of-fire*, where predominantly red and orange lines give the impression of oscillating through the stone; *harlequin*, which is a static model, whereby the colors form mosaics that do not move; *floral pattern*—another static model—where colored many-petaled flowers are formed; and *pinfire*, when the colored flowers are tiny with pinheads. With regard to quality, the opals are classified as noble, extra, strong, medium, weak and very weak or dross.

Effective government action in this region began around 1990 with the Piauí/Maranhão Precious Stones Project, run by CPRM, culminating in the drawing up of a map of gemstone deposits in the State of Piauí in 1998 (Figure 11). At the same time, the Serviço Brasileiro de Apoio às Micro e Pequenas Empresas [Brazilian Small Business Support Service] (SEBRAE) has encouraged the installation of

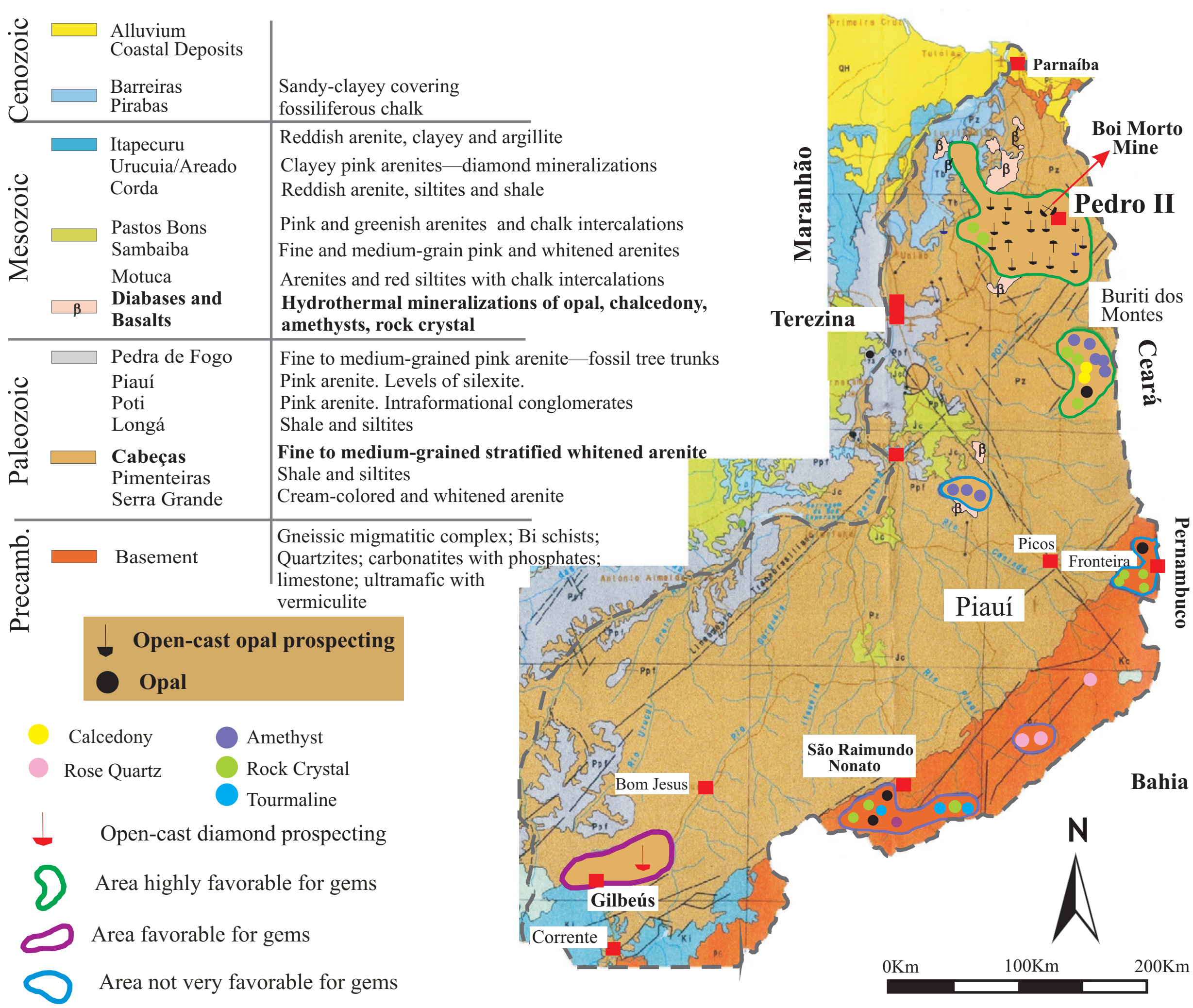

Figure 11. Gemological map of the State of Piauí (Oliveira, 1998 – CPRM).

cutting and polishing, and jewelry and mineral handicrafts businesses. In 2005, the Arranjo Produtivo Local (APL) da Opala [Local Opal Production Arrangement] was introduced to organize this chain of production and to provide support for the Pedro II Prospectors Cooperative and the Pedro II Association of Jewelers and Cutters and Polishers.

According to the IBGM-APEX BRASIL (2006a), in 2005 there were around 200 prospectors working in Pedro II, mostly for multinational companies operating in the region. The municipality also has a small cluster of businesses producing jewelry made of silver and opal, with 16 small businesses, employing around six individuals each.

Oliveira (1998) estimates that 80% of the production at Pedro II has been exported in uncut form for trade in other Brazilian states.

4.4. The tourmalines of Paraíba and Rio Grande do Norte

The Paraíba tourmalines are designated as such because they were discovered in 1988 in pegmatites from Mina Batalha, in the municipality of São José da Batalha in the State of Paraíba. Subsequently, in the 1990s, similar tourmalines were found in pegmatites at Quintos and Capoeiras, in the municipality of Parelhas, Rio Grande do Norte.

The Precambrian Batalha and Quintos pegmatites are encased in muscovite quartzites of the Ecuador Formation, while the Capoeiras pegmatite is encased in metaconglomerates of the Seridó Formation from the same era (Figure 12).

The principal feature of the Paraíba tourmalines is their highly distinctive range of colors, which are popularly described using terms such as electric green turquoise, neon green and peacock blue. In view of their beauty, peculiar shades of green and blue, high shine and limited numbers, these medium-quality gems fetch high prices on the national (US$1,000 – 1,500 per carat) and international market (US$2,500 – 5,000 per carat), and especially good quality stones can fetch as much as US$20,000 per carat on the international market. Lilac-colored tourmalines are also of economic importance.

At Mina Batalha there are six pegmatitic bodies, tabular, parallel or subparallel one to another, with a thickness varying from 20 cm to 4 m and a depth (in 1998) of between 6 and 25 m for terrace mining (Figure 13a). They are intensely kaolinized homogeneous pegmatites, with a general direction of 120º to 130º azimuth with dips from 54º to 75º to the northeast, against the dip of the foliation of the encasing material. In petrographic terms, these pegmatites are composed of quartz (pink, hyaline, milky and morion), muscovite, lepidolite, tourmalines of the schorlite and elbaite varieties (green, turquoise green, blue, pink and lilac), kaolin and columbite/tantalite. The crystals of elbaite tourmalines are fractured and frequently replaced by lepidolite and/or kaolin. They occur within the kaolinic mass and the presence of small pockets of morion quartz in combination with this fine mass of kaolin and lepidolite serve to control the mineralization of elbaite gems (Figure 13b).

In 1993, production at Mina Batalha was partially halted. However, the high price this gem fetches on the market justified opening a new mine situated on the same quartzite ridge as Mina Batalha, and prospectors initiated exploitation of the alluvium of the creek that cuts through the mining area.

The Capoeiras and Quintos pegmatites are heterogeneous (Johnston, 1945) and enriched with rare elements (Černý, 1991). The Capoeiras pegmatite has an internally zoned structure that is not commonly found in Quintos pegmatite, where zoning is masked by intense substitution processes (albitization and lepidolitization). These pegmatites are composed essentially of quartz (milk to hyaline, morion and pink), albite/clevelandite, K-feldspar, perthitic, muscovite, biotite, lepidolite, black tourmaline (the schorlite-dravite series), elbaite tourmaline, beryl (milky and morganite), spodumene, gahnite, cookeite, apatite, autunite, in addition to a diverse accessory mineralogy (Soares, 2004).

Elbaite mineralization, in greens, blues and reds, occurs principally in the contact between large crystals of albite/clevelandite feldspar (Zone 3) with quartz at the center of the array. Elbaite crystals can be up to 60 cm long and are arranged almost perpendicular to the contact (Figure 13c). There are also tourmalines within the feldspar-quartz mass. The tourmaline crystals are frequently zoned and many of them are totally or partially replaced by lepidolite, kaolin and illite (Barreto, 1999).

The turquoise green elbaites, or Paraíba tourmalines, typically contain high levels of copper (0.65% - 1.77% wt of CuO) and manganese (0.35% to 2.46% wt of MnO), which are the chromophore elements of elbaites. Their visible and infrared absorption spectra differentiate them from other green elbaites of these occurrences, since they present on the visible spectrum only the principal 700-718 nm band and on the quasi-infrared the 930-940 nm band, related to "spin-allowed" type transitions $^5T_2 \rightarrow {}^5E$ I the Cu^{2+} ions situated on the Y octahedral (Barreto, 1999).

5. Conclusions

Brazil produces a wide diversity of gemstones and comes first in the world ranking in terms of both the variety and the quantity of gems produced (Figure 14). Deserving special note are tourmalines, topaz, opal, quartz (agate, amethyst and citrine), emeralds, and, on a smaller scale, diamonds, rubies and sapphire. Despite the enormous geographical expanse of the country, the states of Minas Gerais, Mato Grosso, Goiás, Rio Grande do Sul and Bahia are responsible for 97% of official gem production.

Gem production in Brazil is carried out by thousands of prospectors and a few mining companies and this fact, in combination with the heavy tax-burden to which the sector is

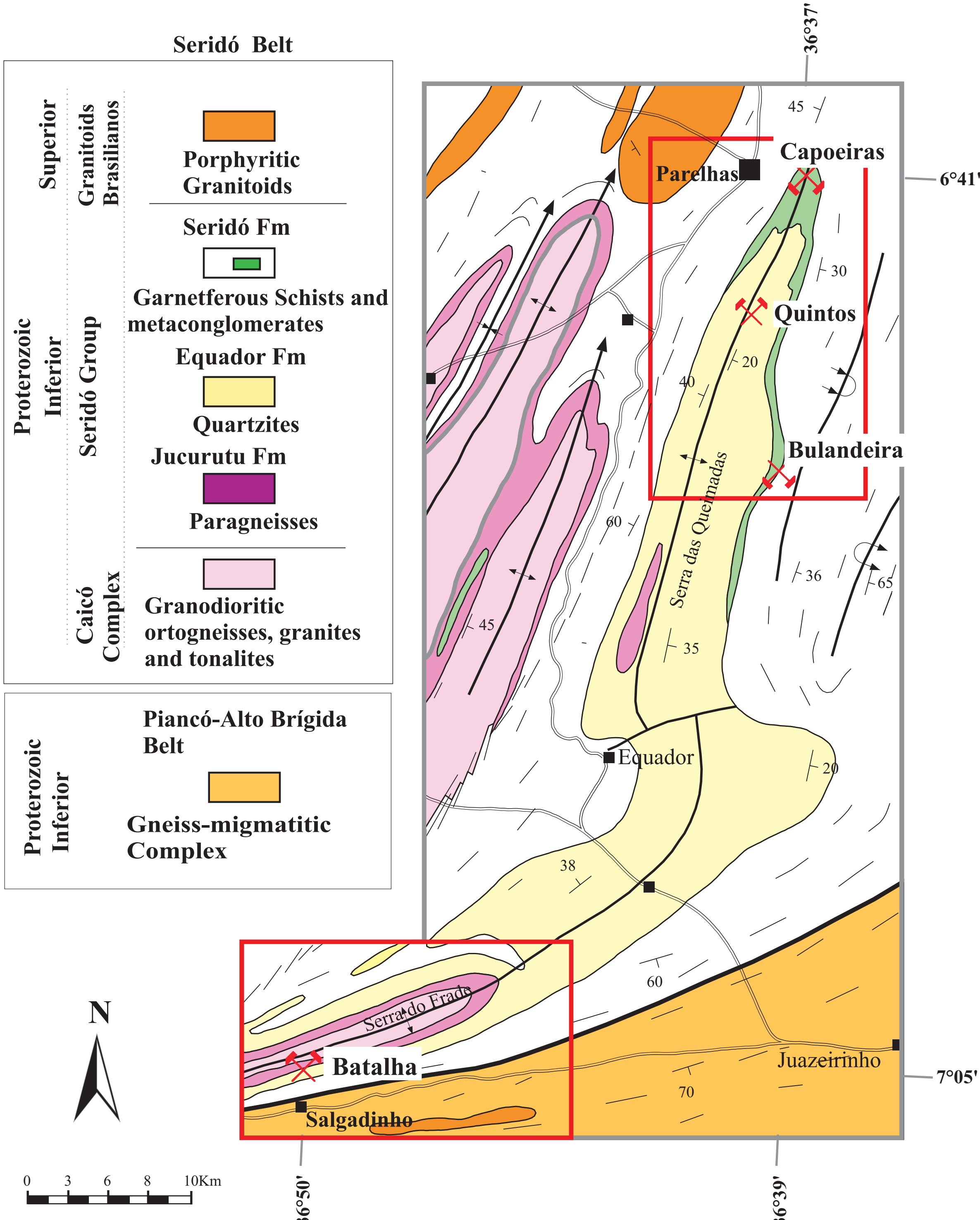

Figure 12. Simplified geological map of the region where Paraíba Tourmalines occur (Barreto, 1999).

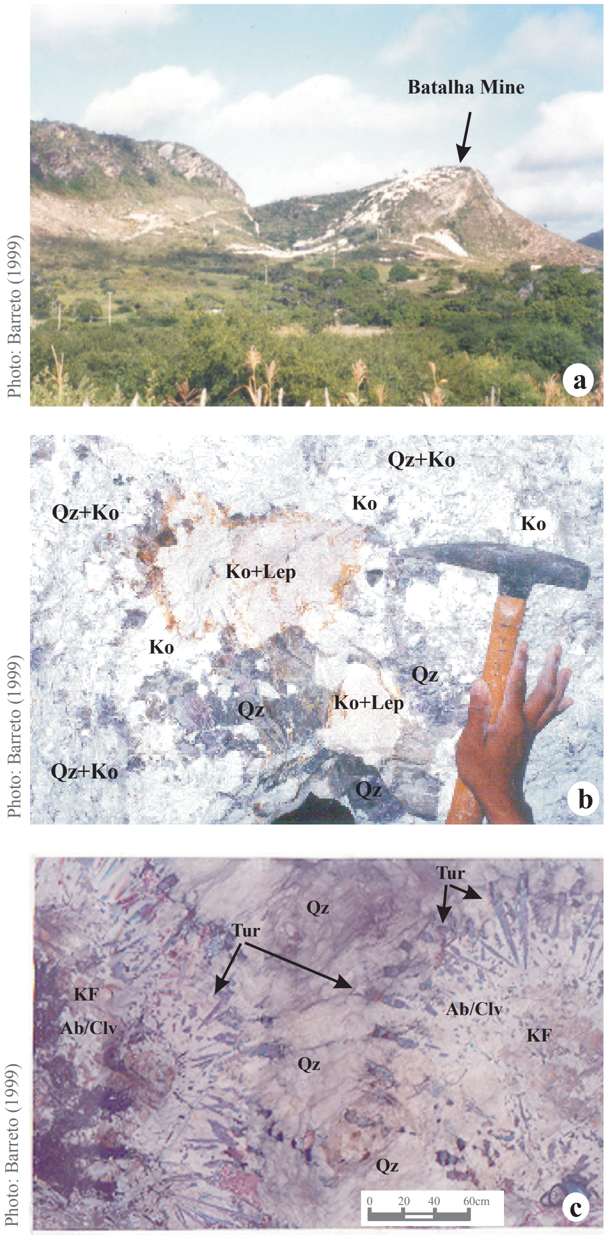

Figure 13. (a) Quartzitic ridge of Morro Alto, in the Mina Batalha area, showing the terraces exploited. Batalha Pegmatite (State of Paraíba). (b) Small pockets of morion quartz in combination with a fine mass of kaolin and lepidolite that serve to control the mineralization of elbaite gems, Mina Batalha. Qz, quartz morion; Ko, kaolinite; Ko+Lep, kaolinite and lepidolite. (c) Elbaite mineralization, in green blue and red, at the point of contact between the large crystals of albite/clevelandite feldspar and potassium feldspar (Zone 3) and quartz in the center, Quintos Pegmatite. Qz, quartz; Ab/Clv, albite and clevelandite; KF, potassium feldspar; Tur, tourmaline.

subject, allows the informal sector to thrive and is reflected in the number of gems smuggled abroad and a consequent discrepancy between the official and the true figures for the production and sale of gems.

The Brazilian government has made efforts to change this, with a view to improving management of the gemstone industry by creating bodies such as the Fórum de Competitividade da Cadeia Produtiva de Gemas, Jóias e Afins, [Forum for Competitiveness in the Chain of Production of Gems, Jewels and Related Products], which has identified Arranjos Produtivos Locais de Gemas [Local Production Arrangements for Gems] (APL Gemas) to provide support for and help manage small mining companies and related businesses.

Acknowledgments

The authors would like to thank all those who contributed to the production of this article and to extend our special gratitude to: Dr. Antonio Luciano Gandini of the Department of Geology of the Federal University of Ouro Preto for allowing us to use texts and illustrations on imperial topaz; Dr. Júlio Cesar Mendes of the Department of Geology of the Federal University of Ouro Preto for information on the State of Minas Gerais; Dr. Ricardo Jorge Lobo Maranhão for his assistance in the area of mining economics and for reviewing the texts; the undergraduate geology students from the Federal University of Pernambuco, Rômulo Leonardo de Souza and Marcondes Assis Menezes da Silva, for their help with the illustrations; the Secretary of State for Trade, Industry, Energy and Mines of the State of Mato Grosso, Dr. Manoel Antonio Rodrigues Palma and his technical assistant Josemara Campelo Giglio for sending information on this state; the Secretary of State for Science, Development and Technology of the State of Pará for sending important information; Dr. Adeilson Alves Wanderley of Companhia de Recursos Minerais (CPRM) for his assistance in providing maps and other information; and Gevilácio A. C. de Moura for sending photographs and providing information on the emeralds of Carnaíba and Socotó in Bahia.

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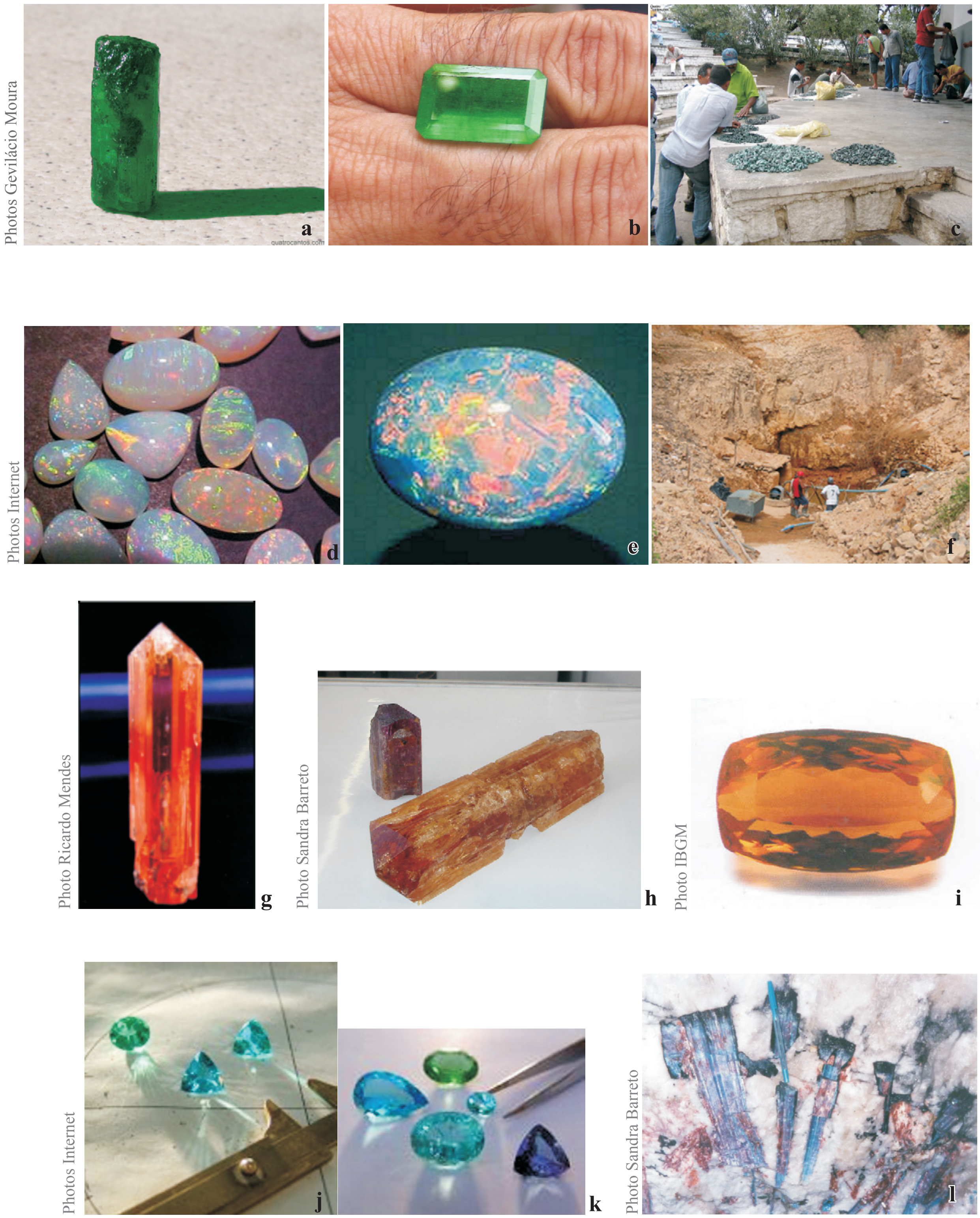

Figure 14. (a) Prismatic crystal of Carnaíba emerald (Bahia). (b) Polished emerald, Carnaíba (Bahia). (c) Emerald traders in the main town of the Municipality of Carnaíba (Bahia). (d) Noble opal from Pedro II. (e) Cabochon of noble opal from Pedro II. (f) Opal mining in Pedro II, (g) Crystal of imperial topaz, Ouro Preto (Minas Gerais). (h) Crystals of imperial topaz for sale at the International Precious Stones Trade Fair – FIPP – in Teófilo Otoni (Minas Gerais). (i) Polished imperial topaz. (j) Polished turquoise-green and electric blue Paraíba tourmalines. (k) Polished Paraíba tourmalines in various colors. (l) Paraíba Tourmaline crystals in a quartz matriz Quintos Pegmatite, Parelhas (Rio Grande do Norte).

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Manuscript received: September 19, 2008.
Corrected manuscript received: June 15, 2009.
Manuscript accepted: July 15, 2009.