Minerals and Mining in the Brazilian Economy

by Evaristo Ribeiro Filho, João B. Moreschi and Arlei B. Macedo

With its gigantic natural resource base, Brazil in the last two decades has become a world leader in the production and export of several important minerals. Following a summary of the major economic indicators - production, consumption, export and import, the authors review the geology of the main ore deposits and discuss mining and exploration policies together with a series of recommendations proposed for their improvement. (Ed.)

Development of Brazil's Mining Industry

The search for mineral resources in Brazil has a long history. During the colonial period, there was much interest in alluvial gold, diamonds and gemstones, encouraged both by Portuguese and English interests. By the 16th century, gold had already been discovered in São Paulo state, but the exploitation of diamonds (in the Diamantina area of Minas Gerais) began only in the 18th century. Geological research started in Brazil in the early 19th century; until then mineral exploration was restricted to gold, diamonds, gemstones and building materials. Manganese and iron were the first raw materials for the steel industry to be produced in Brazil. In the beginning of the 19th century, Baron Eschwege built Catalonian forges in Minas Gerais for the smelting of iron, and by 1894 manganese was already being commercially produced there. The production of coal in Rio Grande do Sul state also began in the 19th century.

Many factors have contributed to the increase of geological research and mineral exploitation in Brazil, especially since the 1960s. Fiscal and tax incentives have been given to the mining industry, the Mining Code has been revised, and geological and mining research has benefitted from overseas funds. Government geological services have been set up in the states. Universities have performed well and have trained many geologists. Research institutes and government mineral and petroleum exploration companies have been established, and many private exploration and mining companies have been formed. Prospecting and research is now based on metallogenetic principles, and geochemical, geophysical, and photogeological and remote sensing techniques are widely used. The discoveries made in the Carajás mineral province of iron, manganese, nickel, gold, copper, bauxite and tungsten demonstrate the success that systematic research and modern prospecting methods have achieved.

The mining of raw materials for the steel industry is a good example of an area where the mineral exploration developed through the association of foreign companies, private Brazilian companies and joint ventures. Iron, which is the main mineral commodity produced in Brazil, in terms of both value and tonnage, is mined mainly in Minas Gerais and in the Amazonian district of Carajás. Although it is produced in greater quantities by a Government company, Companhia Vale do Rio Doce, iron is also mined by MBR, Ferteco Mineração S/A, Samitri, Samarco, Siderúrgica Nacional and other smaller companies.

Though petroleum and natural gas are still being imported, their increasing production demonstrates the success Petrobrás (Petróleo Brasileiro S/A) has achieved in the exploration, research development and exploitation of these fossil fuels. Petrobrás is a government company that has a monopoly on the research and production of petroleum and natural gas in Brazil. Its work since 1973 has increased the reserves and output of petroleum and gas.

Brazil has diversified its mineral production since the 1970s thanks to a mineral policy oriented towards increasing exports and decreasing dependence on products that cannot be replaced in industry and agriculture (Fig. 1 and Table 1). In terms of its GNP, Brazil's mineral production increased from 2 to 4.6% over the past decade with a decrease to 2.8% in 1986. The value of the annual mineral production varies from 7.0 to 10.5 billion dollars. Fourteen mineral commodities account for 94% of Brazilian production: petroleum, iron, gold, natural gas, phosphate, aluminium, building stones, limestone, niobium, sand, tin, manganese, clay and asbestos. Brazil produces also 52 other mineral commodities.

TABLE 1: Principal Brazilian Ore Reserves and Production 1986

Mineral Commodities	Reserves[1] (10^6T)	%[2]	Mineral Commodities	Production (10^3T)	%[2]
Niobium[3]	5.9	91.2	Niobium[3]	17.2	87.8
Barite	135.0	23.1	Tantalum[3]	0.033	15.7
Graphite	25.2	16.8	Tin[3]	26.4	15.3
Talc	174.0	12.9	Iron	128,800.0	15.0
Aluminum	2,511.0	10.8	Manganese	2,400.0	10.2
Kaolin	1,237.8	9.6	Aluminum	6,544.0	8.3
Vermiculite	16.0	9.0	Talc	586.0	7.0
Iron	17,600.0	8.4	Graphite	34	5.3
Magnesite[3]	180.0	7.0	Magnesite[3]	185.0	5.2
Tin[3]	0.2	5.8	Asbestos[4]	204.0	5.0
Nickel[3]	5.4	5.3	Chromium[5]	135	3.1
Asbestos	3.5	3.3	Nickel[3]	21.4	3.0

Source: Brasil, Ministério das Minas e Energia (1987b)
(1) - measured + indicated reserves, (2) - participation in the world supply, (3) - contained metal, (4) - as fiber, (5) - as Cr_2O_3

Table 2 lists the principal non-fuel minerals exported and imported in 1986. In 1987 the total value of all imports was US$4 billion, of which petroleum accounted for 71%, coal 11.4%, natural gas 2.7%, potash 7.8%, sulphur 3.9%, copper 1.8%, zinc and molybdenum 0.4% each and all others 0.6%. Exports in the same year were valued at US$1.7 billion of which iron comprised 86%, bauxite 5.5%, manganese 2.0%, granite 1.3%, kaolin 1.2%, magnesite 1.0%, gemstones 0.8%, asbestos 0.6% and others 1.6%.

Petroleum production has increased in recent years from 200,000 to 600,000 bbl/day. Petrobrás, which has been producing petroleum and natural gas from the Campos, Rio de Janeiro, Espírito Santo, Bahia, Sergipe, Alagoas, Rio Grande do Norte and Ceará basins, is planning to raise output of oil to 740,000 bbl/day and natural gas to 23 x $10^6 m^3$/day by 1989, with the best prospects in the offshore sedimentary basins (see article by Chang et al., this issue).

Iron

Brazilian iron production is now growing, with the giant Carajás deposits aiming to surpass 135 million tons/year, placing Brazil as the second largest producer in the world. Over 90% of Brazilian iron reserves of iron are located in the Quadrilátero Ferrífero ("Iron Quadrangle," Minas Gerais), and in Carajás. The former, which produced 91.5% of the total iron ore in 1986, comprises the classic Itabira

Figure 1: Broad geological divisions of Brazil showing location of major mineral districts and deposits. (After Schobbenhaus and Campos, 1984).

Aluminum:	Al-1	-	Trombetas
	Al-2	-	Paragominas
	Al-3	-	Almeirim
	Al-4	-	Poços de Caldas
Asbestos:	Am-1	-	Canabrava
Barite:	Ba-1	-	Araxá
	Ba-2	-	Camamu
Copper:	Cu-1	-	Salobo 3A
	Cu-2	-	Caraíba
	Cu-3	-	Camaquã
	Cu-4	-	Mara Rosa
Fluorite:	F-1	-	Morro da Fumaça
	F-2	-	Sete Barras
Gold:	Au-1	-	Nova Lima District
	Au-2	-	Serra da Jacobina
	Au-3	-	Araci
	Au-4	-	Middle Tapajós River Province
	Au-5	-	Xingu-Araguaia Rivers Province
	Au-6	-	Madeira River Province
	Au-7	-	Alta Floresta
	Au-8	-	Serra Pelada
Graphite:	Gf-1	-	Pedra Azul
Iron:	Fe-1	-	Quadrilátero Ferrífero
	Fe-2	-	Carajás Mineral District
	Fe-3	-	Urucum
Kaolinite:	Cm-1	-	Capim River
	Cm-2	-	Jari River
Lead:	Pb-1	-	Morro Agudo
	Pb-2	-	Boquira
	Pb-3	-	Panelas
	Pb-4	-	Barrinha
	Pb-5	-	Perau
Magnesite:	Mg-1	-	Brumado
Manganese:	Mn-1	-	Serra do Navio
	Mn-2	-	Azul
	Mn-3	-	Buritirama
	Mn-4	-	Urucum
	Mn-5	-	Lafaiete
Nickel:	Ni-1	-	Americano do Brasil
	Ni-2	-	Fortaleza de Minas
	Ni-3	-	Niquelândia
	Ni-4	-	Santa Fé
	Ni-5	-	Barro Alto
Niobium:	Nb-1	-	Araxá
	Nb-2	-	Tapira
	Nb-3	-	Ouvidor
	Nb-4	-	Catalão
	Nb-5	-	Seis Lagos
Talc:	To-1	-	Brumado
	To-2	-	Nova Lima
Tin:	Sn-1	-	Pitinga
	Sn-2	-	Xingu River
	Sn-3	-	Tapajós-Jamanxim rivers
	Sn-4	-	Rondônia Tin Province
	Sn-5	-	Central Goiás State
Vermiculite:	Vm-1	-	Catalão
	Vm-2	-	Ouvidor
	Vm-3	-	Paulistana
Zinc:	Zn-1	-	Morro Agudo
	Zn-2	-	Vazante

TABLE 2: Principal Export and Import of Non-Fuel Mineral Products in 1986

Mineral Commodities	Exports (10^3t)	% (1)	Mineral Commodities	Imports (10^3t)	% (2)
Iron (ore + pellets)	95,500.0	74	Potassium (as K_2O)	1,161.9	99
Bauxite (dry base)	3,113.1	47	Sulphur	1,056.0	79
Manganese (3)	704.0	29	Marine Salt	783.3	26
Kaolin (3)	204.1	38	Phosphoric acid (6)	196.0	21
Magnesite (3)	76.5	25	Copper (7)	193.0	74
Marine salt	37.5	1.6	Zinc (7)	57.9	36
Asbestos (fiber)	29.6	14	Lead (7)	37.4	36
Chromite (4)	23.7	20	Diatomite (3)	17.5	47
Copper (metal)	22.0	13	Bentonite (3)	15.6	8
Tin (metal)	19.1	76	Zircon (3)	11.0	44
Graphite (3)	9.8	29	Chromite (8)	10.7	100
Niobium (5)	8.0	71	Titanium (3) (as TiO_2)	10.5	20
Barite (3)	6.0	5.5	Asbestos (9)	3.0	1.7
Quartz	3.9	2.5	Molybdenum (3)	1.8	100

Source: Brasil, Ministério das Minas e Energia (1987b).
(1) - export/production ratio; (2) - import/consumption ratio; (3) - concentrates; (4)- as metal and alloys; (5) - Fe-Nb alloy as Nb_2O_5; (6) - as P_2O_5; (7) - metal + metal in concentrates; (8) - refractory Cr_2O_3; (9) - fiber plus powder.

District occurrences of Lower Proterozoic, Superior-type iron formation. For decades now, the Quadrilátero Ferrifero has attracted the attention of many researchers, such as Dorr (1969 and 1973) and Schorscher and others (1982). The iron formation is in the middle Itabira Group (mostly chemical sedimentary rocks) of the Minas Supergroup, where both the lower and upper units consist of clastic sedimentary rocks. The huge deposits of very rich hematite ore are also hosted in the basal formation of the Itabira Group, the Itabirito Cauê.

The iron deposits of the Carajás mineral district were discovered in 1967, and in 1986 supplied 8.5% of the national production. The eventual aim is to mine 135 million tons per year. The Carajás deposits are also hosted in iron formations possibly of Archean Age (with both Superior and Algoma-type features). The relatively recent discovery and the remote location of the Carajás District explain why this region is less well known. Nevertheless in a few years important reserves of copper, nickel, gold, manganese, as well as of iron have been added to the national ore supply, and the production of technical and scientific papers is continually increasing (Beisiegel, 1973; Hirata et al., 1982; Santos e Loguércio, 1984; Hasui and de Almeida, 1985).

The iron ore of the Carajás mineral district occurs in four widely scattered groups of deposits: Serra Norte, Serra Sul, Serra Leste and São Félix. The Carajás Formation is the middle unit of a metasedimentary rock suite with itabirites (metamorphosed oxide-facies iron formation) and subordinate basic metavolcanics in the upper and lower units. The major iron formations, on average 200m thick, cover tens of kilometres (sometimes over 150 km, as in the Quadrilátero Ferrífero) along erosional surfaces often covered by an oxidized surficial rocky formation (called "canga"), highly resistant to weathering and erosion.

In both regions the ore varies from almost pure hematite, hard or friable with grades over 65% Fe, to soft, itabirite ore with over 40% Fe. Phenomena related to diagenesis, metasomatic replacement of the ferruginous rock and silica leaching by weathering are believed to have been the main processes responsible for iron enrichment in these deposits, though there is still much debate.

Along the Brazil-Bolivia frontier, are the iron ore deposits of the Urucum region. These occur in unmetamorphosed jaspilitic oxide-facies iron formation whose age is considered to be Late Proterozoic. These mineral deposits are not so large as those cited above and transport problems make mining difficult. The host rock, locally oolitic, is 300 m thick and averages 50% Fe, composed of hematite and crypto-crystalline silica (usually jasper-like). The iron ore (over 60% Fe) originated through supergene leaching of silica. Associated to the ferruginous sequence there are high grade (averaging 45% Mn) sedimentary manganese oxide beds.

Nickel

About 97% of Brazil's present ore reserves of nickel are lateritic, but two massive sulphide deposits of average size are also known although not yet exploited: Americano do Brasil (Nilson et al., 1982) and Fortaleza de Minas (Cruz et al., 1986). Partly or entirely serpentized ultramafic rocks from different Archean to Mesozoic-Cenozoic geotectonic settings are the sources for the supergene deposits. The major reserves (77%) and production (80%) are concentrated in the central region of the country, such as Niquelândia (Fig. 2), Barro Alto and Santa Fé districts. The ores (averaging 1% to 2% Ni) are dominantly of the silicate type (with minor limonitic material) and represent products of lateritic weathering under special tectono-climatic conditions that occurred throughout Cenozoic times (Trescases et al., 1979).

Figure 2: Open pit in the lateritic nickel deposit of Niquelândia, Goias State

Niobium

About 92% of the world's reserves of niobium are in the Brazilian carbonatite complexes. As a consequence of this Brazil is the greatest world producer of niobium as Fe-Nb-C alloy, and plans are being made to produce metallic Nb too. Columbite-tantalite and djalmaite mostly in pegmatites were for a long time the main sources for niobium produced in Brazil, but pyrochlore is now the most important ore mineral. The Araxá mine in the State of Minas Gerais, represents approximately 70% of the world reserves of Nb_2O_5 and yields over 80% of the national output of concentrates, as well as 60% of the international market.

The Araxa and other Brazilian deposits (Tapira, Ouvidor, Catalão, Morro dos Seis Lagos) are related to alkaline - carbonatitic rock complexes. All are known to be Cretaceous in age except the Seis Lagos deposit whose age is unknown (Schobbenhaus, 1986). Weathering was the principal agent for the enrichment of the niobium ore to grades ranging from 1% to 2.8% of Nb_2O_5. Commonly associated ores include apatite, barite, titanium, vermiculite and REE.

Manganese

The total reserves of manganese oxide ores are about 210 million tons. The total Brazilian annual consumption of manganese ore is about 900,000 tons and the present annual exports are about 1.2 x 10^6t. Brazil was also importing manganese ore from Africa for use in the battery industry, but Carajás will now supply both the metallurgical and the battery-grade manganese oxide.

Aluminum

Brazil is the world's third largest producer of bauxite with an annual output of 6.5 million tons, and with important reserves, notably from the great deposits of the Amazonian Region (e.g. Almeirim, Trombetas, Paragominas, Faro), which represent over 80% of the measured reserves (estimated at 4.4 billion tons) and at least 75% of the total ore production. The remaining reserves are spread over a great number of minor deposits that range from a few thousand tons to tens of millions of tons. Among the latter are the deposits of the Poços de Caldas District, which account for about 20% of the domestic production.

Tropical weathering of suitable rocks has led to the formation of high Al (45% Al_2O_3), low SiO_2 and variable Fe_2O_3 bauxitic ores. The deposits are of residual laterites (blanket type) with gibbsite as the principal ore mineral. They formed during and after the Tertiary Period over several different rock types: continental clayey-silty sediments, which in the Amazonian Region form extensive plateau-type lateritic-bauxitic covers (Grubb, 1979); igneous alkaline rocks, as in Poços de Caldas District (Almeida, 1982); and low to high-grade metamorphic rocks such as those of the Cataguases District (Roeser et al., 1984).

Tin

In 1974 Brazil imported more than 50% of the tin it consumed. Nowadays, with an annual production of 26,400 tons of tin, the country is self-sufficient and even exported 19,000 tons in 1987. The great majority of Brazilian tin deposits are residual or alluvial placers in which cassiterite is virtually the only tin mineral. Most tin reserves and potential resources are located in the Brazilian northern region (Amazon River Basin) and central region (State of Goias), though tin occurrences and small deposits have long been reported from many other parts of Brazil.

In the Amazonian Craton the tin-bearing deposits, occurrences and districts (such as Pitinga, Xingu River, Tapajos-Jamanxim, and the Rondônia Tin Province) are associated with anorogenic rocks attributed to events of reactivation (Montalvao and Bezerra, 1980) or reflect magmatic activity of Middle Proterozoic age (Cordani et al., 1979) or both. Bettencourt and others (1981) have suggested that the granites and related mineralization reflect intraplate hot spots or related events. The major mineral exploration and exploitation involve clastic sediments of valley systems of Pleistocene and Holocene age, as well as in eluvial and colluvial concentrations as summarized by Bettencourt and others (ibid). Several occurrences and small deposits of primary mineralization (including in many places greisens) are known, such as the Potosi Hill deposit in the Rondônia Tin Province (Korpershoeck et al., 1980). Ore grades are commonly in the order of hundreds of grams per cubic metre, sometimes reaching values of few tens or hundreds kg/m^3.

TABLE 3: Base Metals: Brazilian Situation in 1986

	Copper	Zinc	Lead
World reserves*	566,000	303,056	142,000
Brazilian reserves*	11,000 (2.0)	3,056 (1.0)	349 (0.2)
World production*	8,110	6,808	3,400
Brazilian production*	40 (0.5)	158 (2.3)	13 (0.4)
Apparent consumption*	261	158	102
Production/reserves(%)*	0.3	5.1	3.7
Production/consumption (%)**	15	100	13
Reserves/consumption (years)**	42	19	3

* 10^3t contained metal
** For Brazil
Figures in parentheses: percent participation in the world supply.
Source: Brasil, Ministério das Minas e Energia (1987b)

The main tin deposits in the State of Goias are of several types in middle Precambrian rocks: pegmatites, greisen, greisenized granites, disseminated veins and veinlets, albitized bodies and their secondary weathered products (Bettencourt et al., 1981). Columbite-tantalite and wolframite are common associated minerals. The more enriched ore zones grade up to 20% Sn, though the average is about 1%.

Gold

In 1984 Brazil was the fourth largest producer of gold in the Western World, with a production of 55 tons. In 1986 the output of primary gold, mainly from underground mines, added to the amount produced by panners, in alluvial and lateritic gold deposits, officially attained 24 tons (Figs. 3 and 4). It is believed that 75 to 80 tons of gold produced by panners ("garimpeiros"), mainly in the Amazon region, were illegally mined and exported. The Brazilian Government has been encouraging the exploration and production of alluvial gold, but despite its efforts to assist and control the production of alluvial gold, many problems remain to be solved.

The most important gold mines and districts for primary deposits (lodes, disseminations, stratiform, stratabound) occur in greenstone-type volcano-sedimentary sequences and as Rand-type, quartz pebble, meta-conglomerate deposits. Examples of the former include the Nova Lima District, State of Minas Gerais, including the Morro Velho Mine (Ladeira, 1985) and the region of Araci, State of Bahia (Teixeira and Kishida, 1980). The latter are exemplified by the Serra da Jacobina District deposits in the State of Bahia (Molinari, 1983).

Figure 3: General view of small-scale mining of gold at Serra Pelada, Carajas.

Gold occurs or is recovered from itabirite iron ore (Itabira District), copper (Caraíba, Salobo, Mara Rosa) and lead-zinc (Ribeira Valley District) sulphide ores. The residual, lateritic and alluvial deposits are concentrated toward the northern portion of the country (e.g. Tapajós River, Xingu-Araguaia rivers, Alta Floresta, Madeira River, Serra Pelada Provinces). The most important deposits and districts of this type are responsible for about 80% of Brazilian's gold production (Brasil, Ministério das Minas e Energia, 1983; Guimarães et al., 1983; Silva, 1984).

Base Metals

Apart from copper, Brazil has only small reserves of base metals (Table 3). Over 75% of the lead ore reserves are concentrated in Morro Agudo mine, which is comparable to Mississippi Valley-type deposits related to upper Precambrian pelitic and carbonate rocks and reef structures (Dardenne, 1978). This deposit is now being brought into full production. The bulk of the current lead production is from other long-established deposits such as Boquira, Panelas, Barrinha and Perau. These vary from stratiform concentrations in lower to middle Precambrian meta-sedimentary or volcano-sedimentary sequences to remobilized upper Precambrian epigenetic veins (Fleischer, 1976).

About 70% of the reserves and almost all zinc production comes from the high-grade oxidized (Zn silicate + carbonate) deposits of the Vazante region. Additional resources are associated with lead sulphide ores, especially those of Morro Agudo and Boquira.

Though a greater number of deposits and occurrences of copper are known, approximately 75% of reserves are concentrated in the region of Carajás, notably in the Salobo 3A deposit, which contains about 1 billion tons with 0.8% Cu. Here copper sulphides and supergene ore minerals occur in magnetite schists associated with iron formation of Archean age. The processing of this complex deposit will apparently demand heavy investments. Potential ore concentrations (about 10% of the reserves) occur in Archean volcano-sedimentary sequences of the Mara Rosa region. Most of the present copper production comes from long-known deposits of small to medium size whose origins are not yet well established. Among these are the deposits of the Curaçá River valley, including Caraíba, which is hosted in Archean ultramafic-mafic granulites (Hasui et al., 1982) and the Minas of Camaquã in lower Paleozoic clastic sequences.

Figure 4: Detail of Serra Pelada operations with "garimpeiros."

Nonmetallic Ores

Brazil holds some important reserves of barite, kaolin, vermiculite, talc, graphite and magnesite with a relatively important production of the last three plus asbestos. The production of limestone, phosphate rock, clays, and granites (as dimension stone) play a significant part in the Brazilian mineral industry comparable to that of Al, Sn and Mn.

Brazil has the world's largest reserves of barite over 90% of which occur in the carbonatite of Araxá. However, their use as drilling muds is inappropriate because of the presence of radioactive minerals. Smaller grade deposits with suitable composition, such as those of Camamu, are responsible for most of the domestic production.

The Brazilian reserves of graphite are mainly of the plate-like type and are virtually concentrated in the deposit of Pedra Azul, in Minas Gerais (vein and disseminations in Precambrian high-grade metamorphic rocks). Production satisfies the national market, which is mainly represented by the metallurgical industry.

The most impressive concentrations of talc are associated with magnesium-rich carbonate metasediments as in Brumado (State of Bahia) close to huge magnesite deposits, and with mafic-ultramafic rocks such as those of the region of Nova Lima and in the southern region of the country.

Brazilian magnesite occupies the fourth and eighth places in terms of world reserves and production respectively. Large deposits of great economic importance are situated in the region of Brumado, in Proterozoic dolomitic sequences of controversial origin, possibly of sedimentary derivation. The high quality ore presents grades in terms of burned base from 92% to 94% MgO.

Since 1980, as a consequence of the production from the Jari Mine in the Amazon, Brazil began to decrease its imports and increase its exports of kaolin. Over 85% of the measured and indicated reserves of kaolin are in sedimentary deposits of the Amazonian region, such as the Capim River and Jari River districts, which are responsible for 50% of the domestic production. Kaolin deposits, usually related to weathered pegmatites and granitic rocks, are found through the northeast, southeast and southern regions of the country.

The main vermiculite deposits are located in alkaline-carbonatite complexes (such as those of Catalão and Ouvidor), though the greatest production is from deposits related to basic-ultrabasic rocks, such as the Paulistana deposits.

Brazil has held an important place as a Western Hemisphere producer of asbestos for a long time. Almost all its reserves (over 90%) and fiber production come from Canabrava, State of Goiás, where a measured reserve of about 3 million tons of contained fiber is exploited from serpentinites with grades averaging 6.7%.

The most important production of fluorite is from vein-like epigenetic deposits in granitoid rocks (as in Morro da Fumaça District, State of Santa Catarina) or in alkaline rocks (as in Itaboraí region, State of Rio de Janeiro). Strati-form and stratabound deposits associated to Late Proterozoic carbonate sequences were recently discovered in the Ribeira Valley region (e.g. the Sete Barras deposit).

Gemstones

Brazil has long been famous as a producer and exporter of gemstones of high quality. The pegmatitic regions of Minas Gerais, southern Bahia and the northeast are the prime sources of coloured gemstones including emerald, aquamarine, citrine, amethyst, smoky quartz, morganite, tourmaline, topaz, chrysoberyl (cat's eye), kunzite and opal. Imperial topaz, a typically Brazilian gem, varies from yellow to peach pink. Brazil is also a producer of alluvial diamonds and, although the diamonds are usually under a carat, 65% of them are high quality gemstones. The importance of the gemstones in the total Brazilian production of mineral goods is increasing and will improve with the upgrading of the quality of lapidary operations and the control of illegal production and trade.

Legal Systems

Mining in Brazil takes place under five different legal systems (Brasil, Ministério das Minas e Energia, 1987a). The Governmental Monopoly system assigns to the Federal Union the exclusive right to mine oil and nuclear ores. Actual mining is made through governmental companies such as Petrobrás, and Nuclebrás and their subsidaries. The Federal Government allows restricted participation in oil exploration by private domestic and foreign companies through contracts with risk clauses.

The Authorization system is applied to mineral commodities used without processing for building, for structural products (clay) and for soil conditioners (limestone). Authorization is granted for limited terms by municipal authorities, and confirmed by register with the Departamento Nacional da Produção Mineral (DNPM).

Most minerals, however, are mined through Exploration License and Mining Concession systems. The former is granted according to precedence in recording a claim with DNPM. The holder of surface rights has no precedence, but may receive indemnity for damages, remuneration for the area affected by mining operations, and royalties equal to a tenth of mining taxes. The discoverer of a mineral deposit applies for an exploration license to the DNPM: this is granted unless the area has a previous claim or is a part of an Indian Reserve, State or National Park or Free Prospecting Area. Exploration is authorized for a limited time, and if necessary mining may be authorized on a part of the deposit in order to recover exploration expenses.

The exploration results are submitted to DNPM in a report, which may be approved, when the existence of an economic deposit is demonstrated; not approved where the exploration activities are considered unsatisfactory; or filed when the area is shown to be lacking in economic deposits. The holder of an approved exploration report can apply for a Mining Concession by submitting an Economic Exploitation Plan and an Environmental Impact Report that specifies the environmental effects expected from mining of the deposit and the measures proposed to counteract these. If the plans are approved mining rights are granted, but these can be forfeited if mining is abandoned or the operation is in disagreement with the terms of concession.

The Prospection Inscription System regulates the activities of prospectors ("garimpos") and panners ("garimpeiros"), defined as mining operations carried out only by individuals employing rudimentary methods (Figs. 3, 4 and 5), from secondary deposits or weathered surficial portions of primary deposits. Such mining cannot take place in areas claimed under Exploration License or Mining Concession systems, and should preferably be restricted to Free Prospecting Areas, where only this kind of mining can be practised. According to Redenção e Silva (1987), in 1987, 28,242 exploration claims covering 19.4% of the country, 29,565 exploration licenses and 7,381 mining concessions covering 0.13% of the country were registered with DNPM.

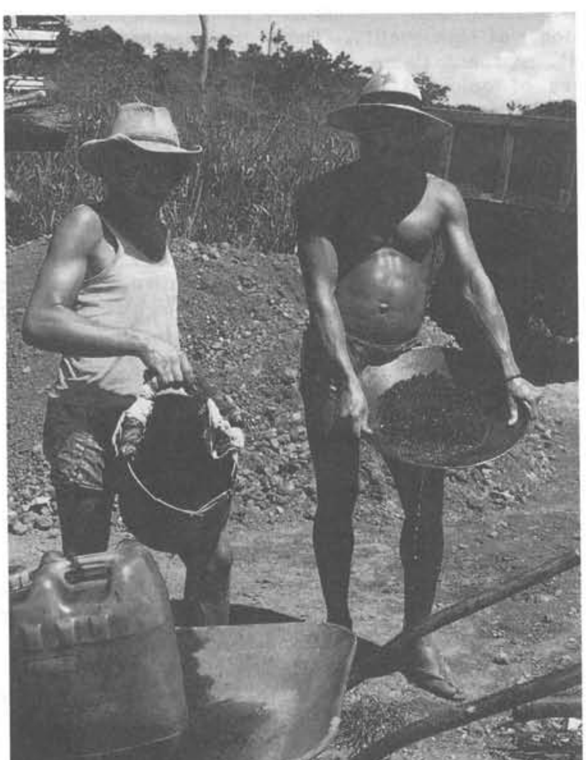

Figure 5: Garimpeiros ready to pan for wolframite.

Policy and Legal Challenges

There are many problems to be solved concerning Brazil's mineral policy and legislation. First, there is little investment in mineral exploration. From 1977 to 1987 there was an annual average of nearly 10,000 exploration claims leading to 1,500 exploration reports, only 300 of which were approved. Seven hundred were regarded as showing insufficient exploration activities (Redenção e Silva, 1987). There are no fiscal incentives for mineral exploration, and the political and economical instability discourages long-term investments in mining.

The concession control systems are deficient. The staffs of the regulation agencies (DNPM, municipal and state mining and environmental agencies) have not enough resources, structure and personnel to carry out their legal functions. Low budgets make basic geological surveying and inspections difficult. As a result development of new mines is retarded and large areas remain too long in the early states of concession procedures. Basic geological information at scales large enough for prospecting is lacking for large parts of Brazilian territory. Even more scarce are the data necessary for environmental impact assessments.

In many cases mining laws are unenforced or even broken by the government itself. Areas under claims may be invaded by prospectors and panners, and in the case of Serra Pelada, these are even stimulated by government.

Long-term mining by prospectors is not recognized by the Mining Code. Well-funded clandestine companies pretending to be engaged in prospecting use mechanized equipment, pay no taxes and exploit workers by low wages and no assistance or protection under labour laws. These clandestine mines, involving rudimentary processing, are responsible for losses due to low recovery of ore contents and environmental damages.

Pollution and environmental degradation due to mining affect large areas, in some cases with drastic consequences, as in coal mines in southern states, in large rivers polluted by mercury from clandestine gold mines, and urban areas degraded by quarrying and sand and clay pits. Clandestine and even legal mining companies extend their activities over Indian lands, in most cases without the approval of the National Indian Foundation (FUNAI). The results are often tragic: native societies are first destroyed and Indians even killed.

In recent years mining policy and legislation have been extensively discussed in Brazil (Minérios, 1986 and 1987). A new Constitution and a new Mining Code are under discussion, and environmental and control systems are being established. These will place mineral ownership in the Union, with mining rights assured to claim-holders. Foreign companies will be subject to restrictions in mining. Greater ease will be allowed in the transfer of mining rights, and exploration licenses. Restrictions on the number of areas that an individual or company can claim will be replaced by control of the area claimed. Taxes proportional to surface areas claimed will be instituted, aiming at preventing purely speculative claims.

Greater technical requirements will be imposed on exploration reports and economic exploitation plans, so that these always include measures for natural resource and environmental preservation and for the maintenance of health and security related to mining operations. The Prospection Inscription System will be replaced by a Prospecting Mining System, with permission to operate issued only to legally established companies. Participation by FUNAI and Indian communities in decisions pertaining to mining on Indian lands will be ensured. Since the enforcement of regulations recommended in the new Mining Code require a strong DNPM, its transformation into a special autonomous agency is proposed, with legal status and resources adequate to engage in basic geological surveys and mining research and to control mining.

Conclusions

Brazil has now made considerable achievements in developing agriculture, industry and technology, and attention can now be turned more toward increasing the contribution of mining to the national economy. The increasing mineral production and the discoveries of ore deposits, since the 1960s, are encouraging signs of the development of mining and mineral-based industries in Brazil. Against a national background with monetary problems, high inflation, international debt, public deficit, illiteracy and problems concerning sanitation, environment, public health, education and social assistance, major efforts will be needed in order to improve the value and the intelligent exploitation of Brazil mineral resources. A main requirement for a strong industry based on an active and well organized mining activity is a new Mining Code, tax encouragements, the controlled entry of overseas funds and an efficient and powerful Brazilian Geological Survey.

Prof. E. Ribeiro Filho is Head of the Department of Economic Geology and Geophysics at the University of São Paulo (USP, P.O. Box 20,899, 01498 São Paulo, Brazil). His main interests have long been on ore deposits, ore microscopy and economic geology in general.

Dr. J. B. Moreschi is an Assistant Professor in the Department of Economic Geology at USP, with major interests in the geology and genesis of mineral deposits.

Dr. A. B. Macedo is also an Assistant Professor in the same Department. His research interests are in geochemical exploration and environmental geology.

References

Almeida, E.B. de, 1982. Bauxite deposits of the Poços de Caldas alkaline massif. In: 2nd International Seminar on Lateritisation Process, São Paulo. IAGC Guide Book Excursion no. 3, p. 49-82.

Beisiegel, V. de R., Bernardelli, A.L., Drummond, N.F., Ruff, A.W. and Tremaine, J.W., 1973. Geologia e recursos minerais da serra dos Carajás. Revista Brasileira de Geociências, v. 3, no. 4, p. 215-242.

Bettencourt, J.S., Damasceno, E.C., Fontanelli, W.S., Franco, J.R. and Pereira, N.M., 1981. Brazilian tin deposits and potential. In: Fifth World Conference on tin, Kuala Lumpur, Malaysia, p. 1-69.

Brasil, Ministério das Minas e Energia, 1983. Garimpos de Brasil. Departamento Nacional da Produção Mineral, Avulso, no. 5, 378p, Brasília.

Brasil, Ministério das Minas e Energia, 1987a. Código de Mineração e Legislação Correlativa. Departamento Nacional da Produção Mineral, Brasília, 333p.

Brasil, Ministério das Minas e Energia, 1987b. Sumário Mineral. Departamento Nacional da Produção Mineral, v. 7, 103p, Brasília.

Cordani, U.G., Tassinari, C.C.G., Teixeira, W., Basei, M.A.S. and Kawashita, K., 1979. Evolução tectônica da Amazônia com base nos dados geocronológicos. In: Congresso Geológico Chileno, 2, Atas, v. 4, p. 137-148, Arica.

Cruz, F.F. da., Brenner, T.L., Moreira, A.F.S., Cunha, C.A.B.R. da, Gallo, C.B.M., Franke, M.D. and Pimentel, R.C., 1986. Jazida de Ni-Cu-Co da Fortaleza de Minas Gerais. In: Schobbenhaus, C. and Coelho, C.E.S., coords., Principais depósitos minerais do Brasil, Departamento Nacional da Produção Mineral, v. 2, p. 275-306, Brasília.

Dardenne, M.A., 1978. Geologia da região de Morro Agudo (Minas Gerais), Belo Horizonte. Sociedade Brasileira Geologia/Núcleo MG, Boletim no. 7-8, p. 68-84.

Dorr, J.V.N. II, 1969. Physiographic, stratigraphic and structural development of the Quadrilátero Ferrífero, Minas Gerais, Brazil. U.S. Geological Survey Professional Paper 641-A, 110p.

Dorr, J.V.N. II, 1973. Iron-Formation in South America. Economic Geology, v. 68, no. 7, p. 1005-1022.

Fleischer, R., 1976. A pesquisa de chumbo no Brasil. In: Anais do Congresso Brasileiro de Geologia, 29, Ouro Preto. Sociedade Brasileira de Geologia, v. 1, p. 19-32.

Grubb, P.L.C., 1979. Genesis of bauxite deposits in the lower Amazon Basin and Guianas Coastal Plain. Economic Geology, v. 74, no. 4, p. 735-750.

Guimarães, G., Santos, H.N., Freitas, J.B. and Guimarães, L.R., 1983. Garimpos Brasileiros - da história aos fatos atuais. In: Simpósio sobre mineralizações auríferas no Estado da Bahia, Salvador. Sociedade Brasileira de Geologia, Núcleo BA, Anais, p. 133-142.

Hasui, Y. and de Almeida, F.F.M., 1985. The Central Brazil Shield reviewed. Episodes, v. 8, no. 1, p. 29-37.

Hasui, Y., Del Rey, L.J.H., Lima e Silva, F.J., Mandetta, P., Moraes, J.A.C., Oliveira, J.G. and Miola, W., 1982. Geology and copper minalization of Curaçá River valley, Bahia. Revista Brasileira de Geociências, v. 12, no. 1-3, p. 463-474.

Hirata, W.K., Rigon, J.C., Cordeiro, A.A.C. and Meireles, E.M., 1982. Geologia regional da Provincia Mineral de Carajás. In: Simpósio de Geologia da Amazônia, 1, Belém. Sociedade Brasileira de Geologia, Núcleo Norte, Anais, v. 1, p. 100-110.

Korpershoek, H.R., Mota, E.R., Kajishima, T. and da Silva, J.S.S., 1980. Nota preliminar sobre a jazida estanífera do Morro Potosi (Jacundá-Rondônia-Brasil). In: Anais do Congresso Brasileiro de Geologia, 31, Balneario de Camboriú. Sociedade Brasileira de Geologia, v. 3, p. 1574-1588.

Ladeira, E.A., 1985. Metalogênese do ouro na mina de Morro Velho e no Distrito de Nova Lima, Quadrilátero Ferrífero, Minas Gerais, Brasil. In: Contribuições à Geologia e à Petrologia. Sociedade Brasileira de Geologia, Núcleo MG, p. 95-151, Belo Horizonte.

Minérios, 1986. O que você pensa do novo Código de Minerção? Minérios, v. 11, no. 117, p. 30-37.

Minérios, 1987. A crise institucional da mineração. Minérios, v. 12, no. 129, p. 34-49.

Molinari, L., 1983. Mineralizações auríferas em Jacobina, BA. In: Simpósio sobre mineralizações auríferas no Estado da Bahia, Salvador. Sociedade Brasileira de Geologia, Núcleo BA, Anais, p. 26-31.

Montalvão, R.M.G. and Bezerra, P.E.L., 1980. Geologia e tectônica da Plataforma (Cráton) Amazônica (parte da Amazônia legal brasileira). Revista Brasileira de Geociências, v. 10, no. 1, p. 1-27.

Nilson, A.A., Santos, M.M. and Cubq, E.A., 1982. The nickel-copper sulfide deposit in the Americano do Brasil mafic-ultramafic complex, Goiás, Brazil. Revista Brasileira de Geociências, v. 12, no. 1-3, p. 487-497.

Redenção e Silva, M., 1987. O subsolo brasileiro e a mineração. Departamento Nacional da Produção Mineral, Brasília, 21p.

Roeser, H., Roeser, U.F., Grossi, A.S.R. and Flores, J.C.C., 1984. Contribuição à origem das jazidas de bauxita de Cataguases, Minas Gerais. In: Anais do Congresso Brasileiro de Geologia, 33, Rio de Janeiro. Sociedade Brasileira de Geologia, v. 8, p. 3853-3865.

Santos, J.O.S. and Loguércio, S.O.C., 1984. A parte meridional do Cráton Amazônico (Escudo Brasil-Central) e as bacias do Alto Tapajós e Parecis-Alto Xingu. In: Schobbenhaus, C., Campos, D.A., Derze, G.R. and Asmus, H.E., coords., Geologia do Brasil. Departamento Nacional de Produção Mineral, Brasília, p. 93-127.

Schobbenhaus, C., 1986. Geologia do nióbio e do tântalo. In: Schobbenhaus, C. and Coelho, C.E.S., coords., Principais depósitos minerais do Brasil, 2. Departamento Nacional da Produção Mineral, Brasília, p. 430-433.

Schobbenhaus, C. and Campos, D.A., 1984. A evolução da plataforma sul-americana no Brasil e suas principais concentrações minerais. In: Schobbenhaus, C., Campos, D.A., Derze, G.R. and Asmus, H.E., coords., Geologia do Brasil. Departamento Nacional de Produção Mineral, Brasília, p. 9-53.

Schorscher, H.D., Santana, F.C., Polonia, J.C. and Moreira, J.M.P., 1982. Quadrilátero Ferrífero - Minas Gerais State: Rio das Velhas. Greenstone Belt and Proterozoic Rocks. In: International Symposium on Archean and Early Proterozoic Geologic Evolution and Metallogenesis, Salvador, Bahia, Brazil, Excursions annex, 44p.

Silva, A.R.B.,1984. Províncias auríferas do Estado do Pará e Território Federal do Amapá. In: Anais do Congresso Brasileiro de Geologia, 33, Rio de Janeiro. Sociedade Brasileira de Geologia, v. 8, p. 3945-3958.

Teixeira, J.B.G. and Kishida, A., 1980. Geologia das mineralizações auríferas estratiformes da Faixa Weber, Araci (BA). In: Anais do Congresso Brasileiro de Geologia, 31, Balneario de Camboriú. Sociedade Brasileira de Geologia, v. 3, p. 1802-1811.

Trescases, J.J., Melfi, A.J. and Oliveira, S.M.B. de, 1979. Nickeliferous laterites of Brazil. In: International Seminar on Lateritisation Process. Trivandrum, India, p. 170-184.