DISTRIBUTION AND ORIGIN OF DIAMONDS IN BRAZIL: AN OVERVIEW

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INTRODUCTION

Brazil was the first western country to produce diamonds from the washing of alluvial deposits found in central Minas Gerais in the early I700s. For a century the country remained the world's greatest producer, losing its position only after the discovery of the Kimberley field in South Africa. Currently there are placer deposits (garimpos) scattered throughout the majority of the states with official production averaging 1,000,000 ct/year. Mechanized exploitation using modern dredges has succeeded only in two distinct localities: along the Jequitinhonha River (Diamantina) and at the Fazenda Camargo (Mato Grosso). Large diamonds of several hundred carats have been found periodically in the area of the municipalities of Abaeté and Coromandel in western Minas Gerais State. Carbonado, a polycrystalline variety of diamond was intensively mined in several localities of the Chapada Diamantina in central Bahia State, mainly in the second half of the last century.

Kimberlite-type rocks, on the other hand, were discovered only in the late 1960s, first in the Coromandel area in Minas Gerais and later in Goiás, Mato Grosso, Rondônia and Piauí States. Little is yet known about these intrusions mainly because the discoveries have been made by foreign companies operating in the country. Detailed studies reported during the Kimberlite Conference of Araxá in 1991 revealed that some intrusions of the Coromandel area have mineralogical and petrographical characteristics as well as major chemical element compositions similar to worldwide kimberlites. However, their isotopic signatures in terms of Sr and Nd are intermediate between Groups I and II kimberlites of South Africa. As to mineral inclusions, Brazilian diamonds contain the common phases of olivine, garnets, pyroxenes, sulphides and oxides as observed in diamonds elsewhere. Furthermore, diamonds from São Luis River in northern Mato Grosso contain, in addition to garnet and pyroxene, periclase, ferripericlase, wüstite, nickel, iron-nickel alloy and moissanite. This high-pressure assemblage resembles the mineralogy predicted for depths of ~650 km, thus suggesting an asthenospheric origin for the São Luis diamonds.

This paper presents a review of general aspects of the most representative deposits of diamonds in Brazil. Field relationships point to the existence of at least three distinct ages for the secondary source rocks as illustrated by the Upper Proterozoic metaconglomerates of Diamantina, the Permo-Carboniferous diamictites of Tibagi and the Upper Cretaceous conglomerates of the Romaria Mine. The primary sources remain still unknown in all localities. Additional comments are provided on the findings of great diamonds, diamond inclusions and on the study of kimberlite-type rocks carried out in the country in the past two decades.

HISTORICAL NOTES

Detrital diamonds were discovered in Brazil around l720 (Barbosa 1991) in the small locality of Tejuco, later named Diamantina, in central Minas Gerais. At that time Brazil was part of the Portuguese Empire, therefore, the exploitation was rigidly controlled by the imperial authorities. Before the end of eighteenth century, diamonds were discovered in the Abaeté area in western Minas Gerais, southeast Goiás, and in Diamantino in Mato Grosso where the exploitation was also strictly controlled.

After the Independence of Brazil in l822 diamonds were discovered and intensively exploited in several localities of the Chapada Diamantina in central Bahia, notable for the occurrence of large amounts of carbonados and other polycrystalline varieties of diamonds. New placer deposits were discovered later in the States of Paraná, Pará, São Paulo, Maranhão, Mato Grosso do Sul, Rondônia, Roraima and Amapá. Currently, the main mining areas are located in the States of Minas Gerais and Mato Grosso.

Diamond mining has been done traditionally by means of diggings. It is a system of mining on a small scale where groups of local workers (garimpeiros) remove and sieve diamond gravels recovered from terraces. They usually use hydraulic jets and jiggs to recover the diamond. In some areas like Diamantina gold is recovered as a by-product. This type of work is financed by middlemen living in towns close to the diggings who buy whatever is produced for subsequent resale to other intermediaries in bigger cities, like São Paulo and Rio de Janeiro, where diamonds are sold to foreigners. The majority of Brazilian diggings have been worked in the same way since the pioneer discoveries three centuries ago. Complete mechanized operations are being conducted by Mineração Tejucana S/A and Mineração Rio Novo along the Jequitinhonha River and Camargo Correia Company near Nortelândia in Mato Grosso State.

According to official data, production fluctuates around 1,000,000 ct/year representing, therefore, 2,0% of world production. This is a relatively small amount considering the large number of occurrences scattered throughout the country. The quality of diamonds varies for each locality: in Diamantina for instance, the gemological types predominate over the industrial ones; in other places, like Juína (Mato Grosso), industrial types predominate.

GEOGRAPHICAL DISTRIBUTION

Diamonds are distributed in Brazil from the Uraricoera River, Roraima (4°N latitude) to the Tibagi River, Paraná (25°S latitude), and from the Pardo River, Bahia (39°W longitude) to the Madeira River, Acre (69°W longitude). In spite of this large extent of placers the production is small compared to other world producers. Figure 1 shows some of the main centers of diggings in Brazil. Considering the specifics of each area, we shall discuss some past and present relevant information for each State.

Minas Gerais: Diamonds occur in modern alluvial/ elluvial/colluvial gravels deposits, in Cretaceous conglomerates of the Bauru Group in the area of Romaria, and in Mesoproterozoic metaconglomerates of the Sopa Brumadinho Formation.

One of the most important diamondiferous zone is located in the western part of Minas Gerais. Several localities, such as Coromandel, Grupiara, Cascalho Rico and Estrela do Sul, for instance, started and developed thanks to the exploitation of diamonds (Leonardos 1956). Other producing localities are Tupaciguara, Monte Carmelo, Ituiutaba, Romaria, Patrocínio, Patos, Carmo do Paranaíba, Tiros and Abaeté, among others.

Figure 1 - Location of selected occurrences of diamond placer deposits in Brazil and neighboring countries. Numbered localities are: 1) Tibagi, 2) Itararé, 3) Franca, 4) Abaeté, 5) Tiros, 6) Romaria, 7) Estrela do Sul, 8) Coromandel, 9) Barão de Cocais, 10) Diamantina, 11) Grão Mogol, 12) Lençóis, 13) Morro do Chapéu, 14) Gilbués, 15) Imperatriz, 16) Marabá, 17) Vila Nova, 18) Tepequém, 19) Surinam River, 20) Mazaruni River, 21) Caroni River, 22) Quebrada Grande River, 23) Guapayito River, 24) Machado, 25) Pimenta Bueno, 26) Juína, 27) Nortelândia, 28) Diamantino, 29) Colinas, 30) Chamada dos Guimarães, 31) Poxoréu, 32) Barra do Garças, 33) Alto Garças, 34) Mineiros, 35) Coxim, 36) Aquidaban River.

In Romaria, a small historical locality 15 km south of Monte Carmelo, diamond has been mined since the end of the last century in a polymictic conglomerate located at the base of the Bauru Group (Svisero et al. 1981). The conglomerate ranges in thickness from 1 to 16 meters and the diamond content is on the order of 0.07 ct/m^3 (Feitosa & Svisero 1984). The physical properties of diamond were established using a representative parcel of 5,317 stones weighing 450 ct (Svisero et al. 1981). Granulometric studies revealed that the majority of the stones fall in the sieve size 1.41-2,0 mm. Morphologically, dodecahedrons predominante over all other crystallographic forms. Flat twins are frequent and polycrystalline types absent. Mineral inclusions in diamond are olivine, Cr-pyrope, pyroxene, chromite, sulphides and diamond as well. Unfortunately, the costs involved in the removal of the overburden prevented the maintenance of the operations and the mine closed around 1984. Those and other sites were recently reviewed by Chaves et al. (1993).

The area between Coromandel and Abaeté can be called "the land of the great diamonds". In fact, since the first discovery in the Abaeté River in the second half of the eighteenth century, several findings of stones weighing more than 100 ct have being registered in the literature (Leonardos & Saldanha 1939, Abreu 1973, Barbosa 1991).

Table 1 reports some of the biggest stones found in Brazil. The biggest is still the Sérgio carbonado, a dark polycrystalline variety of diamond found in Lençóis (Bahia) in 1905. Weighing 3,167 ct it is still the greatest single diamond ever found in the world. For purpose of comparison the famous Cullinan found at the Premier Mine (South Africa) in 1905 weighed 3,106 ct. Except for the carbonados of the Chapada Diamantina, the majority of the great Brazilian diamonds were found in western Minas Gerais mainly in the Coromandel, Estrela do Sul, Abaeté, Tiros and Carmo do Paranaíba Districts (Reis 1959).

Some diamonds, like the Minas Gerais (Barbosa 1938), Presidente Vargas (Leinz 1939), Darcy Vargas (Leonardos & Saldanha 1939), Coromandel (Saldanha 1941), Governador Valadares (Saldanha 1942) and Princesa de Estrela do Sul diamond (Svisero & Haralyi 1978), have been studied in detail. Many others however, are sold before being studied or even registered. We have been acquainted with many findings in the last few years in the Coromandel area, which for commercial reasons were never been registered. These include a 165 ct stone found in Carmo do Paranaíba in 1986 (Table 1), as well as several stones of more than 100 ct found at the Charneca Farm near Coromandel.

Table 1. Some of the greatest diamond found in Brazil.

Name	Weight in carats	year of found	Locality
Sérgio (carbonado)	3,167	1905	Brejo da Lama, Lençóis, BA
Casco de Burro (carbonado)	2,000	1906	Lençóis
Xique-Xique (carbonado)	931.6	-	Andaraí, BA
Abaeté (carbonado)	827.5	1935	Abaeté River, MG
Presidente Vargas	726.60	1938	Santo Antônio River, Coromandel, MG.
Goiás	600(?)	1906	Veríssimo River, GO
Darcy Vargas	460	1939	Santo Antônio do Bonito River, Coromandel, MG
Charneca I	428.0	1940	Santo Inácio River. Coromandel, MG
Presidente Dutra	407.68	1949	Dourados River, Abadia de Dourados, MG
Coromandel VI	400.65	1940	Coromandel, MG
Diário de Minas	375.1	1941	Santo Antõnio River, Coromandel, MG
Vitória I	375	1945	Abaeté River, MG
Tiros I	354	1940	Abaeté River, MG
Bonito I	346	1948	Santo Antônio do Bonito River, Coromandel, MG
Vitória II	328	1943	Abaeté River, MG
Patos	324	1937	São Bento River, Quintinos, MG
Santa Ana (carbonado)	319.5	1960	Rosário do Oeste, MT
Estrela do Sul	261.38	1853	Bagagem River, Estrela do Sul, MG
Cruzeiro	261	1942	Coromandel, MG
Carmo do Paraíba	245	1937	Bebedouro River, MG
Abaeté	238	1926	Abaeté River, MG
Coromandel III	228	1936	Santo Inácio, Coromandel, MG

Regente de Portugal	215	1732	Abaeté River, MG
João Neto de Campos	201	1947	Paranaíba River, Catalão, GO
Tiros II	198	1935	Abaeté River, Tiros, MG
Tiros III	182	1935	Abaeté River, Tiros, MG
Coromandel IV	180	-	Coromandel, MG
Estrela de Minas	179.38	1910	Dourados River, MG
Brasília	176	1944	Preto River, Abadia dos Dourados, MG
Juscelino Kubitschek	174.5	1954	Bagagem River, Estrela do Sul, MG
Tiros IV	173	-	Abaeté River, MG
Minas Gerais	172.50	1937	Santo Antônio do Bonito River, Coromandel, MG
Princesa do Carmo de Paranaíba	165	1986	São Bento River, Carmo do Paranaíba, MG
Coromandel V	141	1935	Coromandel, MG
Nova Estrela do Sul	140	1937	Abaeté River, MG
Charneca III	132	1972	Santo Antônio River, Coromandel, MG
Dresden Branco	122.48	1857	Bagagem River, Estrela do Sul, MG
Cruzeiro do Sul	118.0	1929	Bagagem River, Estrela do Sul, MG
Pau de Óleo (carbonado)	113	1932	Andaraí, BA
Vargem I	110	1940	Santo Inácio River, Coromandel, MG
Jalmeida	109.50	1924	Tesouro, MT
Governador Valadares	108.30	1940	Bagagem River, Estrela do Sul, MG
Independência	107	1941	Tejuco River, Ituiutaba, MG
Abadia dos Dourados	104	-	Dourados River, Abadia dos Dourados, MG
Imperatriz Eugênia	100.0	-	Diamantina, MG
Princesa de Estrela do Sul	82.25	1977	Bagagem River, Estrela do Sul, MG
Rosa de Abaeté	80.30	1935	Abaeté River, MG
Paulo de Fontrein	50	1936	Boa Vista Mine, Diamantina, MG

Note: BA= Bahia State, GO= Goiás State, MG= Minas Gerais State, MT= Mato Grosso State.

The metaconglomerates of Sopa-Brumadinho Formation crop out along a strip that goes from Diamantina up to Grão Mogol. The mining of the metaconglomerates in the vicinities of Diamantina originated several regular mines located around the cities of Extração, Datas, Guinda, Sopa and São João da Chapada (Figure 2). Chaves & Uhlein (1991) presented a detailed review of the Diamantina Diamond District showing that the metaconglomerates of Sopa Brumadinho Formation consist of fault-controlled coarse alluvial and alluvial fan deposits. The diamond-bearing metabreccias were deposited by debris flows probably in a tidal flat environment. According to Chaves & Uhlein (1991) the placers of the Jequitinhonha River are responsible for the largest part of diamonds exploited in Brazil since its discovery. The deposits are characterized by facies variations (lateral and vertical) with sands, black muds and basal mineralized gravels. Boa Vista has been exploited regularly and according to Barbosa (1991) still has 30 million cubic meters of operational metaconglomerates. The plant was acquired by the Anglo American Company in 1986 which resold it later to another private group. Diamond from Diamantina is characterized by a rough surface with a greenish film. This color disappears during cutting, producing stones of very high quality. Inclusions and crystalline defects are rare. On average, three stones make a carat (3:1). Large stones, such as the 50 ct one mentioned in Table 1, seem to be rare.

Diamond was discovered in small diggings and the same method is still being used throughout the country. In order to increment production, several attempts at mechanization have been made in the diggings and most have failed. Since 1966 modern dredges were introduced by Mineração Tejucana S/A in the Jequitinhonha River roughly 100 km north of Diamantina. According to Dupont (1991), three bucket dredges and three section dredges are excavating 9,000,000 m^3/year of alluvial gravels with an average production of 70,000 ct of diamond and 150 kg of gold as a by-product. According Dupont (1991), 90% of the recovered diamonds are gemstones. The gravels have a grade of only 0.008 ct/m^3. However, the reserves are immense, reaching 400,000,000 m^3. Mineração Rio Novo started similar dredging in 1988. Distribution and current total production of Minas Gerais is depicted in Figure 3.

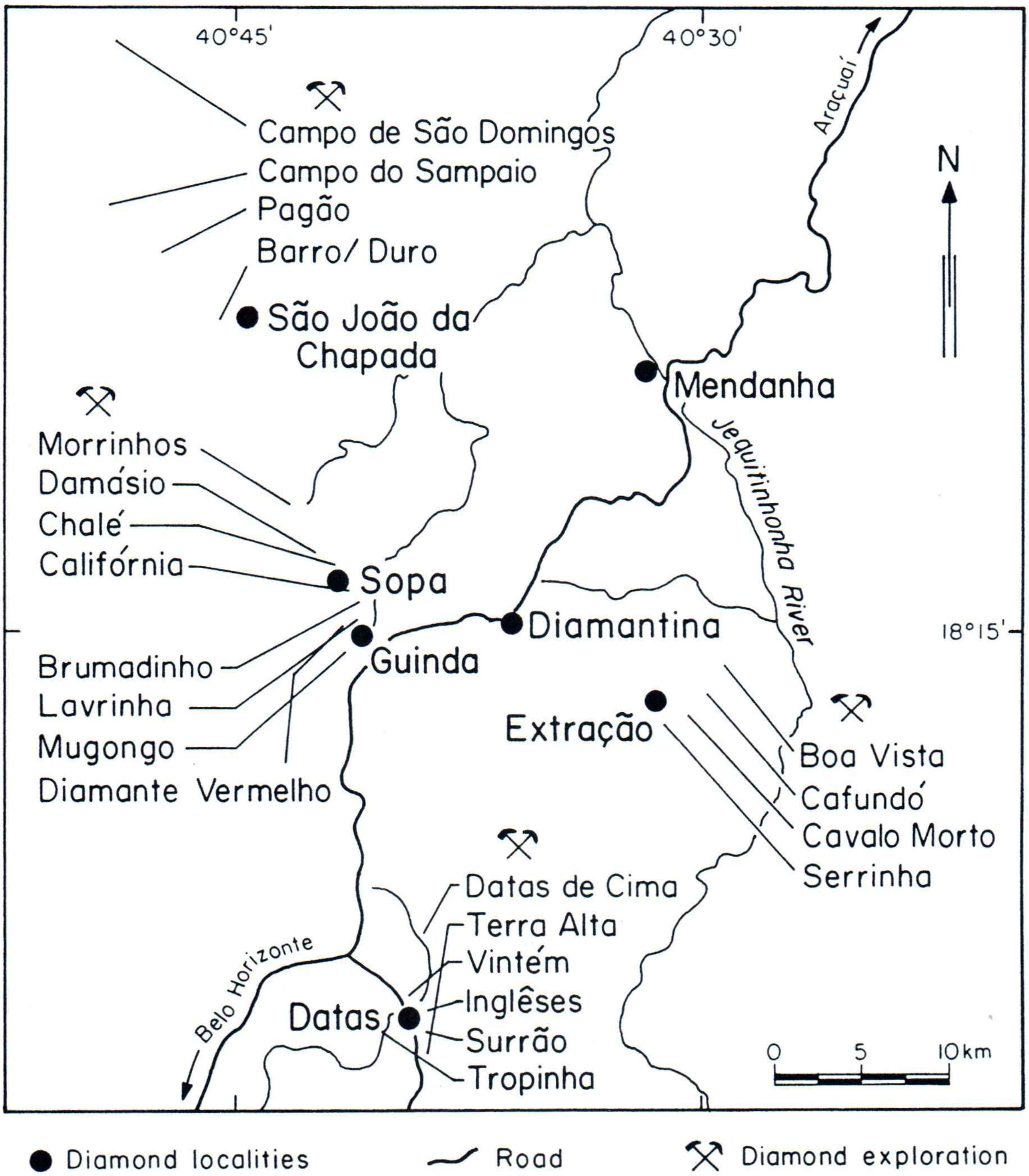

Figure 2 - Location of the main diamond mining sites in the area of Diamantina, Minas Gerais. Redrawn from Chaves & Svisero (1992).

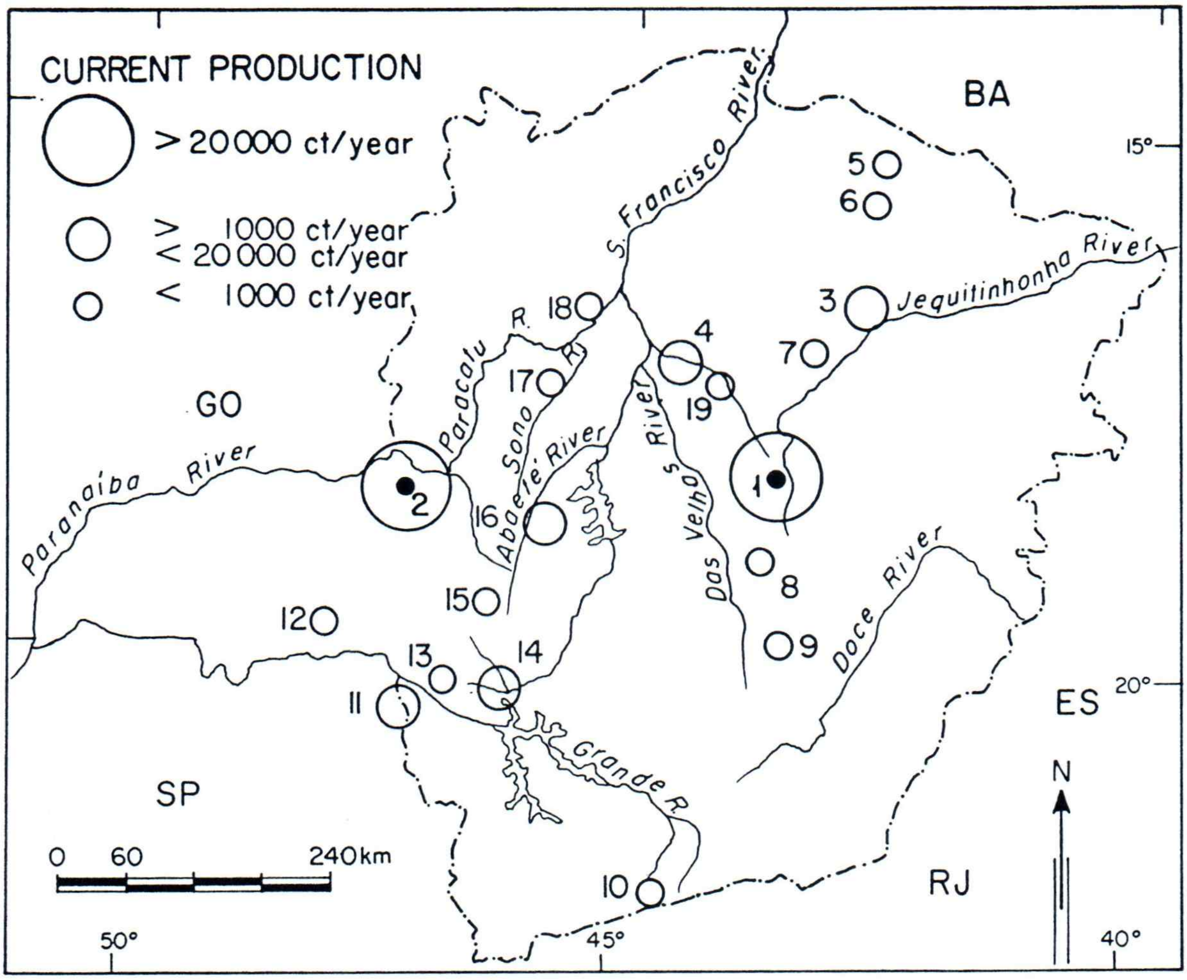

Figure 3 - Distribution of the most important areas of diamond production in Minas Gerais. Numbered localities are: 1) Diamantina, 2) Coromandel, 3) Grão Mogol, 4) Jequitaí, 5) Serra Nova, 6) Porteirinha, 7) Itacambira, 8) Serra do Cipó, 9) Serra das Cambotas, 10) Rio Aiuruoca, 11) Franca (SP)/Capetina, 12) Uberaba, 13) Delfinópolis, 14) Vargem Bonita/Samburá, 15) Rio Ibiá, 16) Tiros, 17) Canabrava, 18) Santa Fé de Minas, 19) Francisco Dumont. Redrawn from Chaves et al. (1993).

Bahia: Diamonds including the polycrystalline variety carbonado were discovered in the Sincorá Range, Chapada Diamantina, a huge plateau in central Bahia comprising the municipalities of Sincorá, Mucugê, Andaraí, Lençóis, Campestre, Palmeiras, Assuruá, Brotas and Morro do Chapéu around 1841 (Abreu 1973). However, the first intensive exploitation started only in 1845 in the Mucugê River. Soon thereafter many new diggings were discovered in other points of the Chapada Diamantina. Lençóis became famous because of the findings of great carbonados including the Sérgio carbonado, the greatest diamond ever found in the world (Table 1). Carbonados of Chapada Diamantina are derived from Mesoproterozoic metaconglomerates of the Chapada Diamantina Group. The primary source rock is unknown.

Exploitation reached its peak in the period from 1850 up to 1870 producing around 70,000 ct of diamonds per year. Barbosa (1991) estimated that the number of miners at that time reached 30,000 people working in the area. However, at the beginning of this century mining activities had decreased and in the years ahead never again recovered the impetus seen during the rush years around 1870.

As is well known, carbonado is a porous aggregate of polycrystalline diamond whose origin is very controversial. Neutron activation analyses of rare earth elements of carbonados from the District of Palmeiras (Bahia) were recently reported by Shibata et al. (1993). The results differ from those of kimberlite and monocrystalline diamond and resemble those of shales. A crustal origin for carbonado was proposed by Shibata et al. (1993).

Diamonds have also been mined in Camassari (north of Salvador) as well as in the Itapicuru (NE Bahia) and Salobro (SE Bahia) Rivers. Camassari has been abandoned and the diggings of Itapicuru and Salobro are of little importance.

Mato Grosso: Following the discovery of Diamantina in central Minas Gerais, diamond was discovered in the headwaters of the Upper Paraguai River at the end of the eighteenth century. Later mining development led to the discovery of diggings in the Jauru, São Lourenço and Itiquira Rivers, which still produce alluvial diamonds (Abreu 1973). Around 1909 several diggings were established between the Rivers Garças and Araguaia. Since that time diamond has been regularly mined mainly in the municipalities of Barra do Garças, Baliza, Tesouro, Guiratinga, Alto Garças and Alto Araguaia. Another area developed during the 1930s is the region of Poxoréu between the cities of Barra do Garças and Cuiabá. The main garimpos are located in the Coité, São João, Poxoréu, Alcantilado, Pombas, Papagaio and Jacomo Rivers and many others. The diamonds of the Poxoréu area are derived from conglomerates of the Bauru Group (Cretaceous). Souza (1991) estimated that the placers have a grade in diamond of 0.04 ct/m^3. Still according to this author, the Coité River has a potential of 662,000 ct/m^3 of diamonds of which only 27% are gemstones. During many years the area of Poxoréu witnessed disputes and conflicts among garimpeiros and some mining companies. In order to settle the disputes, the Brazilian Government created the Reserve of Poxoréu in November, 1979.

Juína, located in the northwest Mato Grosso, saw a rush of 30,000 diggers during the years 1987-1989. Most of the local diamonds are of industrial quality. According to Haralyi (1991), at least three million ct of industrial stones were produced in recent years. Concerning their origin, during the examination of a parcel of 600 ct (Svisero, Unpublished data), we observed hexagonal pits on the octahedral faces of several crystals similar to others previously reported for the lamproitic diamonds of Argyle, Australia.

At Fazenda Camargo near Nortelândia the exploitation of alluvial deposits is totally mechanized. Research carried out by Morro Vermelho Company revealed that gravel reserves amount to $2x10^6$ m^3 of gravel with an average diamond content of 4.5 points/m^3 (Carvalho et al. 1991).

Mato Grosso do Sul: Since the last century detrital diamond has been mined in the Coxim, Taquari, Aquidauana and Brilhante Rivers. There is no official data on the current production nor on the tenor of the placers. As for the diamond, examination of a parcel of 325 ct revealed that the stones have an average size of 19.5 points and that gemstones amount to about 70% of the stones (Svisero, Unpublished data).

Goiás: Diamond was intensively exploited during the Colonial period mainly in the Pilões and Claro Rivers both tributaries of Araguaia River on its right bank (Abreu 1973). According to Lima Jr. et al. (1984), main diggings in the south are located in the Pilões, Claro, Caiapó, Santa Marta, Bonito, Piranhas, Aporé, Verde and Veríssimo Revers. Special emphasis should be given to the Veríssimo River famous for the occurrence of big diamonds like the Goiás diamond, a 600 ct stone found in 1906 (Table 1).

Some years ago a subsidiary company of Mineração São José Ltda, carried out intense research along the Araguaia River that led to the discovery of 135,847,650 m^3 of diamond-bearing gravels. The deposits are distributed in the municipalities of Aragarças and Barra do Garças and contain 0,025 ct of diamond per

m^3. Average medium size is 0.16 ct and the amount of gemstones is on the order of 60% (Lima Jr. et al. 1984).

Tocantins: This new State, once the northern part of the State of Goiás, has a long tradition in diamond mining. Old and current diggings are distributed in the municipalities of Filadelfia (Pau Seco and Arraias Rivers), Wanderlândia (Lages River), Nova Olinda, Miracema do Norte and Presidente Kennedy. It is roughly estimated that 200 workers (garimpeiros, mineiros) are producing around 1,000 ct/year. Additional centers are located along the Tocatins, Taquaraçu, Água Suja, Areias, Garrafas and Gameleira Rivers (Lima Jr. et al. 1984).

Pará: Main deposits are located around Marabá which is the main city at the junction of the States of Pará, Tocantins and Maranhão. As in many other places, the total amount of diamond recovered from the placers is unknown. According to Abreu (1973), the area saw a rush during the thirties, producing 15,000 ct in 1937.

Paraná: Diamond was discovered in the Tibagi River in the beginning of the last century, and later in the Cinzas River and in affluents of the Itararé River. Chieregati (1989) carried out a detailed mineralogical and geological study of the diamonds recovered in the basins of the Tibagi, Laranjinhas, Cinzas, Jaguariaíva and Itararé Rivers. In those areas diamonds occur in placer deposits in concentrations ranging from 0.004 up to 0.60 ct/m3, with annual output fluctuating around 1,000 ct/year. Analyses of several parcels revealed grain sizes granulometry from 0.01 to 5 ct. Large stones of tens or even hundreds ct, like those found in western Minas Gerais, have never been recorded in the Tibagi area. Still according to Chieregati (1989), the morphology is characterized by the predominance of dodecahedral crystals over flat octahedrons and forms intermediate between dodecahedral and octahedral crystals. Flat twins, pyramidal cubes, aggregates, cleavage and fragments are less common. Carbonados are rare. Most of the diamonds are colorless (90%), the remainder showing variations of green, brown and yellow. Examination of parcels totalizing 5,000 ct revealed that 70% are gemstones.

Piauí: The diamondiferous field comprising the municipalities of Gilbués and Monte Alegre is located in south Piauí and was discovered in 1945 (Oliveira et al. 1984). After a brief rush, the deposits were soon exhausted. Today the area is almost abandoned but still produces small amounts of diamonds. One major difficulty in this area is the absence of water, making difficult to wash the gravels.

São Paulo: There are several diggings located in the municipalities of Franca and Patrocínio Paulista in the northeast part of the State as well as minor occurrences in the Verde and Itararé Rivers in the south. Diamonds from Rio Verde are small but have excellent gemological quality. Concerning Franca, it is worth mentioning that the city has been a traditional center of cutting for a long time. Most of the diamonds cut in Franca, however, come from the nearby diggings two hours away in western Minas Gerais. As for the diamond, itself at least 70% are gemstones. In addition, big stones of more than 10 ct have been periodically found in the area (Svisero, Unpublished data). The origin of diamond has been related to the conglomerates of the Aquidauana Formation (Barbosa 1991).

Maranhão: According to Abreu (1973) and Barbosa (1991), the main garimpos are located in the municipality of Imperatriz along the rivers that flow from the southwest border of the Parnaíba Basin. Production is unknown.

Rondônia: The diamondiferous area is located around the city of Pimenta Bueno in the eastern part of the State. Main garimpos are distributed in the headwaters of the Jiparaná and Roosevelt Rivers but the production is unknown (Barbosa 1991).

Roraima: The first diamonds were found in 1917 in the Tacutu River and later in the Cotingo, Quinô and Suapi Rivers. Several diggings developed during the 1950s in the Tepequém Range (Abreu 1973). Presently the washing sites are located along the Maú, Tacutu, Cotingo and Uraricoera Rivers, as well as in the Pacaraima Range in the border with Venezuela. There is no data on the current production. Rodrigues (1991) presented a detailed study of those diggings and commented on the erratic tenor of the placers. As for the production, Rodrigues (1991) emphasized that while the official amount averages 6,000 ct/year, the real estimated value is on the order of 60,000 ct/year. Rodrigues (1991) suggests a derivation from the Mesoproterozoic Roraima Group.

Amapá: The first data on the presence of diamond in the Vila Nova River, Amapá, was presented by Santos et al. (1984). As for other localities, no data on production or quality of diamonds are available.

Other countries: Besides Brazil, detrital diamonds occur within the Guyana Shield in Venezuela (Guaniamo and Caroni Rivers), Surinam (Surinam and Saramacca Rivers), Guyana (Mazaruni River) and Colombia (Guapayito River). Although Venezuelan diamonds have been known since 1887 in placers of the Caroni River, the production only peaked in the 1970s after the discovery of the rich recent alluvium deposits of the Quebrada Grande River, a tributary of the Guaniamo Basin (Baptista & Svisero 1978). During many years geologists linked the source of diamond in Venezuela and neighboring countries to the Proterozoic conglomerates of Roraima Group. Recently, however, Nixon et al. (1989) reported the discovery of diamondiferous kimberlites located near the Village of La Salvacion in the Guaniamo drainage basin. As stated by Nixon et al. (1989), this important discovery opens a new era for diamond exploration not only in Venezuela but also in the Guyana Shield as a whole. In addition, detrital diamonds occur in the Aquidaban River, Paraguay. Geological evidence suggests that similar deposits may occur in the headwaters of the upper Paraguay River in Bolivia.

GEOLOGICAL CONTEXT

Figure 4 presents a schematic framework of the main geological and tectonic features of South America. It enhances the four major cratonic areas represented by the Amazonian, São Luis, São Francisco and Rio de La Plata Cratons, as well as several smaller cratonic blocks which for convenience have not been labeled (Brito Neves & Cordani 1991). All of these cratonic terranes were stabilized before 1.5 Ga and behaved rigidly during the tectonic thermo-metamorphic processes of the Brasiliano Cycle which lasted from the Mesoproterozoic up to the Early Paleozoic. In addition, Figure 4 shows the Proterozoic fold belts surrounding the cratons, the large Phanerozoic covers and the modern Andean Chain.

The majority of the plotted diamond occurrences fall within (cratonic) or near the craton borders (pericratonic). Of the 36 sites the Amazonian Craton houses 13 and the São Francisco Craton 7. The remaining are dispersed along the SE, NE, N, NW and W borders of the Paraná Basin (11) and on S and W borders of the Parnaíba Basin (2). A single locality lies on the minor cratonic block between the Amazonian and the São Francisco Cratons. Diamonds have never been found on either the São Luis or the Rio de La Plata Cratons.

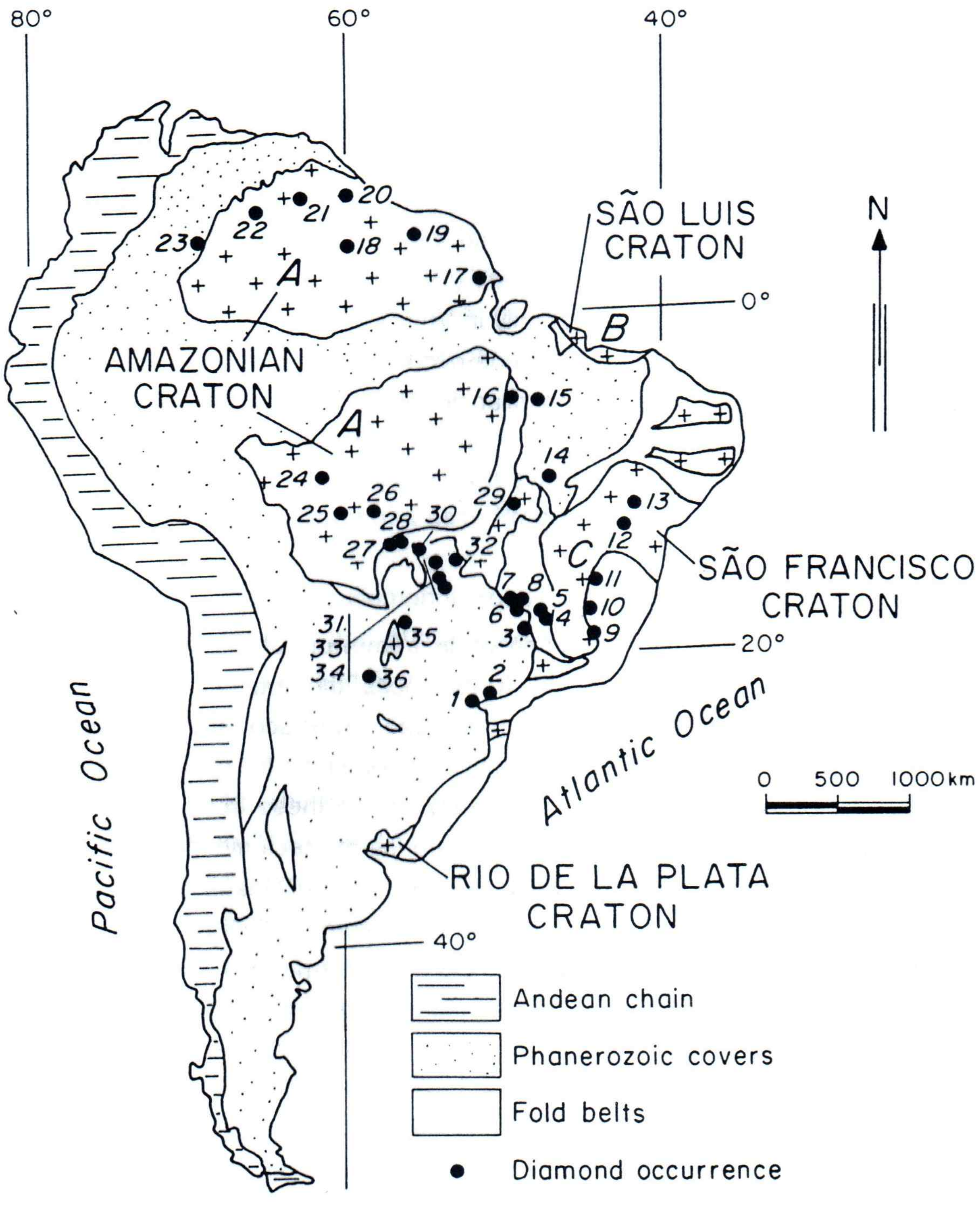

Figure 4 - Gologic and tectonic framework of South America showing placer deposits. Geology based on Brito Neves & Cordani (1991).

As shown in Figure 5 the small segment of São Luis Craton was linked to the huge West African Craton within Gondwana. While diamond is absent on the Brazilian side, the African counterpart contains diamonds as well as kimberlites in Ivory Coast, Liberia, Sierra Leone, Ghana and Mali. Likewise, the São Francisco Craton is only a small projection of the immense Congo Kasai Craton which dominates most of southwestern Africa. The contours of the Parnaíba and Paraná Basins show that both developed intracratonically between much older Pré-Cambrian cratons. Consequently, any discussion of the origin of the detrital diamonds in both synecleses seems at the moment a little bit speculative.

Since the discovery of diamonds in the country, Brazil has been mining detrital deposits including alluvial, elluvial, colluvial and terrace gravels, as well conglomerates of several geological ages. Up to this moment any diamond-bearing kimberlite containing commercial tenors has officially been reported. The age of Brazilian deposits is another controversial question. According to Gonzaga & Tompkins (1991), there are secondary deposits throughout the entire sedimentary record of Brazil from the Lower Proterozoic up to the Quaternary. On the whole, there is still an enormous lack of detailed information concerning most of the diamond deposits in Brazil, including detailed geological data for each site, kimberlite indicator minerals, as well as data on the physical characteristics of diamond and its solid inclusions.

Returning to Figure 4, it is convenient to stress that the plotted numbers are merely representative of a much larger number of occurrences as shown in the Geological Map of Brazil (Schobbenhaus 1981). In order to avoid more generalizations, we will make some comments on three localities where the secondary source rocks are representative of Pre-Cambrian, Paleozoic and Mesozoic ages.

Field evidence shows that diamonds mined in the Diamantina area have an unequivocal Pre-Cambrian origin. The source-rocks are the Upper Proterozoic conglomerates of the Sopa Brumadinho Formation which have been mined since 1725. Therefore, the original primary rock is at least Late Proterozoic in age or even older. The origin of these diamonds have being intensely debated among Brazilian geologists, as reviewed by Chaves et al. (1993). As shown in Table 2, one basic point is the absence of kimberlite mineral indicators among the heavies in the concentrates (Chaves & Svisero 1992). Consequently, the primary sources may have been completely eroded or, alternatively, they may be covered by metasediments of the Bambui Group. The fanglomeratic character of the local metaconglomerates on the other hand, suggests that the primary sources might not have been far from the current mining sites.

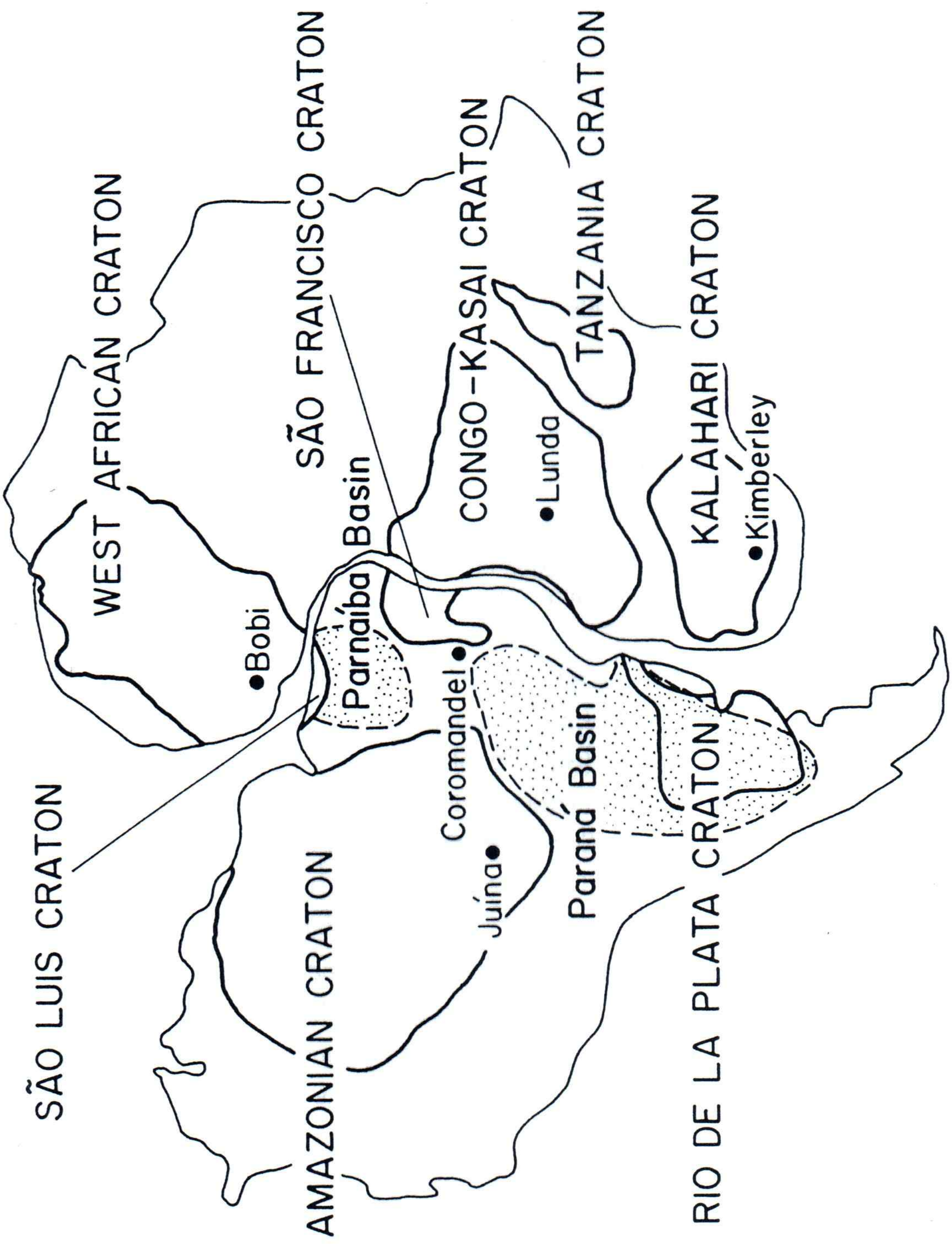

Figure 5 - Pangea reconstruction (ca. 200 Ma) showing the connection of the Brazilian and African Cratons and the Paleozoic Paraná and Parnaíba synecleses. Some notable diamond places are indicated.

Tibagi, in the southeastern Paraná Basin, may be taken as a case study of occurrences related to the Paleozoic syneclese of the Paraná Basin (Figures 4 and 5). Field evidence shows that Tibagi diamonds are related to the clastic rocks of the Paraná Group (Devonian) as well as to the Itararé Subgroup (Permo-Carboniferous). The later contains documented evidence of glacial contribution (Santos 1987). In order to investigate the source of Tibagi diamonds, mineral concentrates were systematically collected at more than one hundred different targets within the area of recorded diamond exploration (Chieregati & Svisero 1990). The mineralogical assemblage identified by X-ray diffraction is shown in Table 2. Although garnet and ilmenite are among the heavies, neither is related to kimberlite sources. Microprobe analyses revealed that garnet is essentially almandine and the ilmenite a magnesium-free type. The absence of kimberlite indicators suggests that Tibagi diamonds are recycled. Geological evidence suggests, on the other hand, that the Permo-Carboniferous glaciation may have played a key role in the origin of these deposits. Figure 6 shows the spatial distribution of the Paraná Group (Devonian) and the Itararé Subgroup (Permo-Carboniferous) sequences, as well as the general trend revealed by several types of structures related to ice movement (Santos 1987). The N-NW trend suggests that the primary sources of Tibagi diamonds were located in the south, either in the Rio de La Plata Craton or the Kalahari Craton (Figure 5).

The Romaria Mine on the northeastern border of Paraná Basin (Figure 4) exemplifies a case of Mesozoic secondary source. Diamond has being exploited at this locality from an Upper Cretaceous polymictic conglomerate located at the base of Bauru Group. The general character of the conglomerate of Romaria resembles in some ways the metaconglomerates of Diamantina although the occurrences are separated in time by almost 2 billion years. Table 2 shows the mineralogical assemblage recovered in the washing plant when the mine was still operating. Mg-ilmenite and Cr-pyrope garnets are among the heavies (Svisero & Meyer 1981). Officially, this is the only place with reported occurrence of kimberlite mineral indicators in a secondary diamond deposit.

The primary sources of diamonds in Romaria as well as in other parts of western Minas Gerais is highly controversial. Some, researchers like Tompkins & Gonzaga (1987), for instance, advocate that diamonds from the Coromandel area were brought by glacial transport from primary sources located somewhere in the São Francisco Craton. Others including Svisero et al. (1977, 1979, 1984), Barbosa (1991). and Leonardos (1991, 1993) maintain that kimberlite-bearing rocks do occur in the area. Particularly we think that the remarkable concentration of great diamonds around Coromandel and the presence of kimberlite indicators in the Romaria heavies are additional arguments for the presence of primary sources in the area.

Table 2 - Mineralogical composition of concentrates from Diamantina (Chaves & Svisero 1992), Tibagi (Chieregati & Svisero 1990) and Romaria Mine (Svisero et al. 1980)

Diamantine Area Minas Gerais	Tibagi River Paranáa	Romaria Mine Minas Gerais
Magnetite	Magnetite	Magnetite
Hematite	Ilmenite	Hematite
Limonite	Leucoxene	Limonite
Ilmenite	Limonite	Mg-ilmenite
Rutile	Hematite	Cr-Pyrope garnet
Anatase	Almandine - garnet	Almandine - garnet
Hornblende	Monazite	Corundum
Staurolite	Xenotime	Monazite
Epidote	Apatite	Rutile
Zircon	Zircon	Tourmaline
Apatite	Tourmaline	Staurolite
Gold	Spinel	Anatase
Diamond	Rutile	Kyanite
	Staurolite	Hornblende
	Anatase	Epidote
	Pyrite	Diamond
	Epidote	
	Hornblende	
	Titanite	
	Cassiterite	
	Gold	
	Diamond	

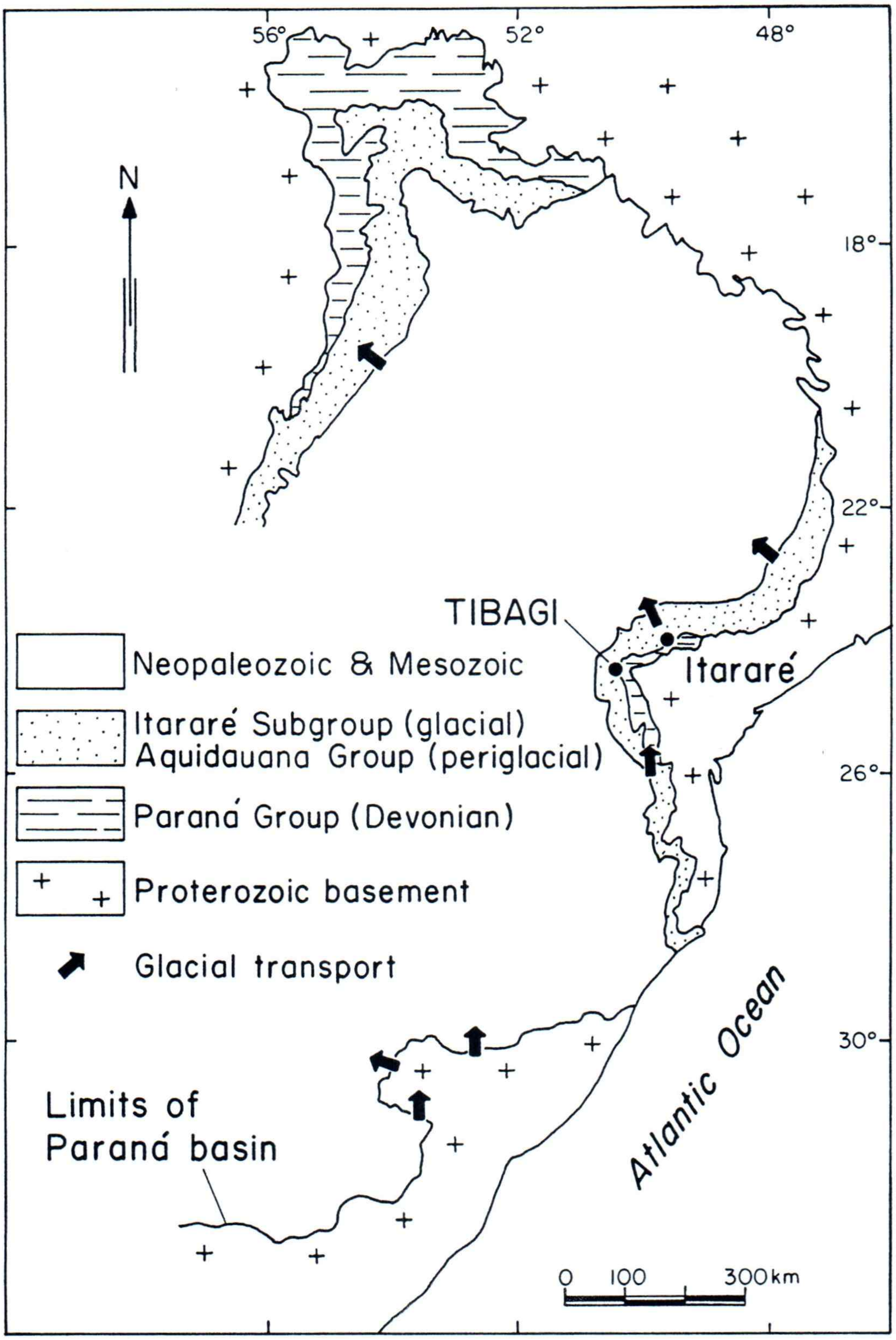

Figure 6 - Directions of ice movement during the Permo-Carboniferous glaciation of Paraná Basin. The N-NW trend suggests that the source area is located to the south either in the Rio de La Plata or the Kalahari Cratons. Modified from Santos (1987).

DIAMOND INCLUSIONS

Svisero (1971) and Leite (1972) reported the first data on mineral inclusions of Brazilian diamonds using X-ray diffraction techniques. Meyer & Svisero (1975) later carried out an intensive chemical investigation of diamonds from the States of Minas Gerais, Goiás, Mato Grosso, Bahia and Paraná. These results and other subsequent determinations of samples selected from parcels of industrial diamonds are summarized in Table 3. Excepting zircon, all the other mentioned phases have been described in diamonds elsewhere (Meyer 1987). Therefore, it is apparent from Table 3 that the diamonds from all sampled localities have a conventional origin from kimberlite and/or lamproite rocks. Unfortunately, such primary rocks have not been found yet in the sampled localities.

Table 3 - Mineral inclusions in Brazilian diamonds

Sampling locality	Mineral inclusions	Reference
Garças and Araguaia Rivers, Mato Grosso	olivine, garnet, enstatite, spinel, diamond	Svisero (1971)
Western Minas Gerais	olivine, garnet, spinel, pentlandite	Leite (1972)
Garças, Araguaia and São Lourenço Rivers, Mato Grosso	olivine, enstatite, Cr-pyrope, pyrope-almandine, zircon, rutile, pyrrhotite, ilmenite	Meyer & Svisero (1975)
Diamantina - Datas area, Minas Gerais	olivine, enstatite, Cr-pyrope, pyrope-almandine, diamond	
Tibagi River, Paraná State	olivine, Cr-pyrope, pyrrhotite	
Paraguaçu River, Bahia	olivine, enstatite, Cr-pyrope, ilmenite	
Caiapônia, Mineiros and Aragarças area, Goiás	olivine, enstatite, Cr-pyrope, pyrope-almandine, rutile, ilmenite	
São Luis River, North Mato Grosso	pyrope-almandine and majorite garnets, clinopyroxene, periclase-wüstite ss., nickel, iron-nickel alloy, pure silicates with compositions of silica, wollastonite and diopside, moissanite	Wilding et al. (1991)

Outstanding results were reported by Wilding et al. (1991) during the 5th IKC in Araxá for diamonds from the São Luis River located in northern Mato Grosso. The phases identified include pyrope-almandine and majorite garnets, clinopyroxene, periclase-wüstite solid solution, nickel, iron-nickel alloy, pure silicates with compositions of wollastonite, silica and diopside, and moissanite as well. Following Wilding et al. (1991), the mineral assemblage found in São Luis diamonds may well be representative of depths around ~650 km.

KIMBERLITE-TYPE ROCKS

Although diamond was discovered as early as 1720 in Brazil, its primary source-rock started being found only in the late 1960s. The main reasons for such delay apparently can be attributed to the intense tropical weathering, absence of expertise of local companies in kimberlite geology, as well as to the influence of the great geoscientist Djalma Guimarães who postulating an acid origin for Brazilian diamond, inhibited a whole generation of geologists.

The first kimberlite-type rocks were discovered in the Coromandel area of Minas Gerais as a consequence of systematic surveys carried out by the Sopemi mining company tracking back kimberlite mineral indicators such as Mg-ilmenite, Cr-pyrope garnet, Cr-spinel and diopside. During the 1970s a local company, Prospec, developed similar surveys, thus increasing the known number of intrusions, but, like its competitor, never published any results. According to Barbosa et al. (1976), the first kimberlitic intrusion was found in 1969 at the Vargem Farm, which would be labeled later as Vargem 1. Knowledge of these rocks can be divided into two distinct periods: prior to and following the Fifth International Kimberlite Conference (5th IKC) held in Araxá in 1991. During the former period, the first geological informations were reported by Barbosa et al. (1976) and Svisero et al. (1977, 1979). Data on the mineralogy and the chemistry of concentrates from the weathered intrusions of Vargem 1, Vargem 2, Poço Verde, Capão da Erva, Lagoa Seca, Morungá, Japecanga and Santa Clara were provided by Svisero et al. (1977, 1984). Geological maps supplied with geophysical data have been published for the intrusions Limeira (Svisero et al. 1980), Sucuri (Svisero et al. 1982), Indaiá (Svisero et al. 1984), Vargem 1 and Vargem 2 (Svisero et al. 1986), Poço Verde Svisero et al. (1987) and Pântano (Meyer et al. 1991). Outside Minas Gerais, kimberlite-type rocks have been reported in the States of Mato Grosso (Fragomeni 1976), Piauí (Svisero et al. 1977), Rondônia (Svisero et al. 1984), Santa Catarina (Scheibe 1980), Goiás (Tompkins 1987) and Rio Grande do Sul (Almeida & Svisero 1991).

The 5th IKC in Araxá in 1991 was a major event for the progress of diamond and kimberlite geology in Brazil. During the meeting new and important results were presented, including those of Bizzi et al. (1991) and Meyer & Svisero (1991) which showed that the Limeira, Indaiá and 3 Ranchos intrusions have mineralogical and bulk chemistry compositions comparable to Group I kimberlites elsewhere in the world. In terms of Sr and Nd systematics, however, these intrusions are intermediate between kimberlites of Groups I and II (Figure 7). Other alkaline ultrabasic intrusions as well as the HPT basalts (enriched in phosphorus and titanium) of the Paraná Basin plot between Groups I and II kimberlites (Meyer et al. In Press, Bizzi et al. In Press). As stated by Bizzi et al. (1991), these are the first documented examples of kimberlites and related rocks with isotopic compositions falling between those of South African kimberlites. Similar conflicting characteristics were observed for the alkaline intrusion of Presidente Olegário. According to Ulbrich and Leonardos (1991), the mineralogy and the texture of the lavas resemble those of ultrabasic lamproites; major element chemistry however indicates a kamafugitic affinity. Other mineralogical and chemical studies of rocks from western Minas Gerais include data for the Fazenda Alagoinha or 3 Ranchos 4 intrusion (Danny et al. 1991), Boa Esperança and Cana Verde pipes (Tompkins & Ramsay (1991), and lavas from Mata da Corda Formation (Sgarbi & Valença (1991). Moreover, several other papers were presented in which new geologic aspects of the Brazilian diamond deposits were discussed.

New and important informations were reported during the First Brazilian Geological Symposium on Diamond held in Cuiabá in August, 1993. These included chemical data on a garnet lherzolite xenolith from 3 Ranchos intrusion (Leonardos et al. 1993), geological and chemical studies of the intrusion Mata do Lenço (Talarico et al. 1993), and Sr-Nd isotope composition of kimberlites and associated rocks of the west side of the São Francisco Craton (Bizzi et al. 1993). Moreover, during the meeting several specific papers on diamond deposits of several localities were reported as those of Fleischer (1993) and Weska et al. (1993). Summarizing, there is a great number of general information on the occurrences of kimberlite-type rocks in several States of Brazil. At the same time, detailed chemical investigations, although still restricted to only a few intrusions, have hopefully increased in the last years.

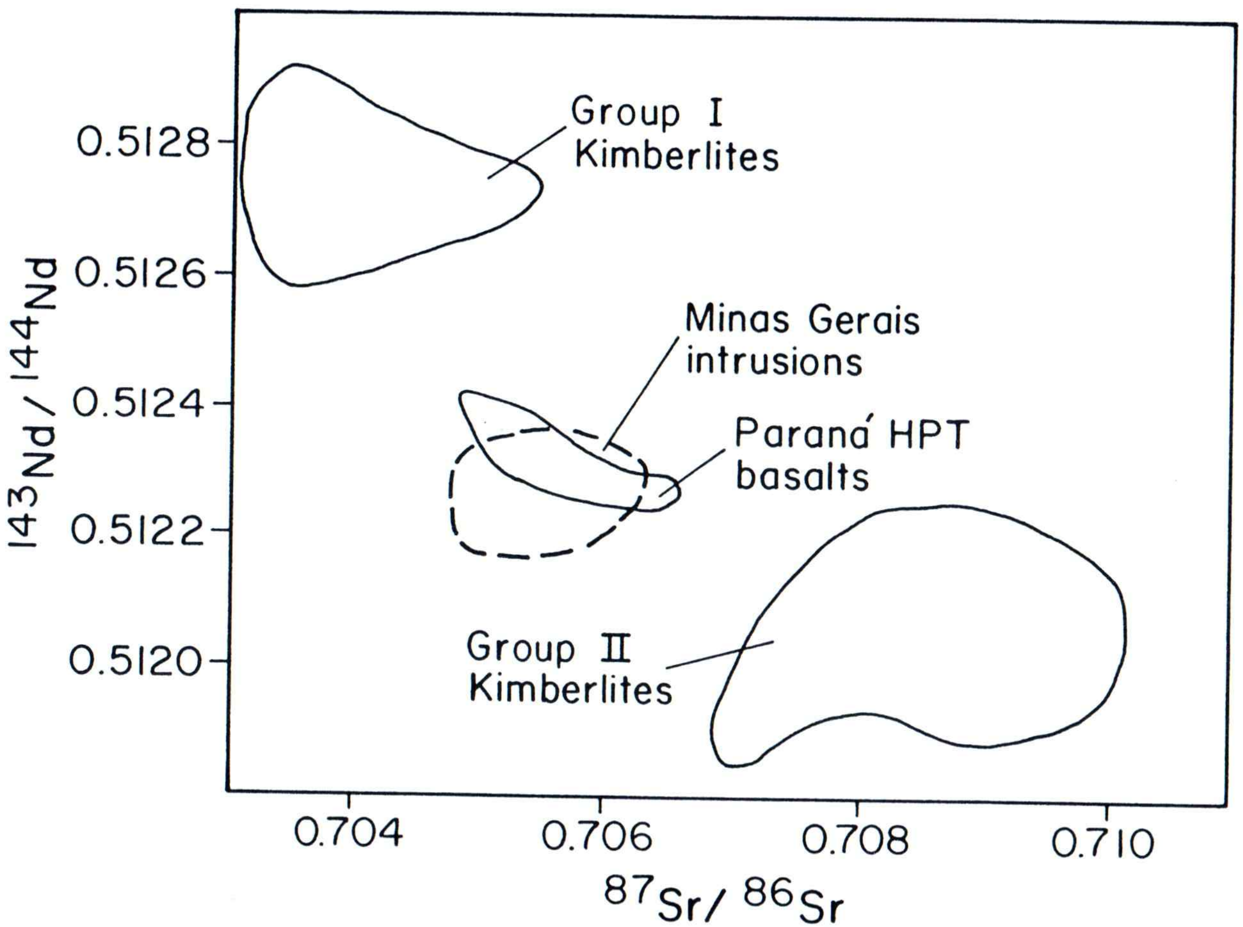

Figure 7 - Nd and Sr isotope composition of western Minas Gerais intrusions (dashed field) after the data of Meyer et al. (In Press). Fields of Group I and Group II kimberlites and Paraná HPT basalts were reproduced from Meyer et al. (In Press). As shown here, Minas Gerais rocks are intermediate between Group I and Group II kimberlites and plot near the Paraná HPT basalts.

As a final comment, we expect that the presence of the highly complex intermediate kimberlitic rocks in the Coromandel area and the discovery of the high-depth mineralogical assemblage in São Luis diamonds, will renew the interest in the origin of diamonds and its primary sources in Brazilian territory.

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