Part I

GENERAL DISCUSSION

Part I General Discussion

Chapter 1: Introduction

1-1 Circumstances for Starting the Survey

Platinum-group metals (hereinafter referred to as "PGM") are very important from economic and strategic viewpoints. In addition to their use as jewelry, their use in various industrial fields especially in the field of electronics and the products to control environmental pollution (automobile catalyst) is now becoming increasingly important. The world PGM resources are unevenly distributed in the largest quantity in South Africa and in the second largest quantity in Russia. The total of PGM distributed in these two countries accounts for 98.5% of the world PGM resources. Among the quantities of PGM consumed in Brazil (approximately 3 tons in '94), its use as automobile catalyst (77.8% of the total consumption) has been rapidly extended. Currently, Brazil imports the entire quantity of PGM required for automobile catalyst.

In spite of its importance as resources, few PGM data had been collected by Brazil before 1990. With this situation as a background, Geological Survey of Brazil (hereinafter referred to as "CPRM") implemented its project "National PGM Project" covering the entire land of Brazil from 1990 to 1995.

Subsequent to the "PGM National Project," MMAJ and CPRM decided in June, 2001 to enforce a regional geological survey of Ni-Cu-PGM ore deposits in the Paraná basin located in the south part of Brazil based on the technical cooperation between the above organizations. The side of Brazil intend to promote prospecting of Ni-Cu-PGM ore deposits by both domestic and overseas companies in accordance with the results of the survey.

Most of the PGM ore deposits are accompanied by three types of basic to ultrabasic intrusive complex. For example: layered intrusive rocks (Bushveld in South Africa), intrusive rocks related to flood basalt (Noril'sk in Russia) and intrusive rocks related to greenstone (Kambalda in Australia). The objective of the survey is to investigate the possibility of the Noril'sk-type Ni-Cu-PGM ore deposit related to the flood basalt in Paraná basin situated in the south part of Brazil.

In Brazil, The five projects based on the technical cooperation between Brazil and Japan have been conducted since 1980 in the districts below.

Anta Gorda District	(survey of resources development)	FYs 1980-1983
Ribeira District	(survey of local development plan)	FY 1984
Palmeiropolis District	(survey of resources development)	FYs 1986-1988
Currais Novos District	(survey of resources development)	FYs 1989-1991
Currais Novos District	(follow-up survey)	FY 1992
Alta Floresta District	(survey of resources development)	FYs 1998-2000

1-2 Summary of the First Year Survey

1-2-1 Purpose of the Survey

The purposes of this investigation are to extract promising district as Ni-Cu-PGM ore deposits from Paraná district in the south of Brazil, to enforce the existing data analysis, satellite image analysis and ground truth survey, to conduct the general analysis of the results obtained, and to efficiently extract promising existence of deposits from regional area.

1-2-2 Survey Area

The survey area is situated in the south of Brazil ranging from the latitude 15° - 34° south in the north- south direction to the longitude 46° - 60° west in the east- west direction with the total area of 1,400,000 km^2 (Fig. I-2-1-1). With regard to the topography of the survey area, most of the survey consists of plateaus of around an elevation of 500 m and grassy plains. However, the central to eastern part of the survey area consists of mountains in an elevation of 1,000 - 1,800 m.

1-2-3 Survey Method

The survey method conducted in this fiscal year consists of the existing data analysis, satellite image analysis and the ground truth survey. Table I-1-1 shows the volume of the individual surveys as well as the items and quantities of laboratory tests.

(1) Existing Data Analysis

A lot of the existing data were involved concerning Paraná basin, such as geological and geochemical theses, reports and drawings, aeromagnetic and gravimetric data, PGM prospecting reports by Canada and Brazil and drilling data for oil prospecting. These materials were collected, analyzed and compiled from CRPM, the local geological survey organizations, colleges and universities, mining and oil companies. The results of the satellite image analysis were also used in these tasks.

(2) Satellite Image Analysis

The satellite image analyses were conducted at the central part of the survey area within a range of approximately 250,000 km^2. Mosaic images of JERS-1/SAR data were prepared, read from geological viewpoints and interpreted together with the existing data. The geological structures related to the generation of ore deposits such as lineaments and circular structures were confirmed on the SAR images to extract the promising area for deposit.

(3) Ground Truth Survey

The ground truth survey was conducted based on the results of the existing data and satellite image analyses. Rock specimens collected from lava, intrusive rocks, etc. were subject to laboratory tests. All the results thus obtained were comprehensively examined, possibility of deposit was studied and prospecting techniques were proposed for the future.

1-2-4 Configuration of the Survey Mission

Japan side :

Kenji Nakamura:	JMEC (Japan Mining Engineering Center for International Cooperation)
Akitsura Shibuya:	JMEC
Kenzo Masuta:	JMEC
Takayoshi Murakami:	JMEC

Brazil side :

Wilson WILDNER:	CPRM (Geological Survey of Brazil)
Adalberto DIAS:	CPRM
Carlos ALBERTO:	CPRM
Norberto LESSA:	CPRM

1-2-5 Period and Quantity of the Survey

(1) Satellite Image Analysis:

July 17 - August 8, 2001

(2) Existing Data Analysis and Ground Truth Survey:

August 9 - November 2, 2001

(3) Laboratory Tests and Comprehensive Analysis:

November 3, 2001 - March 15, 2002

Table I-2-1 Laboratory test

Item	Amount
Thin section	189
Polished thin section	3
Polish chip	5
X - ray diffractometer	4
Whole rock analysis and minor element analysis (61 elements)	198
Stream sediment analysis (30 elements)	316
Water analysis (69 elements)	182
Panning sample analysis (11 elements)	5
Isotopic measurement (Sulfur)	4
Isotopic measurement (Strontium, Neodymium)	34
EPMA	10

Chapter 2: Geography of the Survey Area

2-1 Location

Fig. I-2-1-1 shows the location of the survey area. The area covered by this survey is located from the central to southern part of Brazil, ranging from longitude 45° to 57° west and from latitude 15° to 35° north. The eastern side of the survey area faces to the Atlantic Ocean, while its western side is close to the borders of Paraguay and Argentine, and its southern side is close to the border of Uruguay.

2-2 Topography

The topography of the survey area is rather steep from the coastal mountains to its central part as the edge of Paraná basin shifting from a smooth plateau to a plain. This plain leads to a large grassy plain in the central part of South America Continent called a pampas. The maximum height of the survey area is around 1500 m above the sea. In particular, the hilly area with few rises and falls extends from the central to the southern part of the survey area where pasturing and wheat growing are mainly conducted.

While no dune is developed on the eastern coast of the survey area, tidelands and lagoons are developed on the southern coast.

2-3 Drainage Systems

The main drainage system in the survey area is divided as Paraguai River system, Paraná River system and Uruguai River system. The Paraguai River system with Mato Grosso plateau as its source flows down to the south and joins the Paraná River.

The Paraná River with plateaus surrounding Brasilia as its sources runs through São Paulo Province and Paraná Province and flows down in parallel with the inland side of the coastal mountains. Then it joins the Paraguai River, flows into the La Plata River which runs along the border between Argentine and Uruguay, and flows into the Atlantic Ocean. The Iguaçu River which is famous for Iguaçu Waterfall is a branch of the Paraná River.

Besides, a river runs in the southern part of the survey area and flows into the Lake Patos, a lagoon on the Atlantic coast. Its main stream is the Jacuí River which runs from the west to east through Porto Alegre City.

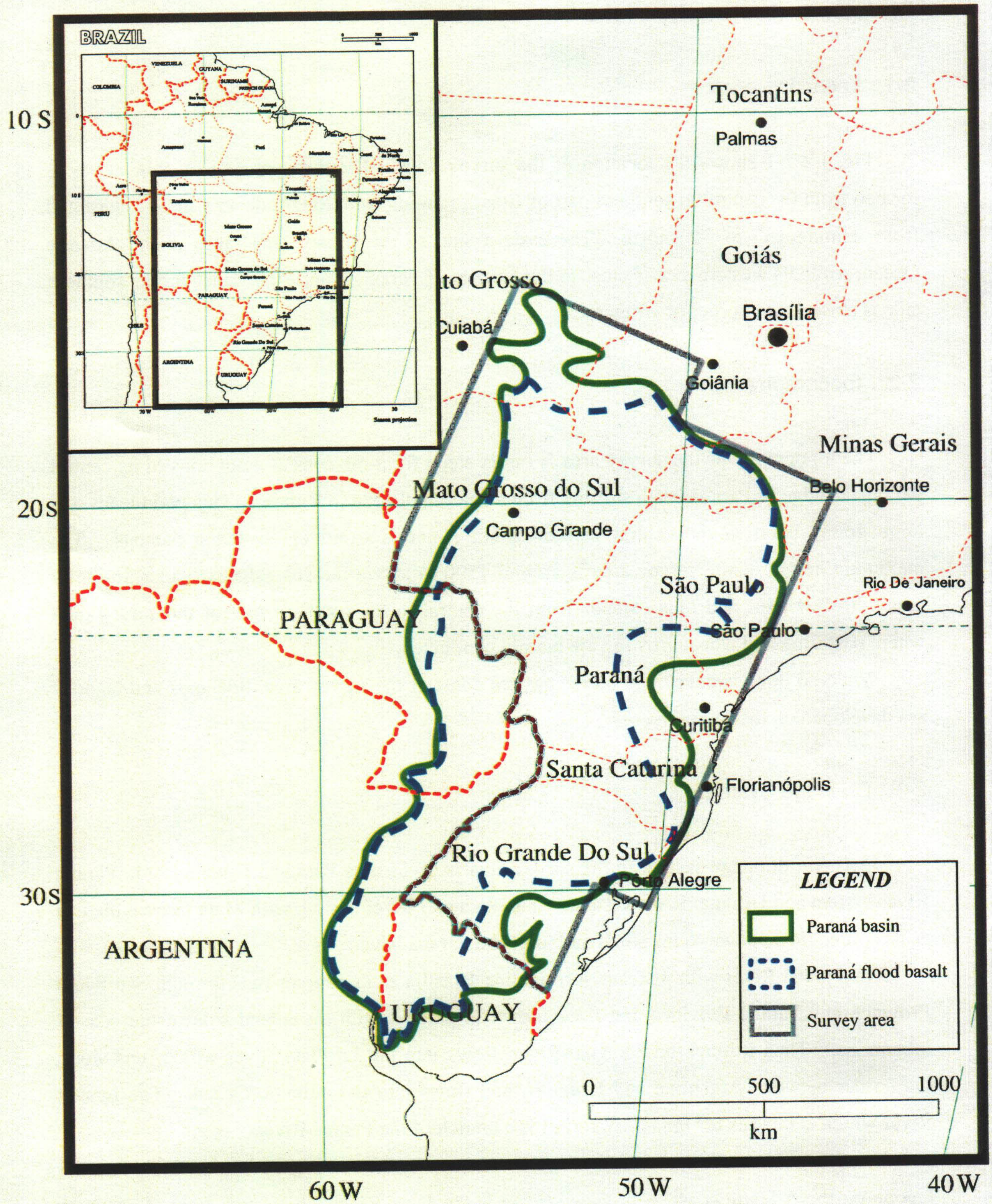


Fig. I-2-1-1 Location of Paraná basin area, Brazil

2-4 Climate

The climate in most of Brazil is either tropical or subtropical. Although the northern part of the survey area belongs to the subtropical zone, the three provinces located from the central to southern part of the area, i.e. Paraná Province, Santa Catarina Province and Rio Grande do Sul Province, belong to the temperate zone. Temperatures there differ much depending on the geographical locations and rises or falls. The seashore of Santa Catarina Province and the periphery of the Paraná River are the places with the highest temperatures of approximately 20 to 25℃, while the temperatures of the central and the southernmost parts are around 17℃. Rain falls regularly there throughout a year. In August and September, however, there is a rainy season just like the rainy season in Japan. In winter, snow falls in the places with high elevation.

2-5 Plantation

In the north-western part of the survey area, especially in the western part of Mat Grosso Province, shrubbs, bushes and grassy plains which grow in swamp are complicatedly mixed up.

Along the eastern coast of the survey area, the plants suitable for muddy land grow as a characteristic of the place, while mangrove grows along the northern to the central coast of the survey area. On the wet coastal mountains developed a little nearer to the inland, jungles of evergreen trees are distributed.

On the flat land from the central to the southern part of the survey area, the thick-growing gramineous plants constitute a treeless grassy plain.

In the Paraná Province, Santa Catarina Province and Rio Grande do Sul Province, Paraná Pine Trees (Araucaria) grow thick. They are utilized for lumber and food (seeds only) and their economic efficiency is high. In addition, nuts and yierba mate are produced there.

Chapter 3: Geology, Mineral Deposits, and Mining of the Survey Area

3-1 Recent Mining Situation

3-1-1 Mining Production

The Federal Republic of Brazil is abundant in many mineral resources. Its niobium and rutile reserves rank first; tin, second place; bauxite, third place. Iron ore production ranks second place (reserve ranks sixth place) in the world. In addition, magnesium, manganese, tantalum, gold, and many other mineral resources are produced in Brazil. Meanwhile, the productions of bauxite, tin ore, bullion, and manganese ore rank fourth place. Besides these, Brazil is a major producer of rare earth and other non-ferrous metals. The quantity of the aluminum bullion imported to Japan from Brazil accounts for some 17 % of the total import of aluminum bullion. Brazil also supplies Japan with nickel bullion, manganese ore, and other ores.

Brazil reformed the Constitution in 1995. Since then, the restriction of investment by foreign firms has been abolished. As a result, the exploration and development of mineral resources have been opened to foreign firms, and privatization of the government-owned corporations has been on the increase. For example, Companhia Vale do Rio Doce(CVRD), formally owned by the government, was privatized in 1997.

Table I-3-1-1 and Table I-3-1-2 respectively show the production of major mineral resources and production quantities by company.

Table I-3-1-1 Production of main minerals of Brazil

Commodity	Unit	1997	1998	1999	99/98(%)	2000	00/99(%)
Copper	Metal（t）	39, 952	34,446	31,371	-8.9	31,786	1.3
Zinc	Metal（t）	152,634	87,485	98,590	12.7	100,254	1.7
Tin	Metal（t）	18, 291	14,238	13,202	-7.3	14,200	7.6
Nickel	Metal（t）	31,936	36,764	41,522	12.9	45,317	9.1
Niobium	Nb_2O_5（t）	25, 688	33,795	31,352	-7.2	31, 190	-0.5
Tantalum	Ta_2O_5（t）	153	377	390	3.4	419	7.4
Chromium	Cr_2O_3（t）	112,274	209,596	207,123	-1.2	276,105	33.3
Gold	total（kg）	52,335	46,031	51,422	11.7	52,420	1.9
	company（kg）	41, 062	37,787	42,367	12. 1	42,025	-0:8
	garinpeiro(kg)	11,273	8, 244	9,055	9.8	10, 395	14.8
Iron	ore(1,000 t)	184,970	197,500	194,000	-1.8	210,000	8.2
Fluorite	1,000 t	78	72	45	-37.5	43	-4.4
Manganese	conc.（1,000 t）	2,124	1,940	1,656	-14.6	2,192	32.4
Aluminum	Bauxite（1,000 t）	11,671	11,961	13,839	15.7	13,846	0.1
Kaolin	1,000	1,165	1,374	1,517	10.4	1,735	14.4

Data from SUMARIO MINERAL 1999 and 2000(DNPM)

Table I-3-1-2 Mineral production of main companies of Brazil

Commodity/Company	Unit	1996	1997	1998	1999	98/99(%)
Aluminum	1,000 t	1,197.40	1,189.00	1,208.00	1,249.60	3.4
Albras		339	338	344.7	361.2	4.8
Alcan		93.4	93.3	102.5	102.4	-0.1
Alcoa		283.4	279.7	281.4	289	2.7
Aluvale		50.2	50.6	51.5	50.2	-2.5
Billiton		210.7	206.5	206.9	212.9	2.9
CBA		220	221	221	233.9	5.8
Copper	t	172,075	177,060	167,205	193,014	15.4
Caraiba		172,075	177,060	167,205	193,014	15.4
Tin	t	18,361	17,525	14,342	11,989	-16.4
Paranapanema		15,242	14,763	11,429	10,112	-11.5
Cesbra		1,611	1,739	1,347	1,396	3.6
Best		1,085	1,023	853	481	-43.6
Nickel	t	16,432	18,200	25,748	32,268	25.3
Codemin		6,223	6,751	6,891	6,503	-5.6
Niquel Tocantis		7,849	8,849	13,008	16,430	26.3
Morro do Niquel		2,360	2,600	1,184	0	-100
Fortaleza		-	-	4,665	9,335	100.1
Zinc	t	186,339	185,701	176,806	187,010	5.8
CMM		100,016	95,556	104,714	109,398	4.5
Inga		22,914	19,445	1,224	0	-100
Paraibuna		63,409	67,690	70,868	77,612	9.5

Data from Brazl Mineral, May 2000

3-1-2 Mining Policy

The Government of Brazil formulated a "Comprehensive 10-Year Plan" in 1964 as part of mineral resource evaluation. The evaluation was conducted by the Departmento Nacional da Producao Mineral (DNPM). The major projects implemented by the competent department are as follows:

(1) 1:1,000,000 geological mapping project
(2) Basic regional geological survey project
(3) Specific project for resource development

In addition, the following special projects were carried out.

(1) RADM project : 1:250,000 mapping was conducted by using radar image that covers the entire land including the Amazon.
(2) The air-borne geophysical exploration project by using gamma spectrum
(3) Continental shelf survey project

In addition, Projecto Geofisico Brasil-Canada (PGBC: 1975-79), the air-borne geophysical exploration was conducted (magnetic and γ -ray) in broader areas over Para Province and Goias Province. The result of the project led to finding diverse ore deposits in surroundings of Carajas district to the central area of Goias Province.

In 1970, CPRM (Companhia de Pesquisa de Recursos Minerais) was set up. Since then, all of the projects under DNPM were carried out by CPRM, which is a government-owned corporation under the Minister of Mine and Energy. The "Comprehensive 10-Year Plan" was also conducted by CPRM and completed in 1979, four to five years behind from the original schedule.

Since 1980, the "Second Comprehensive 10-Year Plan" was conducted. The plan included the planning of a basic geological study (1980-1989). As a result of this plan and implementation, geological mapping (on the scale of 1:50,000 to 1:250,000), geophysical and geochemical prospecting project, and hydraulic mapping project, etc. were conducted. However, along with the stagnant economy, many of the project implementations were behind the schedule.

The Government of Brazil has been promoting organizational reformation. For example, DNPM has been transformed into an independent administrative agency. As a result, the main business of DNPM has transformed itself into a agency of mining claim management, mine safety, mine pollution prevention measures, etc. Meanwhile, CPRM discontinued its own exploration since 2000, and trying to focus on the role of geological survey office.

In the past, every province had a resource exploration and development corporation to explore mineral resources within the province. For example, METAMIG Corporation for Minas Gerais Provinces, METAGO for Goias Provicne, and CBRM for Baia Province used to engaged in mineral resource explorations. At present, these companies have been liquidated, and mine claims were controlled by the provincial government.

3-1-3 Exploration and Development

INCO, Utah/BHP group, Billiton, a subsidiary of SHELL, RTZ, and other foreign-capital controlled private companies are engaging active explorations. Meanwhile, CVRD, Paranapanema, and other domestic-capital controlled companies are engaging in mineral resource prospecting, especially centering on the finding of gold ore deposit.

RTZ developed Morro do Ouro gold deposit in Paracatu City in 1987. In addition, the company engaged in the exploration of many mining concessions succeeded to BP, and also expressed the participation in the development of Salobo copper deposit of CVRD (J/V Project).

Aoki Corporation from Japan once acquired 49% of Nova Astro's share and began to develop Saramangore gold mine, owned by Nova Astro, in the Lorenco district in Amapa Province since 1986. Although the gold mine produced about 350 to 800 kg of gold a year, Aoki Corporation withdrew from the operation.

Sumisho Mineral Resources Development Co., Ltd. planned and carried out a number of projects, including the exploration of beach placer deposit in southern Salvador and rare metals and rare earth explorations in Tocantins Province. Mitsui Mining Co., Ltd. conducted rare earth explorations in Goias Province in 1991.

3-1-4 Recent Mining Situation

Mining productions in Brazil except those of iron ore and niobium have stagnated in recent years. Since neighboring countries one after another succeeded in developing mines by inviting foreign firms and began to increase mining productions and exports, the Government of Brazil also began to invite foreign firms to boost mining production. Although the mining production in Brazil is stagnant, domestic demand for copper continued to increase. To meet such demand, Caraiba Copper Smelter, the only copper smelter in Brazil, is planning to double copper production.

Caraiba Mine is located deep inside Baia Province, northeast of Brazil. The mine produced 102,416 tons of copper concentrate (34,446 tons of copper) in 1998. However, since copper ore reserve for open-cut mining was almost exhausted in Caraiba Mine, its copper production for 1999 was expected to go below 30,000 tons.

According to a document of DNPM, as for copper supply in 1998, Caraiba Smelter produced 167,205 tons of copper, 54,150 tons of copper scraps were collected, and 128,781 tons of copper cathode were imported mostly from Chile. In total some 350,000 tons of copper were supplied for domestic demand in 1998.

The copper production in Caraiba Mine and collection of copper scraps amounted to some 90,000 tons while domestic demand for copper recorded more than 310,000 tons. Thus, some

220,000 tons of copper is in short supply a year in Brazil.

Brazil has to import 200,000 tons of copper a year to meet domestic demand. A vast amount of copper reserve waits for explorations in Carajas district in Para Province. The copper ore deposits in the district are owned by CVRD, the largest iron ore producer in the world, which was privatized in 1997. Development of these copper deposits depend on the company. CODELCO, a government-owned corporation in Chili and the largest copper producer in the world, is negotiating with CVRD for explorations of copper in Brazil.

Brazil can produce a little over 50% of zinc ore for domestic demand, and imports zinc concentrate from Peru to meet the domestic demand shortage.

Rio Tinto Brazil Co., Ltd. began to produce nickel in Fortaleza Mine in 1998. The mine has continued to boost production. The company also produces and exports some 20,000 tons of copper, cobalt, and platinum mattes a year to Outokumpu Co., Ltd. Brazil also occupies over 90% of niobium production of world (source: Mineral Summary 2000, DNPM). Some 80% of the niobium is produced by CBMM, which has completed a plant construction to enhance production processes.

Brazil moved to civilian control from military rule and proclaimed the Constitution in 1988. This constitution which has been rather favorable to domestic companies, allows a foreign firm to own at most 49% of share in a company. Today, however, the Government of Brazil is formulating a series of reform package bills, called "Reformation of Brazilian Mineral Sector(Reforma do Sector Mineral Brasileiro)," to pass the parliament by around July 2001 and push forward the reforms. The reform bills include the modernization of mine concession management to prevent speculative ownership of mines, a tax reform to introduce incentives for mine exploration and development, formation of mine safety and mine closure regulations, and restructuring of the government agencies.

3-1-5 Mining Related Regulations

The 1988 Constitution of Brazil defines that spot side partner contributes the majority, and the rest for a foreign mining company to own less than half of shares of a joint venture in Brazil, respectively. Since then, the mining industry in Brazil has changed substantially. It seems that the Government of Brazil still thinks that investments from foreign countries are necessary and therefore does not take extreme measures that will discourage foreign investments.

The new Constitution also encourages individual diggers (garinpeiro). Under the new Constitution, individual diggers are allowed to apply for mining right in a primitive manner, which was banned in the past.

3-2 Summary of Geology and Ore Deposits in Brazil

3-2-1 Summary of Geology

(1) Precambrian in Brazil

Geological distribution of Archaean and Proterozoic in Brazil is compiled in detail in the report of project finding survey FY 1992 (MMAJ, 1993). Therefore, here we give our brief summary by referring to the document prepared by Jenks, W.F. ("World Geology" translated by Yoshio Katsui, Vol. 13, Chapter 4: Geology of South America).

The wording of "South American Platform" as advocated by Almeida (1971) means a stable continental district of Precambrian age in South America. In the margin of this stable continent, structural movements and igneous activities arising one after another in Phanerozoic eon caused continental growth. Table II-3-2-1 shows the major geological events in the South American Continent, while Fig. II-3-2-1 shows the ages of the major structural movements and igneous activities there.

From the data of geological structures and radiation age measurement, Almeida (1971) divided Precambrian age of South America into the following three groups:

Late Precambrian age:	570 ~ 1800 Ma
Middle Precambrian age:	1800 ~ 2600 Ma
Early Precambrian age:	>2600 Ma

As shown in Fig. II-3-2-2, five major platforms (Guiana, Guaporé , São Louis, San Francisco, La Plata River and Imataca composite rocks are included in the South American platform.

The largest stable mass of them is Guiana shield where the northern part of Amazon basin in Brazil and the southeastern district of the Orinoco River in Venezuela are included. Guaporé Craton is distributed to the south of Amazon basin constituting the basement of the basin. Probably it belongs to the same structural unit as that of Guiana Shield. Other shields are distributed in São Luis district extending over Minas Gerais and Bahia Province, Uruguay and La Plata River area in the northern part of Argentine.

Table I-3-2-1 Major geological events in the South America

Western Marginal Belt	Platform District:
(No record remains)	3400-3000 Primitive platform (North Guiana Shield)
(No record remains)	3000-2700 Imataca Orogenic Cycle
(No record remains)	2000-1800 Trans-Amazon Orogenic Cycle gave impact to the entire platform
(No record remains)	1800-1700 Roraima formation became a plain. (continental sediment, marine sediment in part)
~1300 Metamorphism in fragments of the platform (the northeastern part of Colombia)	1400-1100 Uruacuan orogenic cycle (the eastern part of Brazil)
750~600 Brazilian Orogenic Cycle (Gneiss on the southwestern coast of Peru, etc.)	750-500 Brazilian orogenic cycle -- destruction and re-welding of the old platform
550~350: Thick continental shelf and slope sediments of the lower Palaeozoic	550-350 Marine sediment (Amazon, Parunaiba and Parana basin)
~280 Glaciogenic deposits (the southern part of Bolivia, the western part of Argentine and Chile)	~280 Gondwana continental glacier (the southern part of Brazil and Argentine)
~200 Volcanic activities of andesite in the Triassic period (Chile and coasts in Peru)	~200 Mafic volcanic movement (Guiana Shield)
~180 Development of volcanic island arcs and intrusion of western Marginal belt batholith (convergent plate boundary)	~180 Large-scaled extrusion of Parana basalt, etc. (with its peak in 130 ~ 120 Ma)
↓	↓
~40	~110
~118-88 Long and large marginal basin arose in the southern part of Chile and ~150-80 Subduction of Caribbean plate (Colombia, Venezuela)	~140-80 Contrary to the state in Africa, rapid clockwise revolution in South America Basin formation on the continental edge through trench forming Continuation of thick sediment activities
~60-10 Caribbean plate and South American plate were lateral fault to the right and transformed — migration fault. Probably lateral fault to the left in the southern end of South America	~80-0 Continuation of sediment activities on the continental shelf
~20-0 Upheaval of Andes Mountains, continuation of subduction, neutral/felsitic volcanic activities	

(Figures represent ages. Unit: Ma)

Figura 4.1

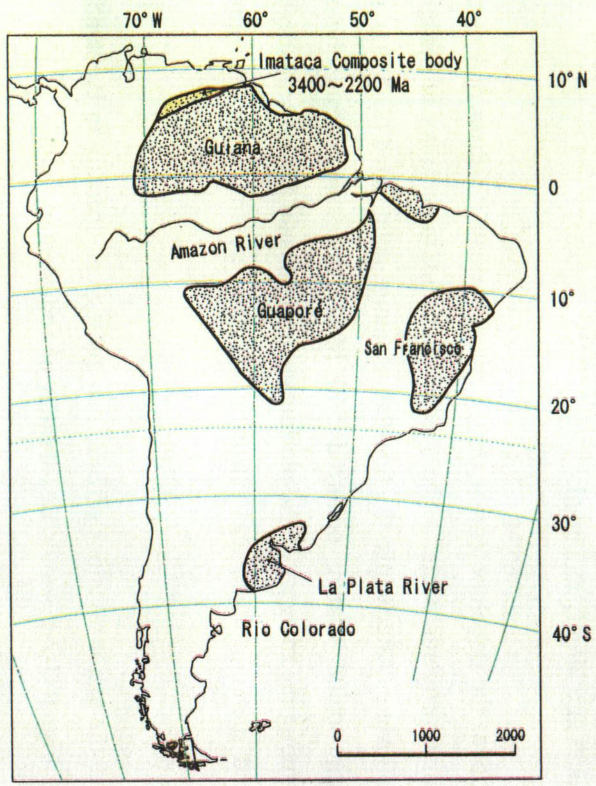
Cronologia dos principais eventos tectônicos e magmáticos

Idade (Ma)	Unidades geocronológicas		Principais eventos: Extensional (anorogênico)	Principais eventos: Compressional (orogênico)	Ciclos tectonogeológicos
	FANEROZÓICO	CENOZÓICO			
65		MESOZÓICO	Sul-atlantiano		
235		PALEOZÓICO			
460			Pós-brasiliano	Brasiliano 600 ± 100Ma	Ciclo Brasiliano
570	PROTEROZÓICO	NEO	Rondoniano ± 1.000Ma		
1.000		MESO	Parguazense ± 1.500Ma Uatumã ± 1.800Ma	Uruaçuano/K'Mudku 1.200 ± 100Ma	Ciclo Uruaçuano
1.800		PALEO		Transamazônico 1.900 ± 100Ma	Ciclo Transamazônico
2.600	ARQUEANO			Jequié/Aroense 2.700 ± 100Ma	

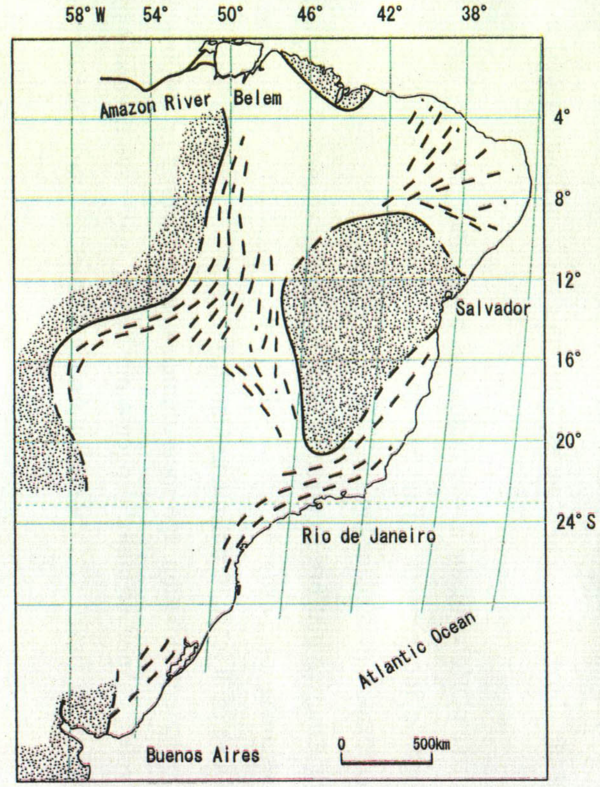
> *Obs.*: Os principais eventos geogeotectônicos pré-cambrianos do Brasil são aproximadamente sincrônicos através do País, mas nem sempre se correlacionam perfeitamente com os eventos pré-cambrianos em outras partes do mundo.
> As subdivisões do Proterozóico (Paleo, Meso e Neo), como aqui usadas, não correspondem necessariamente às subdivisões internacionais (propostas por Cowie et al., 1989).

Fontes: US Geological Survey; CPRM, 1995.

Fig. I-3-2-1 Ages of major tectonic movements and igneous activities in Brazil



Distribution of Precambrian major stable craton in the South America.
After Cordani et al.(1972), Hurley & Rand(1973)



Direction of folding or metamorphic belts (broken line) at east of South America.
Dotted area shows old stable massif. After Cordani et al. (1972).

Fig. I-3-2-2 Major old stable continental blocks in Precambrian age of South America

Fig. I-3-2-3 Directions of orogenic belts in orogenic cycles in Brazil

The oldest age that has ever been measured is 3000 Ma or older mainly derived from Guiana shield especially from Imataca composite rock. Reports on such oldest age scarcely exist in relation to the Guiana shield in Brazil. The radiation ages obtained through the whole-rock analysis of the above rocks and other metamorphic rocks in South America are 3000 - 2700 Ma.

The core or primitive platform of the above craton has been either cut up or covered by the subsequent major orogenic movements. The first of such movements which is known as Transamazonian orogenic cycle took place before 2000 ~ 1800 Ma.

Most of the South America platforms currently exist to the east of Andes Mountains were caked at the end of Transamazonian orogenic cycle. It is presumed that the continental crust of South America had an area of at least 10 million km^2 at that time.

The values of subsequent radiation age measurements were focused on 1400 ~ 900 Ma (Uruacuan orogenic cycle). Another major orogenic movement may have occurred in Minas Gerais and Goias Province in Brazil and the mountainous district of Sierra Nevada de Santa Marta in Colombia.

Subsequently, a further larger Precambrian orogenic movement occurred before 750 ~ 450 Ma. This movement is called Brazilian orogenic cycle. The curly metamorphic/igneous rock zones were developed in the manner as to cut up and wrap the platforms under the impact of Transamazonian orogenic cycle (Fig. II-3-2-3). It is considered in general that the orogenic cycle continued during the late Precambrian age. However, the cycle extended to Ordovician.

We consider that it was in the age of Brazilian orogenic cycle that the core of Precambrian platform was cut to pieces and largely extended.

As stated above, the development of the South American Platform of Precambrian Age ended with Brazilian orogenic cycle. The ages of many plutonic rocks of synkinematic granite were around 650 Ma. Afterwards, the final/latter changes continued till 650 ~ 500 Ma, and an especially large-scaled change occurred 540 Ma. Because of this change, the sedimentary rocks in/among the margins of the platform were intensely folded, cut at faults and influenced by advanced metamorphism and intrusion of many neutral/acidic plutonic rocks depending on places.

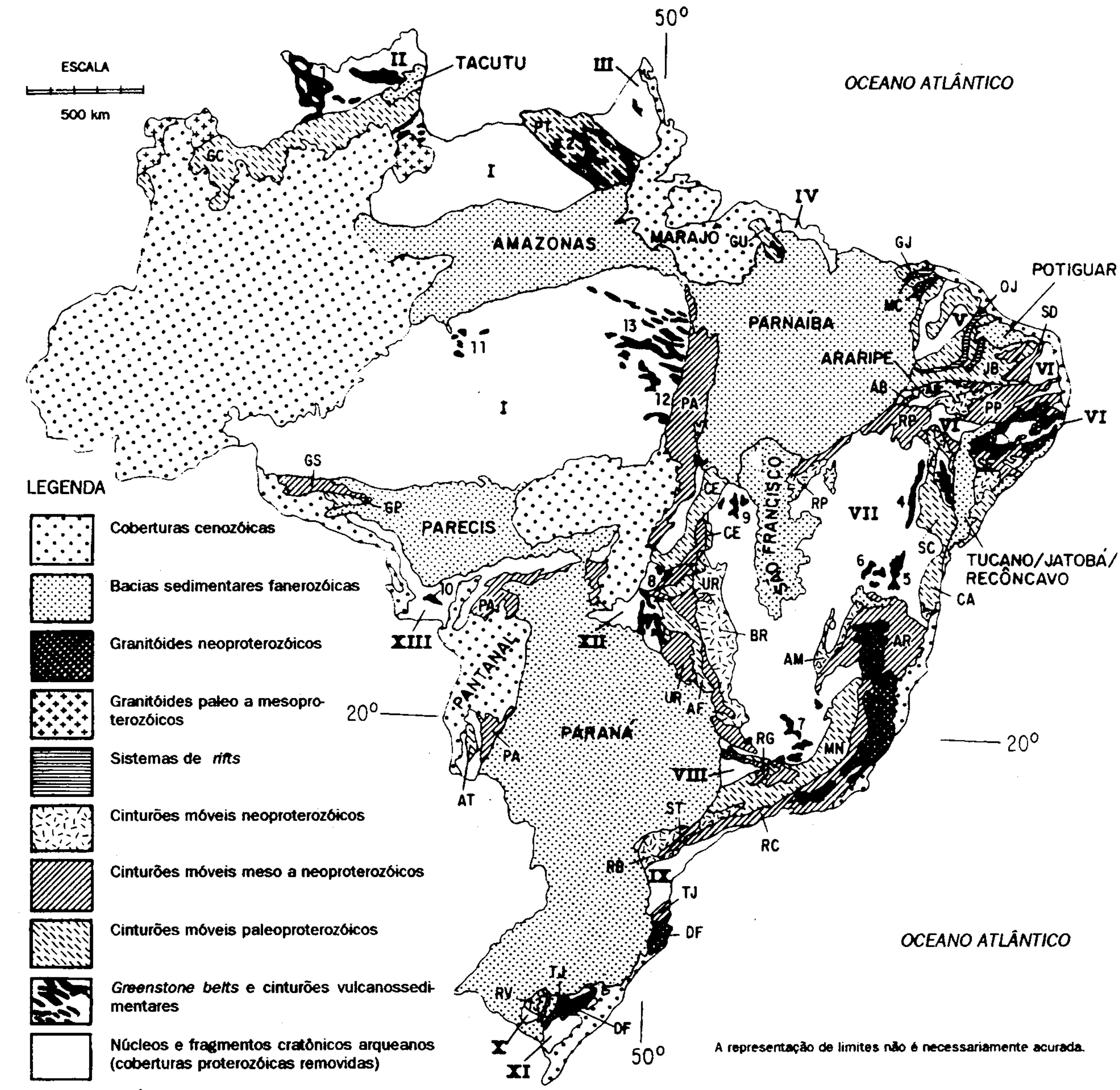
Fig. II-3-2-4 shows the major divisions of Brazilian geological structure in Precambrian by DNPM (1995a), while Fig. II-3-2-5 shows distribution of sedimentary basins of Phanerozoic eon.

(2) Palaeozoic

In South America, three major sedimentary basins among platforms, ie. Amazon, Parnaiba

Mapa 4.1

Brasil: principais feições tectônicas pré-cambrianas



UNIDADES TECTÔNICAS:

Núcleos e fragmentos cratônicos arqueanos: I. Cráton Amazônico; II. Núcleo Urariquera; III. Fragmento Oiapoque; IV. Fragmento São Luís; V. Fragmento Tróia; VI. fragmentos do Nordeste; VII. Cráton São Francisco; VIII. Maciço Guaxupé; IX. Fragmento Luís Alves; X. Fragmento Taquarembó; XI. Fragmento Pinheiro Machado; XII. Maciço Goiás; XIII. Núcleo Paraguá.

Greenstone belts *e cinturões vulcanossedimentares, arqueanos e paleoproterozóicos*: 1. Cinturão Parima; 2. Paru–Tumucumaque; 3. *Greenstone Belt* Rio Itapicuru; 4. Cinturão Itapicuru–Jacobina; 5. Cinturão Contendas–Mirante; 6. *Greenstone Belt* Ibitira–Brumado; 7. *Greenstone Belt* Rio das Velhas; 8. *Greenstone Belt* Goiás; 9. *Greenstone Belt* Natividade; 10. *Greenstone Belt* Jauru; 11. *Greenstone Belt* Tapajós; 12. *Greenstone Belt* Andorinha–Serra do Inajá; 13. Cinturão Itacaiúnas.

Cinturões móveis de alto grau, arqueanos a paleoproterozóicos: GC: Guiana Central; PT: Paru–Tumucumaque; GU: Gurupi; GJ: Granja; JB: Jaguaribiano; SC: Salvador–Curaçá; CA: Costa Atlântica; MN: Mantiqueira; AF: Alfenas; CE: Ceres; GP: Guaporé; AT: Alto Tererê.

Cinturões móveis meso a neoproterozóicos: SD: Seridó; PP: Pajeú–Paraíba; SE: Sergipano; RP: Riacho do Pontal; AR: Araçuaí; RC: Ribeira–Costeiro; ST: Setuva; TJ: Tijucas; UR: Uruaçu; RG: Alto Rio Grande; PA: Paraguai–Araguaia; GS: Cinturão de Cisalhamento Guaporé.

Cinturões móveis neoproterozóicos: SE: Sergipano; AM: Araçuaí–Macaúbas; BR: Brasília; RP: Rio Preto; AB: Alto Brígida; RB: Ribeira–Vacacaí; DF: Dom Feliciano.

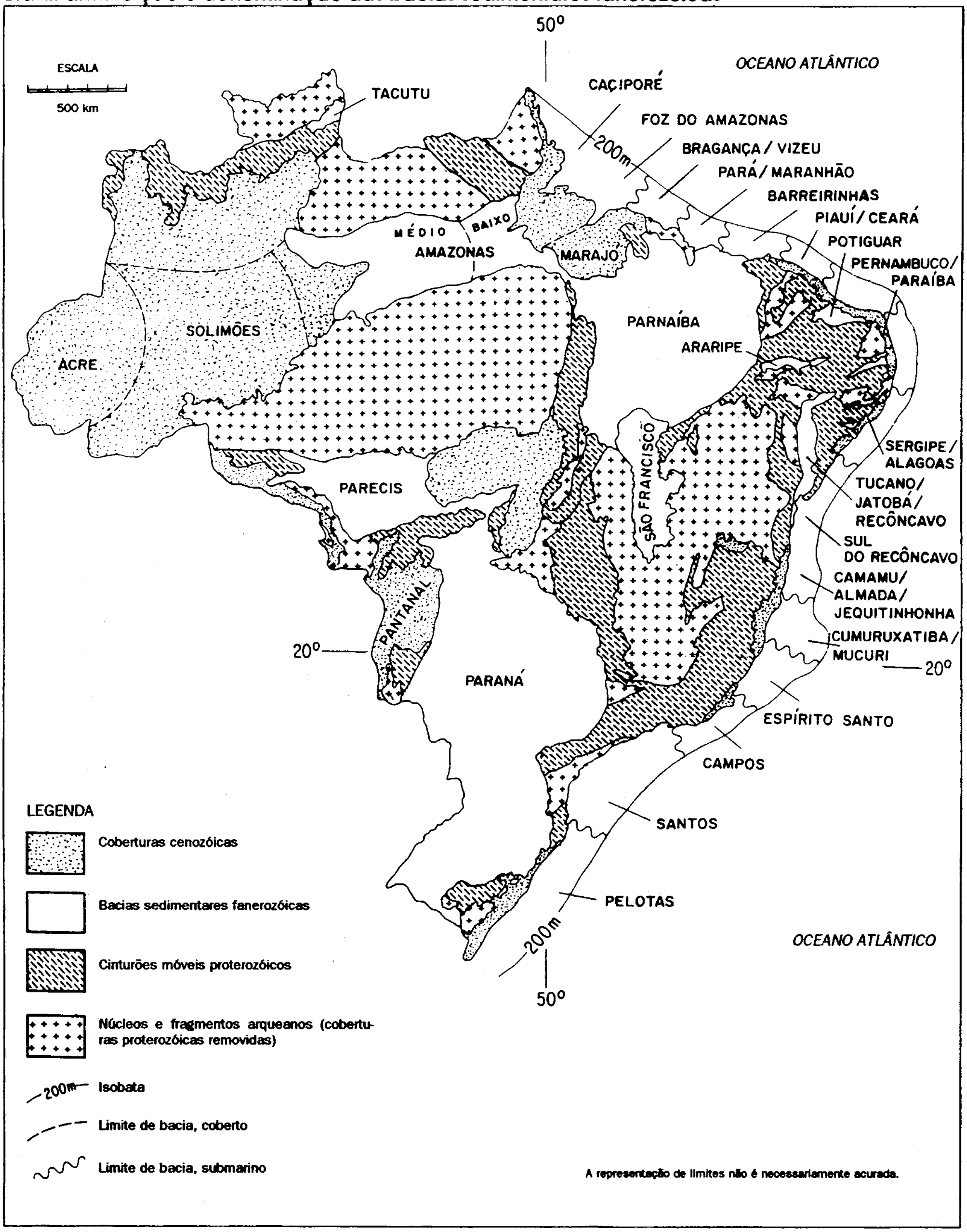
Sistemas de rifts *meso a neoproterozóicos*: OJ: Orós–Jaguaribe; MC: Médio Coreaú.

Fontes: USBM e DNPM, 1995.

Fig. I-3-2-4 Major geological structure sections in Precambrian age in Brazil

Mapa 4.2

Brasil: distribuição e denominação das bacias sedimentares fanerozóicas



Fontes: USBM e DNPM, 1995.

Fig. I-3-2-5 Distribution of sedimentary basins in the Phanerozoic eons in Brazil

and Paraná basins arose in Palaeozoic. These sedimentary activities were activated in early Palaeozoic. Sediments and volcanic rocks were continuously provided up to Mesozoic age.

a) Amazon Basin

It is not yet known well about the basement of lower Palaeozoic sedimentary rocks. The first layer containing fossils in Amazon basin is of Silurian system.

A part of thick Devonian system developed in Amazon basin is abyssal facies containing abundant fossils in part. Maeuuru formation unconformably covers Silurian system in outcrop area. However, it is known as a result of drilling conducted in the central part of the basin that marine sedimentary activities were continuously made from Silurian to Devonian. In the eastern part of the basin, subsidence was larger and sediments were thick as it went toward the supply source. In the southern and northern ends, on the other hand, the sediment thinned out accompanying local unconformity in the southern and northern edges of the basin.

In late Carboniferous, relatively thin and wide distribution of sandstone layer (Monte Alegro formation) was observed after the periods of erosion and no sediment. Most of Nova Olinda formations of the final Carboniferous were distributed only in the central part of Amazon basin. In the eastern part of Manaus, a thick stratum of evaporite consisting of halite and anhydrite exists under the land surface, and its maximum thickness is reported as approximately 500 m (Bigarella, 1973). Also in the eastern part of Manaus, sandstone exists under the land surface which may have evaporates of Permian system on its upper layer and its maximum thickness reached 645 m (Bigarella, 1973). The total thickness of the above-mentioned layers of Palaeozoic is estimated as 7000 m and 3000 m in the central part and western part of Amazon basin respectively. No proof of glacier activity of late Carboniferous has been discovered.

b) Parnaiba Basin

Parnaiba Basin was developed between Guaporé and San Francisco platforms and having Palaeozoic geo-history similar to that of Amazon basin. Unlike long-extending Amazon basin, Parnaiba basin was almost in a circular shape, and the utmost subsidence and sediment were made in its center.

Here, marine deposits of Silurian and Ordovician systems cover Precambrian basement rock with clear unconformity. These strata are further conformably covered by the sandstone containing abundant fossils of Devonian system, siltstone and shale.

Small-scaled unconformity exists on the upper layer of lower Carboniferous system where upper Carboniferous and Permian systems are accumulated with its thickness having reached 700 m at maximum in the center of sedimentary basin.

c) Paraná Basin

Although Paraná basin was only an extremely shallow depression during Palaeozoic, it was developed to become a large structural basin in Mesozoic. The basin covers wide areas of the central/southern parts of Brazil, the eastern part of Paraguay and the northeastern part of Argentine.

On the basin edge in the eastern part of Paraguay, the marine sandstone, which may be of Ordovician system, is distributed covering Precambrian metamorphic rocks, and the marine sandstone is slowly inclined westward to the side of Paraná basin.

The oldest Palaeozoic in Uruguay is the marine sediment of lower Devonian system, but it lacks Devonian system in Paraguay.

In the margin of Paraná basin, the continental sediment strata of upper Carboniferous system are observed in many places unconformably covering the above-referred lower Palaeozoic stratum. Palaeozoic sedimentary activities in Paraná basin ends with sedimentation of continental clastics of lower Permian system.

(3) Mesozoic - Dismantling of Gondwana Continent

Till the end of Palaeozoic, South American platform was unified as the main part of huge Gondwana continent. In this way, dismantling of Gondwana continent started in an essentially stable condition. South America and Africa constituted a continental mass before dismantling of Gondwana continent through opening of a graben and a large-scaled plate motion that took place in Mesozoic.

On the eastern side of Andes Mountains, no sedimentary rocks of early/middle Triassic is observed even in the three large Palaeozoic sedimentary basins (Amazon, Parnaiba and Paraná basins). In the late Triassic, however, Paraná Basin became one of the largest old deserts in the world, and animal fossils of the reptiles and amphibia similar to those produced in South America are saved at the bottom of the lake or riverbed sediments under large-scaled sandstone layer.

In latter Triassic period, large-scaled igneous activities began on the eastern side of Andes Mountains (see Fig. II-3-2-6). Dolerite dikes of the late Triassic period are widely distributed in Guiana shield with strikes of NNE-NE on the western side and NNW on the eastern side and K-Ar age of approximately 220 Ma. There are mafic intrusive rocks of the similar age also in Amazon Basin. The average age of the oldest Mesozoic mafic rocks existing in the basin is 181 Ma.

In latter Jurassic period, a large-scaled basaltic lava eruption began to occur on the South American platform. These lava flows known as Paraná basalt (or Serra Geral basalt) flow

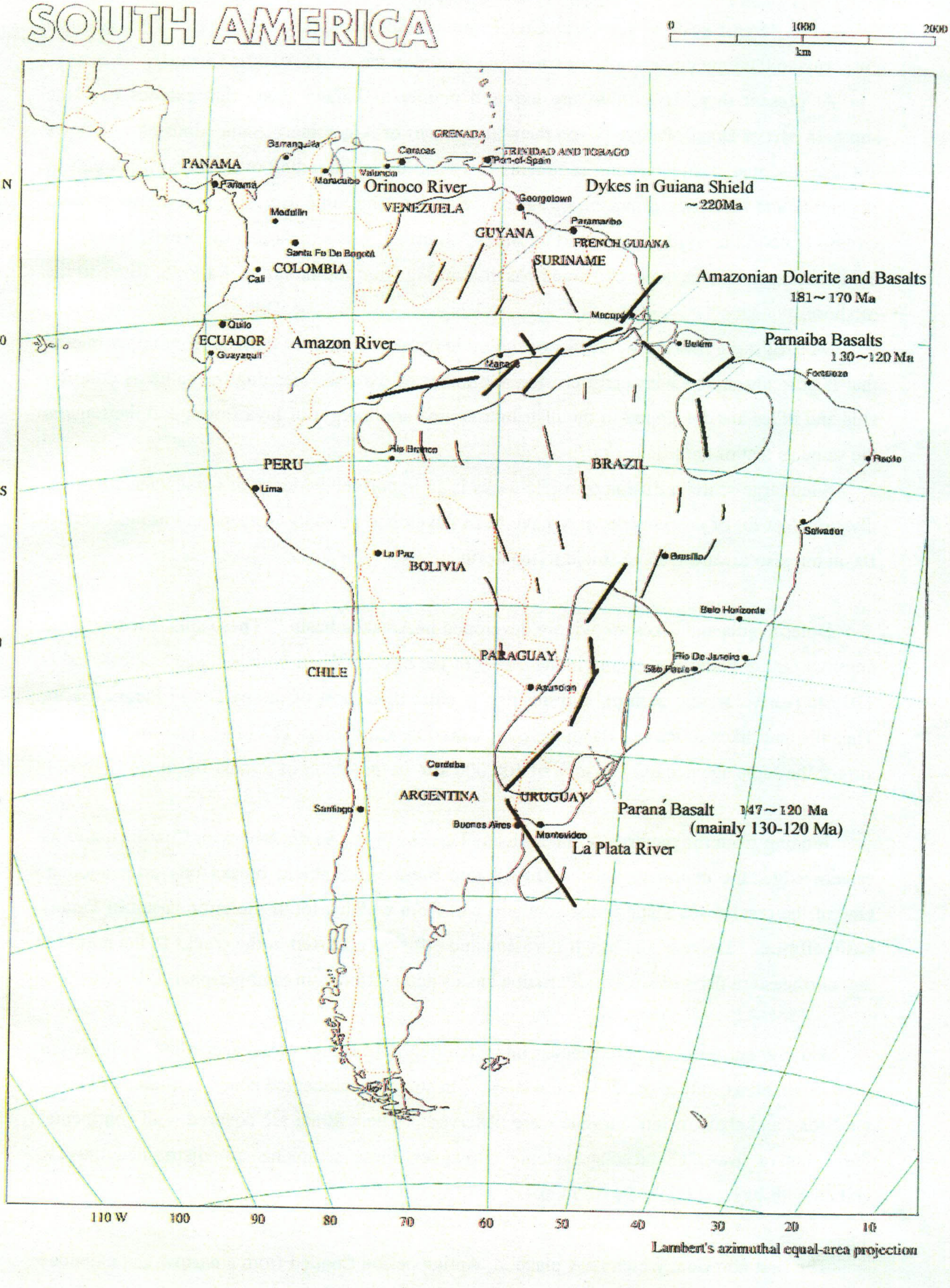


Fig. I-3-2-6 Mesozoic mafic igneous activity in eastern South America (compiled from Rezende, 1972; Bigarella, 1973; McConnelll, 1975; Zamborano & Urien, 1974; Cordani et al., 1967)

reached its largest scale in the early Cretaceous period (about 130~120 Ma). This age also conforms to the time when sea-floor spreading started in the South Atlantic Ocean.

At present these lava flows are exposed mainly in Paraná Basin that extends over the southern part of Brazil, Paraguay and the northern part of Argentine. Same kinds of lava flows are also discovered under young sediments in Chaco basin extending over the northern part of Argentine and the western part of Paraguay. Basalt of the same age is observed also in Mato Grosso State in the southwestern part of Brazil. Further, it is known that there exist lava flows almost comparative to those of Paraná basalt, ranging from the mouth of La Prata River to the offshore.

Most of these lava flows consist of tholeiitic basalts, obviously derived from upper mantle that is scarcely mixed with earth crust. A number of diabase (meaning the same as dolerite) sills and dikes are developed in the distribution area and margin of lava flows, and their age is the same as that of basaltic rocks.

Such large-scaled effusion of mafic rocks is an important evidence of Gondwana continent division. A lot of deep cracks may have been developed not only beneath and around Paraná Basin but also toward Guiana shield to the north.

Dolerite sills and dikes are widely developed in Amazon basin. These sills reached to the depth of 600 m under the ground in the center of the basin. Their youngest age as measured is 170 Ma (early Jurassic period), and this age is older than most of the basalts in Paraná Basin. The sills and dikes in Paraná Basin were measured by Cordani as 127 Ma. The basalt lava of almost the same age occupies an area of 100,000 km^2 in the center of Paraná Basin.

Judging from the patterns of the faults and cracks in the South American Continent and its eastern edge, the continent was destroyed into mosaic-like shield blocks one after another. One of the cracks was made in the southern part from which a lot of tholeiitic basalt of Paraná basin effused. Dolerite and basalt intrusion and effusion occurred in the cracks in the northern and northeastern parts of Amazon/Parnaiba basins and platforms in their periphery.

Throughout the early Cretaceous, intensive trench forming took place in the northeastern parts of Brazil as well as on the eastern coast. In some of submerged zones, non-marine clastic sandstone and shale of late Jurassic were observed. These strata are covered with continental sediments of lower Cretaceous system. However, these sediments are distributed only in graben with its local thickness of 5 km.

The first abrasion, which took place in, Aptian period flooded from a narrow and extended bay to Brazilian coasts. At first, blocked by its convex structure, it was possible for this primitive bay to be enlarged and connected only in the southern part. Therefore, dry climate continued in the inland and thick strata of evaporate was sediment (Ponte et al., 1977). Afterwards, a stratum of carbonate rocks was piled from Albian stage, and then it was inclined to the seaside and thick sediment was accumulated on the continental edge.

3-2-2 Outline of Ore Deposits

The location of ore deposits in Brazil is described on the 1:2,500,000 scale "Mapa Geologico do Brasil" (DNPM, 1995b). In addition to this map, the location and outline of major ore deposits are summarized on the 1:7,000,000 scale attached to the CPRM (1995).

(1) Ore deposits of Archean Era

Gold, copper, manganese, and iron ore deposits that accompany Greenstone belt volcano-sediments, and nickel, copper, chromium and asbestos deposits that accompany basic to ultra-basic composite rocks are known as ore deposits of this era.

The primary gold ore deposits related to the Greenstone belt include the Morro Velho ore deposit in Minas Province, the Mara Rosa, Crixas, Pilar de Goias ore deposits in Goias, and others. Some of them have copper mineralization.

Tapajos, Madeira, and the southeastern part of Pará Province are typical placer gold ore deposit distribution areas in Amazonia. It has been known that the provenance of the gold is the auriferous quartz vein in metabasites and amphibolites in Complexo Xingu. Today, some of these basic rocks are considered to belong to the Greenstone belt.

These belts are distributed as volcano-sediments in the Salobo area and as Jacareaçanga metamorphic rocks in the Tapajos area. Grupo Vila Nova and others are distributed as an ore deposit host rock from Amapá Province to the northeastern part of Pará Province.

Auriferous quartz veins generated by the remigration of gold and gold deposits generated by the intrusion of granites of the Proterozoic often occur in the crush zone in the NW-SE and NE-SW directions.

(2) Ore Deposits in the Lower Proterozoic

In addition to the primary gold ore deposits that are occurred in the Greenstone belt, sandstone-type gold ore deposits, sedimentary gold, copper, and manganese ore deposits, iron ore deposits, deposits that accompany basic to ultra-basic rocks, and volcanic polymetallic ore deposits are known as ore deposits of this era shifting from the Archean to the Proterozoic.

There are auriferous and uranium ore deposits, which is held in a sandstone layer, called the Witwaters Rand type and the Blind River type as a sandstone-type ore deposit. Mineralization in the metaconglomerate layer of Grupo Jacobina in Bahia Province, Supergrupo Minas in Minas Province, and Cidade de Goias in Goias Province are good examples of the auriferous and uranium ore deposits.

The Serra Pelada gold ore deposit in the transgressive sedimentary facies of a Rio Fresco layer type distributed near the Serra dos Carajás (the Carajás mountain range), the Bahia copper ore deposit, and the Azul manganese ore deposit are sedimentary-type ore deposits.

An iron ore deposit is classified as Algoma-type and Superior-type BIF (Banded Iron Formation). The deposits in Supergrupo Minas at the iron square zone in Minas state, and an iron ore deposit that are located in Grupo Grao Para in the Carajás area, Pará are good examples.

The Americano do Brasil in Goias Province, the Mangabal ore deposit, and the Ti-Fe-V ore deposit in the Campo Alegre de Lurdes gabbro - anorthite composite mass in Bahia Province are Ni-Cu-Co ore deposits that accompany basic to ultra-basic intrusive rocks.

Boquira Pb (-Zn-Ag) ore deposit in Bahia Province, Barra do Perau Pb (-Ag-Zn) ore deposit in Paraná Province, and Palmeiropolis Zn (-Pb-Cu) ore deposit in Tocantins Province are typical volcanic polymetallic deposits.

(3) Ore Deposits in the Middle Proterozoic

A tin ore deposit is a major ore deposit of this era. In addition, nickel, chromium, and asbestos ore deposits have been known. Some diamond ore deposits have also been found.

With the development of the platform-type sedimentary basin, the tectogenesis occurred in this era. A thick layer of sediment that accompanies acid – neutral volcanic rocks and pyroclastic rocks is widely distributed. Granites that penetrate through this layer develop and a tin deposit is formed. Almost all the tin mineralization in Brazil belongs to this era; in particular, it is distributed much from Amazonia to the Goias area.

Alpine type ultra-basic rocks intrude near a fold belt, and have mineralization of nickel, chromium, asbestos (the Morro Feio, Dois Irmao, Quatipuru deposits, and others).

The kimberlite intrusion accompanied by the first diamond mineralization in Brazil, which is the source of the palaeo-placer deposits of each subsequent period, belongs to this.

(4) Ore Deposits in the Upper Proterozoic

Pegmatite ore deposits that accompany granite intruding the tectonic zone of the Brasiliano orogenic movement and pegmatite, non-ferrous metal ore deposits that occur in sedimentary rocks of the fold belt, copper deposits that are mineralized in volcanic and sedimentary rocks, iron – manganese ore deposits near the Amazon craton, etc. are ore deposits of this era.

The pegmatite ore deposits are distributed in Minas Province, Bahia Province, the northeastern part of Brazil, and other areas and contain beryllium, tin, niobium, tantalum, lithium, etc.

The non-ferrous deposits in sedimentary rocks include the Panelas Pb (Au and Ag) deposit, the Sete Barra fluorite deposit, and Perau Pb-Zn deposit in Paraná Province, the Itapeva Cu deposit in São Paulo, etc. In addition, the Vazante Zn deposit and Morro Agudo Pb-Zn deposit in Minas Province are good examples of the Mississippi Valley type deposit.

Also, the copper ore deposits that in volcanic and sedimentary rocks include the Pedra Verde ore deposit in Seara Province and the Canidade de São Francisco ore deposit in Sergipe.

A deposit in the Corumba area in Mato Grosso do Sur is a typical iron – manganese sedimentary ore deposit.

(5) Ore Deposits in the Phanerozoic Eons

A molasse-type sediment develops in the rift zone of the southern part of Brazil from the late Proterozoic Era to the early Palaeozoic, and the Camaqua copper mine and the Caninde de São Francisco Pb-Zn ore deposit in Rio Grande do Sur occur as a disseminated or vein-like ore deposit.

Various types of sedimentary deposit occur in the sedimentary basin generated with the blocking of craton. In the Paraná basin, uranium mineralization is found in the Devonian stratum in Goias Province, and coal seam and peat beds are found in the sedimentary stratum of the Carboniferous in Rio Grande do Sur Province. In the Amazon basin, halite and potassium - gibbsite ore deposits are known in the Carboniferous – Permian strata, and a gas field is discovered in the sandstone bed of the Carboniferous.

Halite, potassium, sulfur, petroleum, and gas deposits occur near the Parnaiba basin from Sergipe to Goias Province.

Various kinds of mineral such as phosphor, niobium, titanium, nickel, uranium, zirconium, and diamond are generated as mineralization that is accompanied in alkaline rock, carbonatite, and kimberlite rock masses, which are considered to have resulted from igneous activities concurrent with the period of the division of the Gondwana land.

On the other hand, some of the residual and alluvial deposits occurred from the Cenozoic to the Recent, are of much commercial value. The bauxite, kaolin, placer gold, and placer tin deposits in the Amazon are representative examples. In the Amazonia province where these types of deposit are found, a primary ore-bearing, which supplies the minerals above as an ore source, is very likely to exist. The Brazilian government is putting a great deal of effort into the exploration and development of this area.

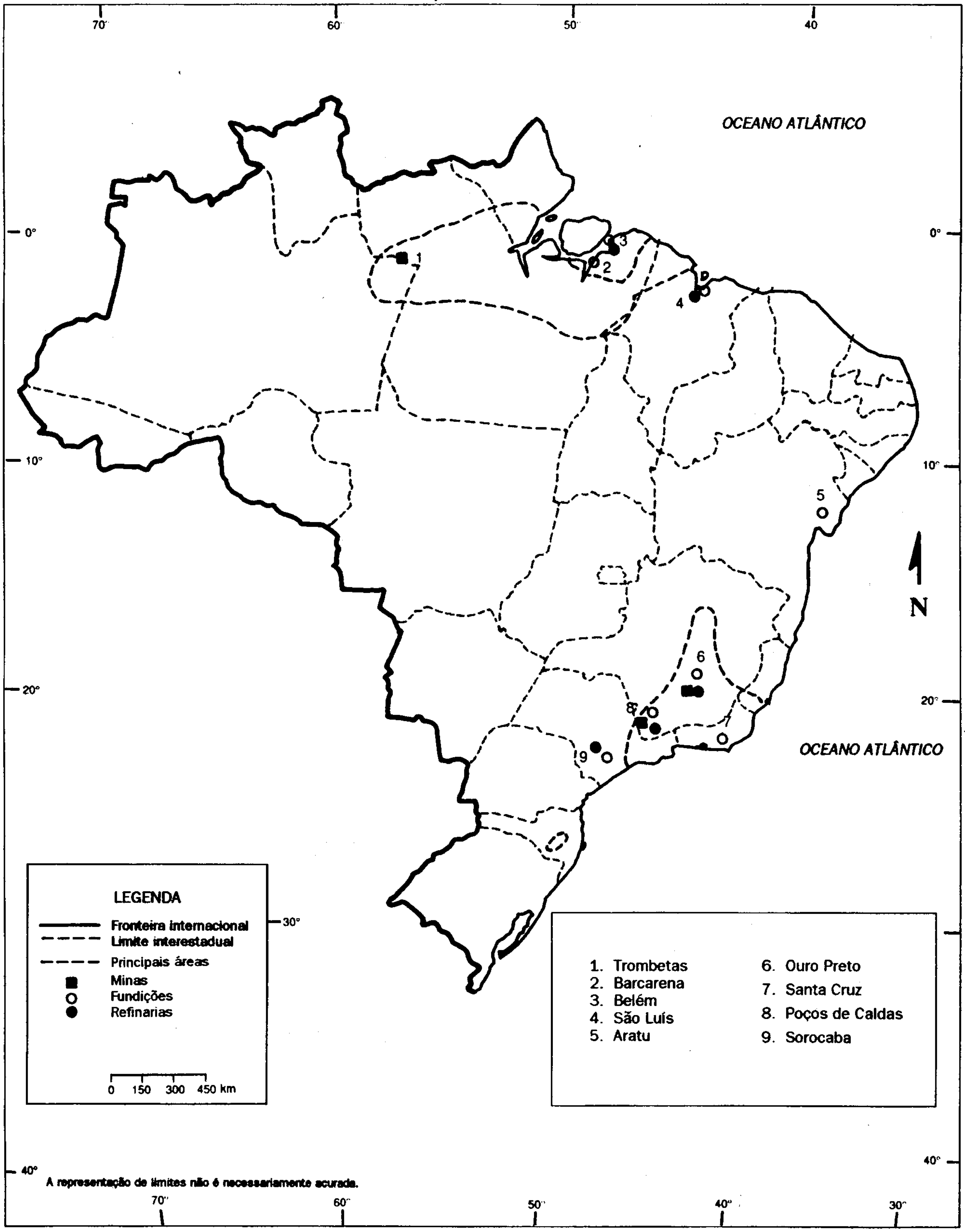
3-2-3 Mines, Ore Deposits, and Ore Showings

The location of major mines and ore deposits in Brazil is summarized by ore type in the DNPM (1995) and the outline is set out in the table. The maps by ore type are shown in the present report (Figs. II-3-2-7, II-3-2-8, II-3-2-9, and II-3-2-10).

Major ore deposits are described in the DNPM and CVRD (1986, 1988, and 1991). For reference purposes, the summary of these ore deposits included in the fiscal 1992 Report of project finding survey (MMAJ, 1993) is available in Japanese.

Mapa 6.1

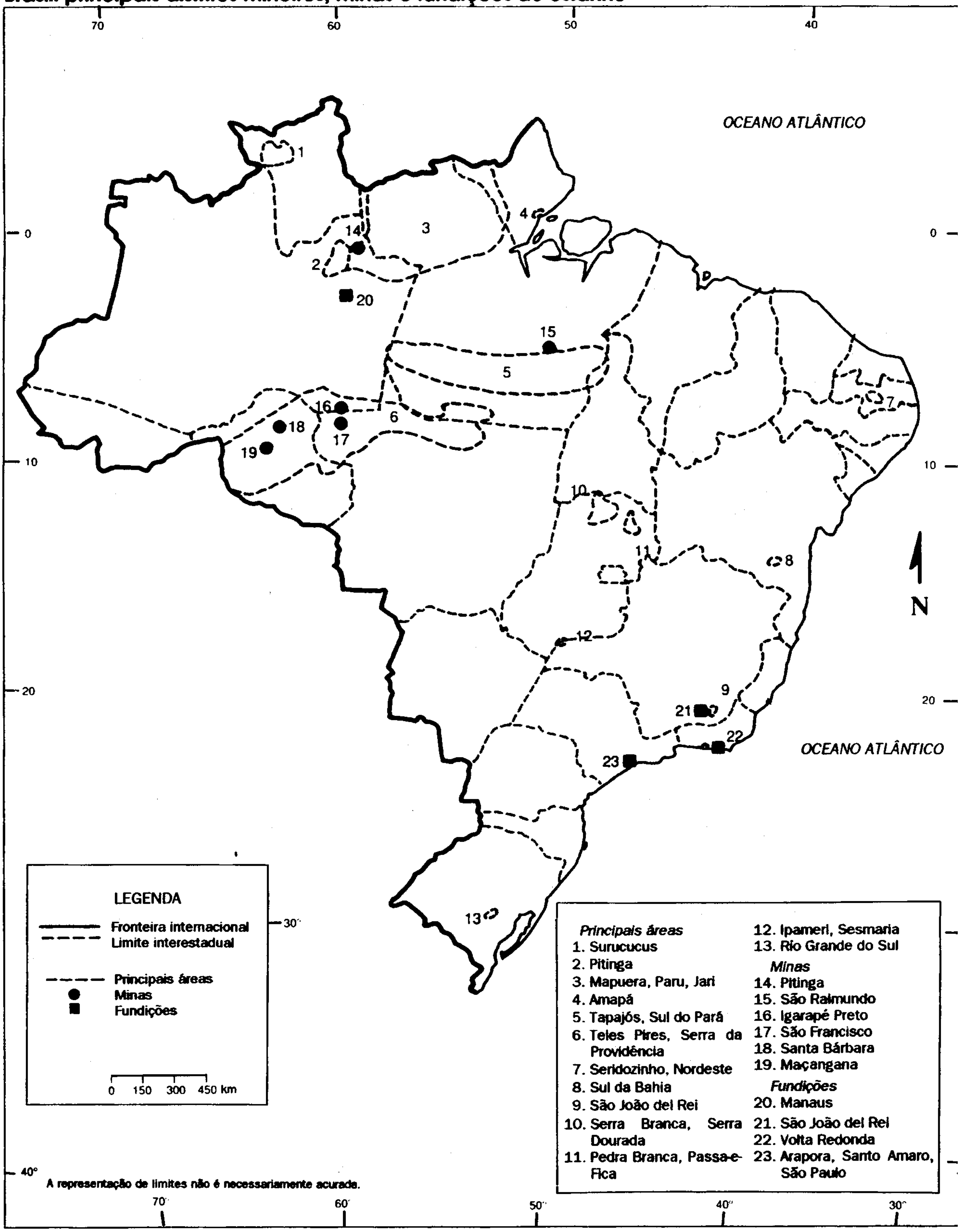
Brasil: minas de bauxita e usinas de alumina/alumínio



Fontes: USBM e DNPM, 1995.

Fig. I-3-2-7　　Distribution of aluminum ore deposits and smelting factories

Mapa 6.2
Brasil: principais distritos mineiros, minas e fundições de estanho

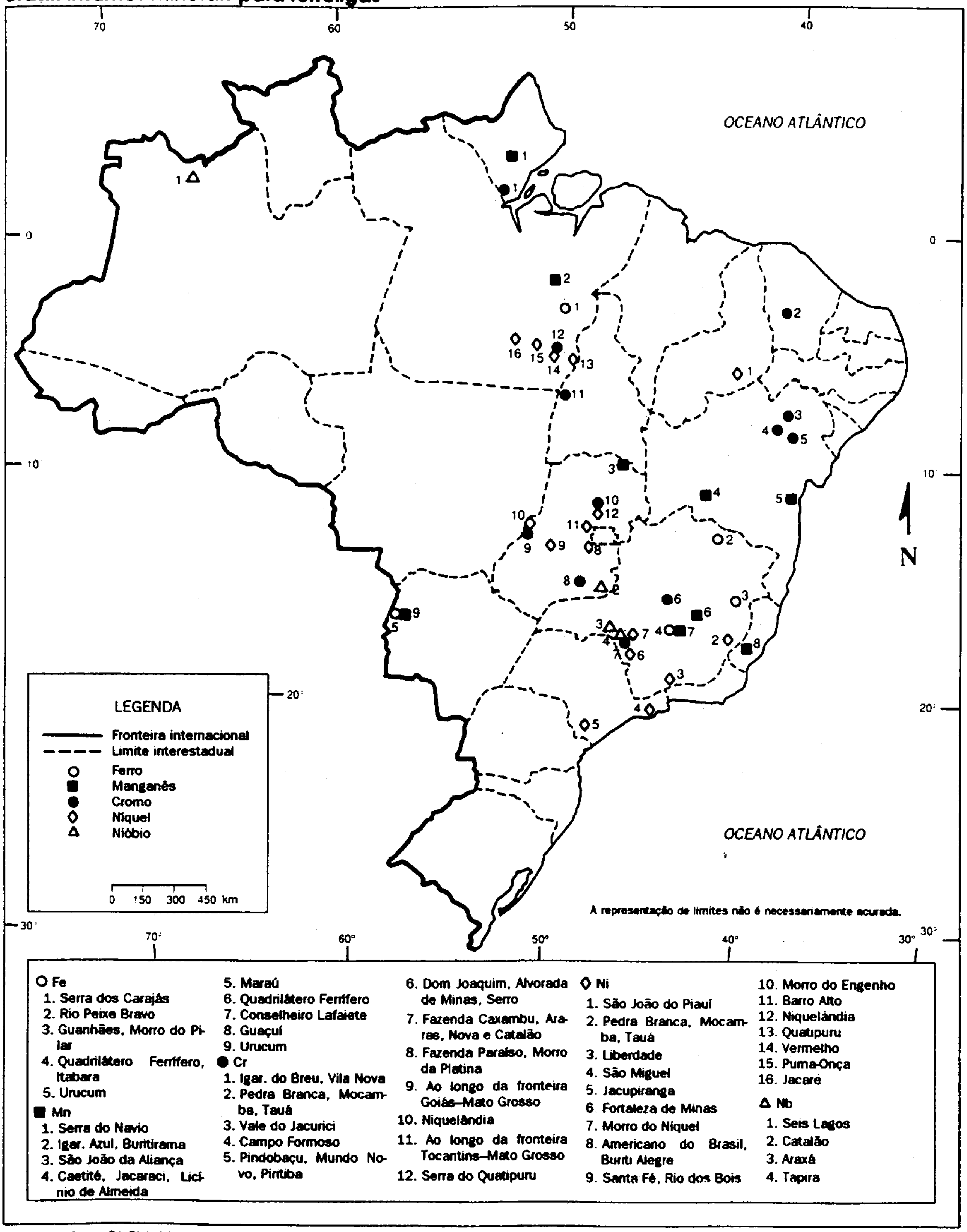


Fontes: USBM e DNPM, 1995.

Fig. I-3-2-8 Distribution of tin ore deposits

Mapa 6.3

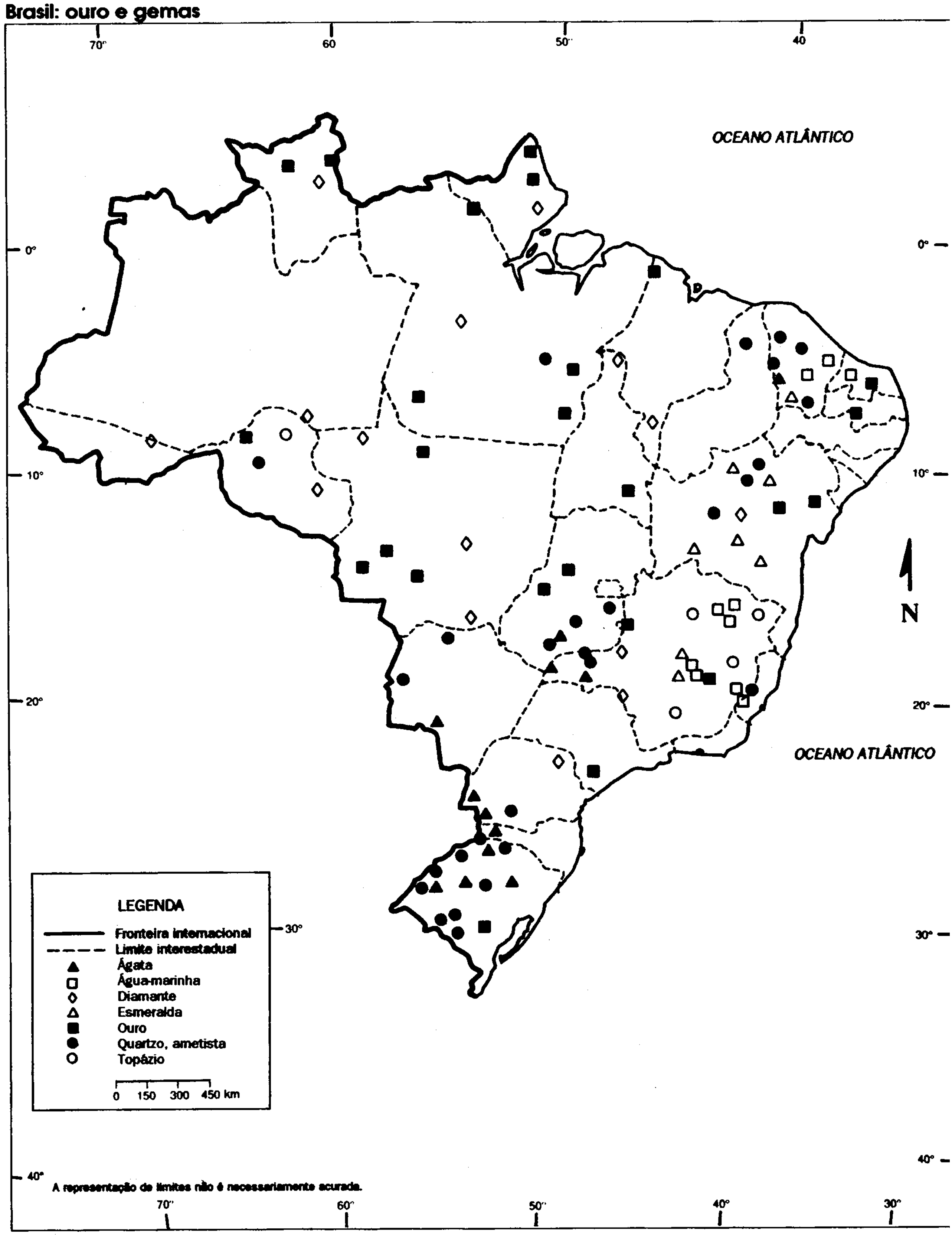
Brasil: insumos minerais para ferroligas



Fontes: USBM e DNPM, 1995.

Fig. I-3-2-9 Distribution of Fe/Mn/Cr/Ni/Nb ore deposits

Mapa 6.4
Brasil: ouro e gemas



Fontes: USBM e DNPM, 1995.

Fig. I-3-2-10 Distribution of gold and gem stone deposits

3-3 PGE National Program of the CPRM

3-3-1 Histories

The platinum group metal (PGM) or the platinum group element (PGE) consists of six elements: platinum (Pt), palladium (Pd), rhodium (Rh), ruthenium (Ru), osmium (Os), and iridium (Ir). These elements are similar in physical and chemical properties and are produced naturally in combination. They are known as precious metals like silver. They are difficult to melt in high temperatures, chemically inactive to many elements, and excellent in catalytic capability. The elements are extremely high in specific gravity; iridium has a specific gravity of 22.65, the highest in nature. Also, the melting point of osmium is as high as 3,045 ℃ and that of platinum is as high as 1,769 ℃ These platinum group elements are always contained in basic to ultra-basic rock as a compound or a natural alloy.

The PGM combines with anions such as oxygen, sulfur, arsenic, antimony, bismuth, tellurium, tin, and lead to serve as cations. Also, the PGM is mixed with titanium, iron, gold, and mercury into a natural alloy. Some of the popular minerals are sperrylite ($PtAs_2$), braggite ((Pt, Ni)S), cooperete (Pt, Pd)S, natural platinum, natural palladium, and natural osmium.

The importance of the PGM lies in its physical and chemical properties (The application of the PGM depends on its physical and chemical properties). The PGM is important not only as jewelry and investment property but also to electronic components and pollution-control substances (e.g. automobile catalyst) in various industrial fields. Also, it is used for the fuel cell as a new technology and applied to a new electronic industry and medical treatment.

The PGM reserves in the world concentrate in South Africa. Russia is the second place in the PGM reserves. These two countries account for 98.5% of the world's reserves. The same applies to the amount of production. Some people are anxious about the future, stable supply of the PGM because of this uneven distribution.

With this in view, the Brazilian government started to carry out a basic study about the potential of its country's PGM resources in 1990s. The government paid particular attention to the Mesozoic flood basalt that widely covers the southwestern part of Brazil (Geological Map of Paraná Basalt area in Fig. II-3-3-1).

Against this background, Paraná Mine Public Company (Mineropar) showed a positive attitude in liaison with the Brazilian government's effort and carried out a wide-range stream

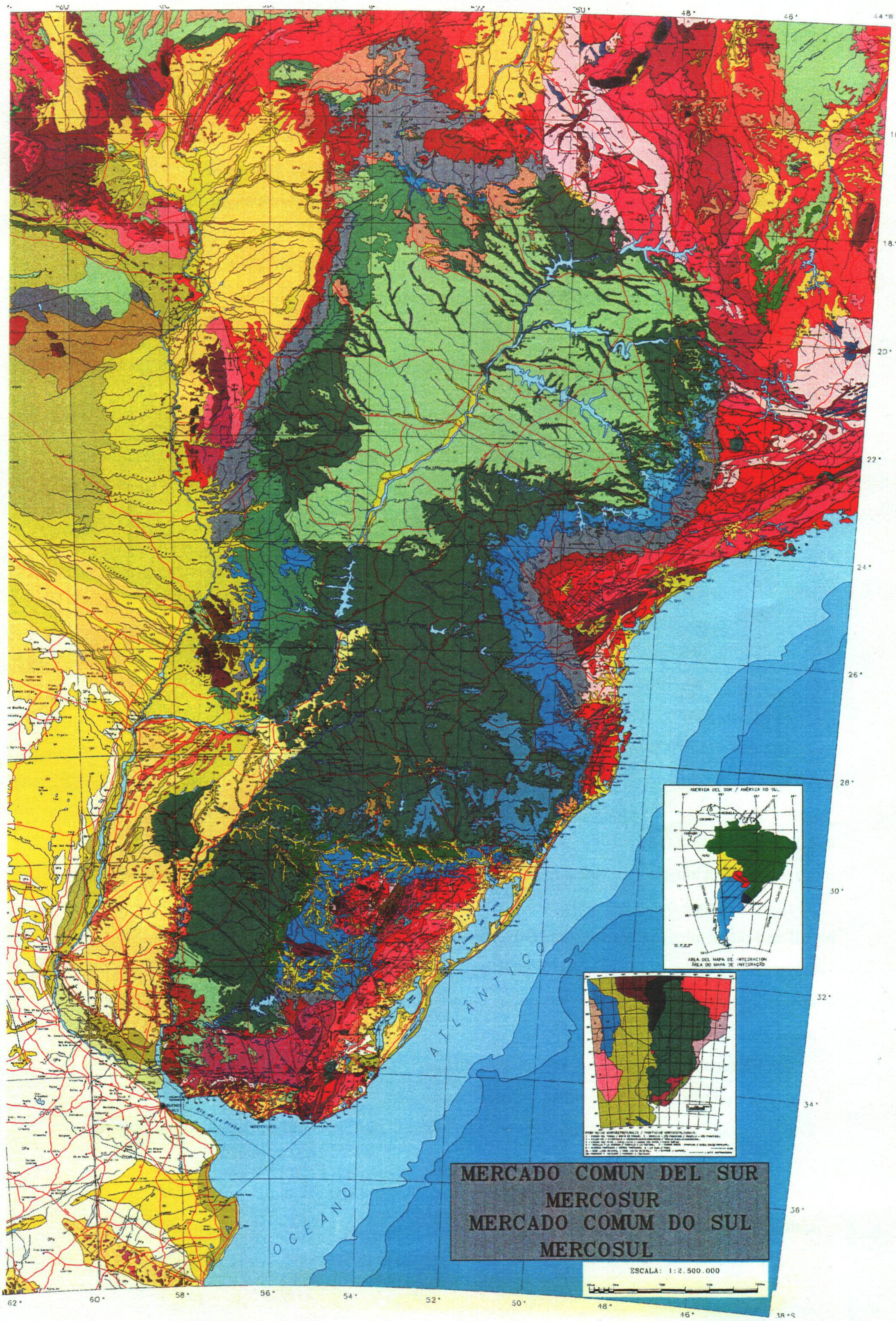


Fig. I-3-3-1 Geological map of Paraná basalt region

sediment geochemical survey (area: approximately 160,000 km^2, number of samples: approximately 700) in Paraná state cooperation with a governmental organization in 1994. Although the sampling density of this reconnaissance survey (one sample at approximately every 230 km2) was extremely low, this survey allowed Mineropar to determine the geochemical anomalies of nickel, chromium, and copper as well as platinum and palladium in the southwestern part. Subsequently, Mineropar conducted its own survey in the anomaly area, and analyzed sill-like doleritic rocks discovered at some points and obtained high geochemical anomalies of palladium from some of the doleritic rocks.

3-3-2 Overview of CPRM's Platinum Project

It seems that CPRM-led PGE (PGM) (PGE: Platinum group element; PGM: Platinum group mineral) project was promoted actively at the first phase until 1995. However, information on the following progress has been hardly available. Therefore, this section describes CRPM's operation during 1990 to 1995, based on the report by Farina (1996).

(1) Geological Conditions

PGM ore deposits can be formed under many geological environments. In reality, however, they are limited to basic to ultra-basic basement rock bodies. Farina (1988) classified such geological environments into 15 categories. According to Farina, the following three types of ore deposits account for 99% of the world's reserves and 98% of the production in the world.

a) Layered Intrusion (LI)

Layered intrusion is distributed in the plate and anorogenic belts, disregarding flood basalts and basic to ultra-basic intrusive rock bodies in continental environment.

b) Sill and other intrusive rock bodies (FB: Flood Basalt)

Layered intrusion (mainly sill), consisting of dolerite to gabbro composites. This was related to rifting and flood basalts in the continent. The rock body is found in the plate or in anorogenic belts.

c) Lava of Komatiite constituents and layered intrusive rock in Greenstone Belt (GB)

d) Anorogenic basic-ultra-basic intrusive rock bodies (AI)

Those classified into this type can be reclassified by later examination when they are considered as important.

e) Unclassified basic to ultra-basic intrusive rock body (MU: complex or Mafic and / or ultramafic unclassified bodies)

This covers those that the definition of an ore deposit type does not fit the objects.

Table II-3-3-1 lists PGM reserves in the world and PGM production volumes in the world.

(2) National program of platinum group deposit exploration

CPRM started this program under the following four conditions:

- Highly economical and political significances that platinum group has
- Brazilian land has high potential for geological development, especially the land is rich in basic to ultra-basic rock bodies.
- No exploration has been done.
- Brazil does not produce platinum group.

This program began in 1990, defining the scientific basis on the goals and the exploration method. This program is permanent, and set the first stage end to 1995.

Table I-3-3-1 Type of PGE deposits in the world and their reserve and production

Type	Examples	World Reserve Base(1988) %	World Production Base(1988) %
LI	・Bushveld (South Africa) ・Sudbury (Ontario, Canada) ・Stilwater (Montana, USA) ・Great Dike (Rodesia)	90.2	50
FB	・Noril'sk, Talnakh, Mairk e Taymir (Siberia, Russia)	8	37
GB	・Thompson, Manitoba (Canada) ・Kambalda (West Australia) ・Fortaleza de Minas (Minas Gerais, Brazil)	1.2	11
Others		0.6	2
Total		100	100

LI: Layered Intrusion, FB: Flood Basalt, GB: Greenstone Belt

Eleven standing geological engineers and three non-standing geological engineers have dealt ten projects, with support from CPRM regional offices in Brazil.

This program is under the Government of Brazil and aims to support and subsidize mining companies in the private sector who engage in wide area exploration. However, the program does not include those are at the detail survey stage to explore an ore deposit and who engaging in economical evaluation.

This program is applicable to any person or company who engages in exploration in areas where the production of platinum is promising. In other words, this program neither defines any specific mining sites nor guarantees any ores under the name of CPRM.

(3) Exploration Method

The exploration method almost controls the result of the program--whether succeeding the program or not depends on the exploration method. The following items were selected, for which a training program will be provided, at the time of starting this project.

Training:

A workshop will be held on the following items to train individual teams.

- Geology and petrology on basic and ultra-basic rocks
- Mineralogy on platinum ore deposits
- Ultra-basic rock in Greenstone Belt
- Overview of laterite and gossan
- Practical training of geochemical prospecting
- PGE ore deposits and how to explore

Selecting target points:

The target points were selected by examining the following factors:

- To extract basic to ultra-basic rock bodies, especially large rock bodies, by using existing geological maps.
- Data on airborne magnetic prospecting.
- Geochemical anomaly of Ni, Cu, Co (Cr)
- Ore deposits of Ni, Cu (Co) sulfides
- Definition of ore deposit types (LI: layered Intrusion; FB: Flood Basalt; GB: Greenstone Belt;

AI Anorogenic Intrusion; MU; unclassified intrusion)

Selective Geological Mapping:

Focuses on platinum exploration by reediting and revising existing geological maps to make or edit a selective geological map.

Mineralogical Pan-Concentrate Prospecting:

Exploration of heavy minerals separated from alluvial sediments by panning is important since the density of platinum group elements is extremely large. The prospecting method should be routined; the quantity of a raw sample is supposed to have 15to 20 litters. In a special case, the soil sample must also included in the target of test.

Geochemical prospection:

As a routine, two types of a sample should be gathered. One is a sample of heavy minerals and the other is a sample of stream sediments at the same site. Soil samples should be gathered when necessary.

Ground physical exploration:

Magnetic exploration and IP exploration should be conducted in a special case.

Exploration by drilling: Should be conducted when necessary.

Laboratory testing:

Laboratory testing includes the following types of routine work:

- Rock: Petrography.
- Rock accompanying sulfides:To describe rocks and copper minerals and others; to analyze rocks for Pt, Pd, Au, Cu, Co, Ni, and Mg.
- Gossan: To analyze for Cu, Co, Zn, and Ni; to conduct chemical analysis for Pt, Pd, and Au.
- Heavy minerals (panning concentrate): To identify minerals by stereoscope and electron microscope; to analyze minerals for Pt, Pd, Au, Cr, and sometimes for Ir.
- Fluvial sediment and soil: To analyze for Cu, Ni, Co, Zn, Au, and Cr; to analyze rocks for major 13 oxides, REE, S, Ba, Sr, Rb, H2O+, and H2O- when necessary.

Data Processing:

Each of the samples must have a data file where coordinates, geology, and other data are entered.

Map and Report making:

To examine and analyze data collected at field survey and laboratory. The result shall be made in the form of an annual report including maps.

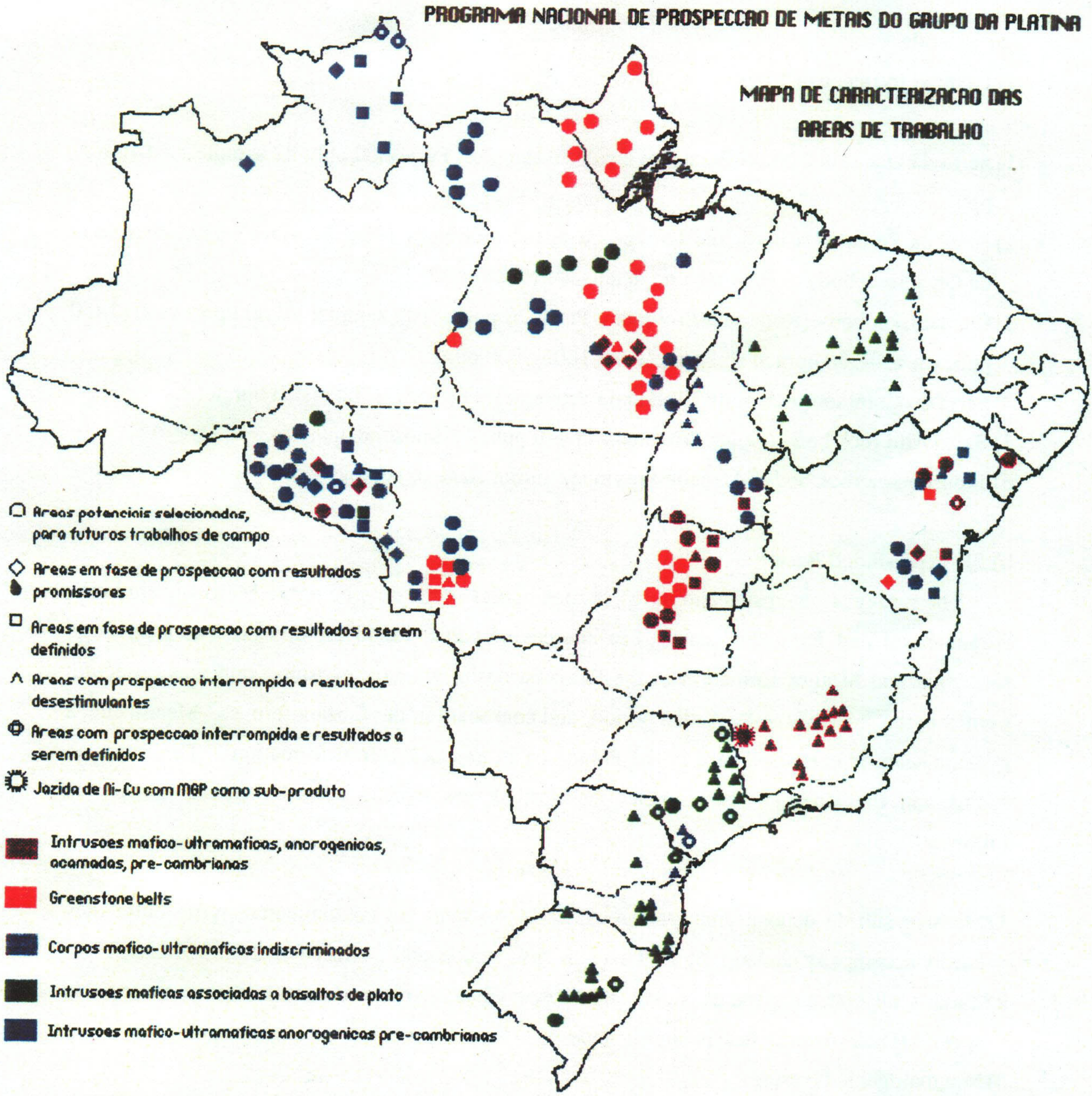
(4) Work so far completed

Table II-3-3-2 lists prospection records for 1992 to June 1995. Fig. II-3-3-2 shows locations of rock bodies by types.

Table I-3-3-2 Samples already collected and analysed by CPRM PGE project

Project	Pan Concentrate		Stream Sediments		Soils		Rocks		Totals	
	Sampled	Analysed	Sampled	Analysed	Sampled	Analysed	Sampled	Analysed	Sampled	Analysed
Platina - RS/SC	41	41	0	0	0	0	359	162	400	203
Platina - SP/PR	419	210	440	440	48	48	278	207	1,185	905
Platina - MG	4,572	1,633	3,030	1,352	3,372	3,124	954	590	11,928	6,699
Platina - BA/SE	342	163	315	315	8	8	234	112	899	598
Platina - PA/AP	3,160	62	2,101	2,063	0	0	165	97	5,426	2,222
Platina - AM/RR	258	247	133	123	27	27	382	162	800	559
Platina - RO	895	167	621	454	433	375	599	497	2,548	1,493
Platina - GO/TO	1,469	1,029	408	388	1,128	826	710	710	3,715	2,953
Platina - MT	129	0	4	0	0	0	34	0	167	0
Platina - PI/MA	152	37	12	0	33	19	72	38	269	94
Total	11,437	3,589	7,064	5,135	5,049	4,427	3,787	2,575	27,337	15,726

Abreviations of state names; AP: Amapa State, BA: Bahia State, GO: Goias State, MA: Maranhao State, MG: Minas Gerais State, MT: Mato Grosso State, PA: Para State, PI: Piaui State, PR: Paraná State, RO: Rondonia State, RR: Roraima State, RS: Rio Grande do Sul State, SC: Santa Catarina State, SE: Sergipe State, SP: São Paulo State, TO: Tocantins State.



PRECAMBRIAN LAYERED ANOROGENIC MAFIC-ULTRAMAFIC INTRUSIONS	○ - SELECTED POTENTIAL AREAS FOR FUTURE FIELD WORK
GREENSTONE BELT	◇ - AREAS WITH PROSPECTING WORK IN PROGRESS AND WITH GOOD RESULTS
UNCLASSIFIED MAFIC- ULTRAMAFIC BODIES	□ - AREAS WITH PROSPECTING WORKS IN PROGRESS AND RESULTS TO BE DEFINE D
MAFIC INTRUSIONS ASSOCIATED WITH PLATEAU BASALTS	^ - AREAS WERE PROSPECTING WORK HAS BEEN STOPPED DUE TO UNSTIMULATING RESULTS
PRECAMBRIAN ANOROGENIC MAFIC-ULTRAMAFIC INTRUSIONS	- AREAS WERE PROSPECTING WORK HAS BENN STOPPED BUT WITHOUT DEFINITIVE RESULTS
	- Ni-Cu DEPOSITS WITH PGM AS BY-PRODUCT

Fig. I-3-3-2 **Target areas and bodies for PGE Prospecting by CPRM**

(5) Results

a) Layered Intrusion--LI type

1) Serra da Onca rock body (Para Province); 36 samples, Pt 04-800 ppb; 42 samples: Pd 10-400 ppb
2) Serra da Puma rock body and Igarape Carapana rock body (Para Province): similar to Serra da Onca rock body. However, no details were surveyed.
3) Cacoal rock body (Rondonia Province): Pt 10-20 ppb at pan sample; Pd 30 ppb, Au 10-1450 ppb; Cu 450-900 ppm at soil sample; Ni 1600-3000 ppm.
4) Serra do Colorado rock body (Rondonia Province): The rock is interested but not surveyed.
5) Barro Alto rock body (Goias Province): Pt 440 ppb. Almost no analysis.
6) Tapuruquara rock body (Amazon Province): Initial stage of survey.

b) FB Type--Flood Basalt

The survey targeted sills and intrusive rock bodies in the dolerite of the Mesozoic era in the Paraná basin and Parnaiba basin. The sources of sulfur found include the Pedra do Fogo formation and Motuca formation in the Parnaiba basin, where a gypsum seam was observed; pyrites in the shale of the Devonian period; and coal seam in the Carboniferous. Meanwhile, a gypsum seam is extremely rare in the Paraná basin except the Irati formation. The Brazilian basins and the Russian basins including Noril'sk are similar in many points except the following:

1) Massive sulfide deposit and basic rock: Most of them are contaminated pyrite only; they hardly accompany chalcopyrite. There are few whose total S exceeds 1-2%.
2) Large-scale concentration of Nickel and copper: Chalcopyrite and malachite were observed in spots. Their quantity has no significance.
3) Magmatogenic layering
4) Existence of olivine and picrite rock:
   Olivine is missing in most of sills except rock bodies in Port Alegre Provincial capial and in Jose Fernandes of Paraná Province. This will be a target for future survey.
5) Assimilation of host rock and re-crystallization: identical-spot low-temperature(?) thermal metamorphism is known.
6) Existence f platinum minerals in Pan-concentration

Port Alegre Province capital----Picrite rock is located in a 6-km^2 rock body called "Lomba Grande."

The quantity of olivine accounts for 17-36% (maximum: 50%), which could be called "dolerite/gabbro." The quantity is interested from mineralogical viewpoint. However, porphyritic chalcopyrite, a small quantity of natural copper, and moshrite(?) (NiAs) were observed. No conditions of "a", "b", "c", "e", "f" are recognized.

Jose Fernandes gabbro rock body----Located in Adrianapolis Country of Paraná Province. it has an 5-km^2 area in irregular form. Olivine accounts for 15-20% of the rock body. The host is made of a variety of beds in the Precambrian age. Except for the Paraná basin, this rock body is the only dyke of the Mesozoic era.

A small quantity of pyrrhotite, chalcopyrite, pentlandite, cubanite, sphalerite, and mackinarite were observed in polished sections. Gold grains were observed in Pan-concentration. No conditions of "a", "b", "c", "e", and "f" were recognized.

c) GB type--Ultra-Basic Rock in Greenstone Belt

1) Fortaleza de Minas (Minas Gerais Province)

This is a Ni/Cu ore deposit. According to a mine owner, the rock contains Ni=2.6%, Cu=0.4%, Co=0.06%, Pt=0.32 ppm, Pd=0.47 ppm, Rh=0.06 ppm, Ir=0.1 ppm, Os=0.09 ppm, Ru=0.2 ppm, Au=0.09 ppm, PGE + Au = 1.33 ppm.

The grade of the ore deposit in the oxidized zone fall into: Ni=0.74%, Cu=0.48%, Co=0.03%, PGE + Au=1.76 ppm.

Ore amounts include: 5.3 x 105 tons of sulphide minerals and 445 x 103 tons of oxide minerals. Gossan is important for prospection, which is distributed in wide areas. The average thickness of the mineralization belt stands 3 m only.

2) Serro and Morro do Pilar (Minas Gerais Province)

It is widely known that platinum minerals are produced in Alluvium in Ribeirao Limeira in Pilar County and Corrego Bom Sucesso in Serro County in Minas Gerais Province. According to 89 samples of Pan-concentrations gathered, 13 samples had 6-3,550 ppb of Pt and 24 samples had 10-10,000 ppb of Pd, both of which were detected together with Au. A grain from Corrego Bom Sucesso had 92.2% of Pt, 5.9% of Pd, and 2% of Ti according to the ERMA analysis. Another grain from the same area showed 40-83% of Pt and 13-56% of Pd.

3) Guajeru area (Bahia Province)

This area is located in Guajeru, Malhada das Pedras, and Janio Quadros Counties. A number of Pan-concentrations show 40-720 ppb of Pt + Pd, accompanying 10-1380 ppb of Au.

d) AI type--Anorogenic Intrusive Rock

Most of the anorogenic intrusive rocks are not surveyed or just under initial stage of survey.

What is interesting are found in Rondonia, Para, and Roraima Provinces.

1) Pedra Preta and Cotingo sills (Roraima Province)

Sills consist of dolerite of anorogenic intrusive rock in the Proterozoic period. The sills reach more than 100 km in length in the entire Brazil land. In Venezuela and Guiyana, the sills are 2 km in thickness.

e) MU type--Unclassified Ultra-Basic Rock

1) Rio Branco/Alta Floresta area (Rondonia Province)

This area is located in Alta Floresta D'Oeste County and Sao Miguel do Guaporé Country in Rondonia Province.

The major lithofacies include gabbro, troctolite, metagabbro and amphibolite. Metamorphism and shear zone are observed. The metagabbro may indicate a combination of pentlandite, chalcopyrite, pyrite, pyrrhotite, arsenopyrite, bravoite, violaraite, sphalerite, and platinum groups.

Pan-concentrations by EMPA identified platinum minerals--64-95% of Pt, 1.8% of Pd, and 4.7% of Rh while 8 samples of Pan-concentrations in the metagabrro indicated 30-660 ppb of Pt and 10-220 ppb of Pd. In addition, Cu and Ni of fine-grained fluvial sediment samples indicated marked anomaly.

2) São Felipe / Santa Lizia area (Rondonia Province)

This area has gabbro, norite, olivine-gabbro, anphibolite, and metagabrro rock bodies. The composite is known as having combinations of chalcopyrite, pentlandite, violaraite, bravoite, pyrite, pyrrhotite, and platinum groups. Although fine-grained fluvial sediment samples indicates Cu and Ni anomaly, Pan-concentrations indicated no platinum minerals.

3) Nova Brasilandia Rock Body

This rock body consists of fine-grained to coarse-grained-basic rocks, metagabbro, and anphibolite. Some of them was altered while other shear zones went through hydrothermal alteration.

As for minerals of the metagabrro, pyrite, pyrrhotite, chalcopyrite, pentlandite, bravoite, violaraite, and arsenopyrite were recognized. 44 samples of pan-concentration indicate 60-21,890 ppb of pt, 10-7,890 ppb of pd. Pan-concentration indicated a small quantity of mineral grains--59.7 % of Pt. Fined-grained fluvial sediment samples indicated anomaly of 270 ppm of Ni, 120 ppm of Cu, and 175 ppm of Co, at maximum.

We conducted two test borings (94 m, 181 m) at IP anomaly points in a sulphide mineralization belt (sulphide mineral: 25 %). Although pyrite and pyrrhotite were recognized, no PGE mineralization was observed.

Chapter 4: Summary of Investigation Results

4-1 Analysis of Existing Data

4-1-1 The Feature and Origin of the Flood Basalt around the World

As for the origin of the flood basalt, although there are some views such as the active involvement of the mantle plume or the upwelling of the asthenosphere at the time of continental break-up, they have not been well established as theory. Regional differences and features about the magma activity and composition exist between of the flood basalt and LIPs in the world. Therefore it is difficult to consider the relationship of the PGE ore deposit and the origin of flood basalt.

Almost PGE concentrated within the core in the initial stage of the earth. Moreover, because it fundamentally concentrates in solid phase, it is rarely contained in the continental crust where the differentiation has been progressed. Therefore, it is reasonable that the PGE in flood basalt is of mantle origin. In the period of the forming of flood basalt, a huge volume of magma was generated compared to the period of ordinary igneous activity. Consequently, melt on a large scale occurred and there is a possibility that PGE, which ordinarily concentrates in the solid phase, may be relatively highly concentrated within the melt.

As the original magma of the flood basalt with PGE mineralization, it seems to be most appropriate to consider that the magma that is of mantle plume origin and was generated by large scale partial melting of the plume itself and the surrounding mantle material.

However, the above condition can apply to the general LIP. Factors, such as the supply of silicate magma and sulfur, and regional tectonic setting, seems to be more critical for the PGE concentration.

4-1-2 Noril'sk Cu-Ni-PGE deposits and key factors in their exploration

In order to clarify the key factors in the exploration of the Noril'sk style deposit, which is the exploration target of the project, the documents regarding the Noril'sk deposits and other deposits were collected and analyzed on the their special features and genesis. As the result, the magmas, which originated the Noril'sk deposits, were thought to have been picritic to basaltic compositions and sulfur undersaturated (and hence PGE rich). Addition of crustal materials into these magmas generated immiscible sulfide melt. It is thought to be the origin of the Noril'sk deposits that copper, nickel, and PGE were condensed into the immiscible sulfide melt in a center of the magmatic activity where the sulfide melt could react on a voluminous quantities of silicate magmas. From the above, the following three critical requirements can be presented as the generation of the Noril'sk style deposit.

(1) Generation of sulfur undersaturated magma and their transportation to shallow crustal level
(2) Sulfur saturation of the magma and forming immiscible sulfide melt
(3) Reaction of the immiscible sulfide melt with voluminous quantities of silicate magmas.

The following key factors in the exploration of the deposits, which satisfy the above requirements, are presented.

(1) The existence of "Low-Ti" and PGE rich magmas (lavas, intrusions)
(2) The existence of magmas showing the signatures of crustal contamination and sulfide segregation associated with above PGE rich magmas (lavas, intrusions)
(3) Being a center of the magmatic activity where crustal suture exists. Considering sills as conduits through which magmas of flood basalts ascend (Naldrett et al., 1992), the center of intrusive magmatism may be promising.
(4) The existence of picritic magmas (lavas, intrusions). The high temperature picritic magmas have higher potential to assimilate crustal materials to form immiscible sulfide melt. However, considering most of the magmas that related to the generation of the Noril'sk deposits are basaltic, it is doubtful that picritic magmas are required to generate the Noril'sk style deposits.

As the result, it is proposed that the areas, which satisfy above key factors, should be targeted in the Paraná basin area.

4-1-3 Geology and Geological Structure of Paraná Basin

M.S.M. Mantovani et al. (2001) estimated the thickness of lithosphere in the South American Continent by analysis of tidal gravity anomaly and explained that lithosphere of Paraná basin (with thickness of 68 km or less) is thinner than those of craton and orogenic belt (with thickness of 72 km or more) of the Archaean to the Proterozoic and that mantle plume exists on relatively shallow depth (Fig. II-1-4-2). This type of basin is called an intracratonic basin. The movement of mantle plumes causes swelling and shrinking of lithosphere and creates the cycle of sedimentation and erosion. As plume activities became most active, the intracratonic basin led to eruption of flood basalts and rupture of the Gondwana continent (Fig. II-1-4-15).

The Paraná basin was an intracratonic basin in the western part of Gondwana continent.

Gondwana continent consists of Archaean craton blocked with faults and the surrounding Brazilian Pan-African orogenic belt of the late Proterozoic (Fig. II-1-4-4~5). The major structural directions of the basement rocks are ENE-WSW and NW-SE (Fig. II-1-4-6). In addition, there is Asuncion arch in the N-S direction. While the ENE-WSW direction does not accompany any intrusive rock, the structural direction of NW-SE sometimes accompanies a number of tholeiitic doleritic dikes and sills such as Ponta Grossa Arch.

When mantle plume enter into lithosphere, lithosphere becomes heavier. Then, lithosphere subsides by isostasy and basin formation starts (Fig. II-1-4-16). The Paraná basin activities lasted for 390 Ma from the late Ordovician to the late Cretaceous. E.J. Milani et al. (1995) divided the sedimentary rocks and volcanic rocks of the Paraná basin into six supersequences (Figs. II-1-4-9~14). Out of them, Rio Ivai, Paraná, Gondwana I and Gondwana III supersequences mainly deposited most thickly along the Paraná River from the western part of Paraná Province to the southwestern part of São Paulo province. As the plume was more active at the Gondwana I epoch, the basin subsided largely and the Gondwana I supersequence deposited in the entire basin centering along the Paraná River (Fig. II-1-4-11). In the subsidence curve of the basement by means of the backstripping method (Fig. II-1-4-19), a remarkable subsidence is observed in the period of 296-245 Ma (the late Carboniferous~the early Triassic) which corresponds to the Gondwana I epoch. The large-scaled subsidence is a phenomenon in common with rift basins which occurred all over the world after Hercynian orogenic movement (M.C.L. Quintas, 1995).

As the plume was most active at the Gondwana III epoch, magma reached the ground surface and a large amount of flood basalts erupted all over the basin (Fig. II-1-4-13). A large-scaled subsidence is observed in the subsidence curve in the period of 144-128 Ma (the late Jurassic ~ the early Cretaceous) which corresponds to the Gondwana I epoch.

M.C.L. Quintas (1995) calculated the attenuation factor (ε) of lithosphere using the thermodynamic model of Royden & Keen (1980). However, from the subsidence curve observed, the commencement of asthenosphere distensible activities were decided as the following. 1st Period: Late Ordovician (440 Ma); 2nd Period: Before Upper Carboniferous (296 Ma); 3rd Period: Jurassic ~ Cretaceous (144 Ma). From the 1st Period to 3rd Period, a high ε zone is observed along the Paraná River which runs from the western part of Paraná Province to the southwestern part of São Paulo province in the NE-SW direction (see Figs. II-1-4-20, 22 and 24). Lithosphere of the area along the Paraná River is the thinnest in the Paraná basin and plume ascended there. In the northwestern part of Paraná Province large amount of sills and dikes are intruded (see Fig. II-1-4-21). Both the Rio Ivai Supersequence and the Paraná Supersequences are also the thickest in the area. The highest ε value of the 3rd Period is observed in the southwestern part of São Paulo province. The basalt lava pile of 2-CB-1-SP drilling is 1,723 m thick. It is the thickest value all over the Paraná basin. The ε value is 1.26

there. It is the highest value of the ε values of the 3rd Period. Probably, Paraná flood basalt magma may have erupted or intruded at areas of the high ε values.

Since the lithosphere is thin in the rift zone, as noted in the example of the midcontinent rift in the U.S.A., a gravity anomaly is high in the rift zone (Fig. II-1-5-1). Comparing the residual gravity anomaly map (Fig. II-1-4-28) with the isopach maps of attenuation factor, the high gravity anomaly and the high ε zone are situated in the same area. From these facts, the high gravity anomaly and high ε zone along the Paraná River may possibly indicate a large magma feeder, and the Cu-Ni-PGE deposit of rift type is expected there.

4-1-4 Tectonics of Ni- Cu- PGE Ore Deposits Accompanying Continental Flood Basalt

It is discussed how a series of geological phenomenum such as the mantle plume, the Paraná basin, the Paraná flood basalt and Ni- Cu- PGE deposit can be formed, based on the examples of the Dulth ore deposit in the U.S.A. and the Noril'sk ore deposit and the Paraná basin.

It is well known that conjugate shear fractures form diagonal secondary shear fractures like echelon inside them as a lateral movement progresses and the secondary shear fractures are tied with one another and a large-scaled tensional fracture called Cymoid Loops as the lateral movement progresses further (Fig. II-1-5-22). P.W. Weiblen (1982) explained that a shear fracture of conjugate shear fractures is developed to a rift, while the other is developed to a transformed fault (Figs. II-1-5-10 and II-1-5-11).

In the Duluth ore deposit, the shape of the midcontinent rift and the locations of the transformed faults can be confirmed by the anomalies of gravity and airborne magnetic anomalies (Figs. II-1-5-13 and II-1-5-23). The Duluth complex intruded into the tensional fracture formed by the lateral movement of two parallel transform faults, and the Ni- Cu- PGE ore deposit was formed there. Assuming that the principal intermediate compressive stress axis (σ_2) is vertical in the regional stress field, the principal maximum compressive stress axis (σ_1) is the NE-SW direction and the principal minimum compressive stress axis (σ_3) the NW-SE direction.

The Noril'sk ore deposit exists along Noril'sk-Kharayelakh Fault in the NNE-SSW direction (Fig. II-1-5-19). From the shape of the ore bodies (Fig. II-1-5-21), the fault is considered as a dextral strike- slip shear fault. On the other hand, Noril'sk deposit is situated at the Kayerkansky- Pyasinsky anticline in the NNW-SSE direction. Since the NNW-SSE direction coincides with that of Gydansk-Omsk rift, it is presumed to be the direction of the principal maximum compressive stress axis (σ_1). From the direction of (σ_1), the principal minimum compressive stress axis (σ_3) is presumed to show the ENE-WSW direction. The Talnakh ore deposit of the west of the fault in the shape of a triangle stretching to the northwest is considered to have been formed in the tensional fissure zone. Both Noril'sk and Talnakh deposits are located at the crossing of both NNE-SSW direction and NNW-SSE direction and, at the same time, they are located at the thickest part of the Nadezhinsky basalt lava unit, i.e. at the volcano-center.

A series of faults and fractures in the Paraná basin can be interpreted as a regional stress field in the rift zone (Fig. II-1-5-25). The Paraná River in the north and central parts of the Paraná basin runs almost in the NE-SW direction. The direction coincides with the direction of the coastal line in the eastern part of the basin, what is the direction of the tensional fracture between the South American continent and the African continent. The high ε zone in the first to third periods, the high gravity anomaly zone, and the thick doleritic sills and dikes are found along the Paraná River. The thick sedimentary sequences and flood basalt lava units are along the Paraná River. Judging from these events, it is inferred that the Paraná River is a great tensional fracture connected to the mantle, i.e. a rift. Assuming that the rift has the NE-SW direction, the stress axis in the NE-SW direction will be the σ_1 and the NW-SE direction will be the σ_3.

The ENE-WSW trending fractures also predominate in the Paraná basin. The fractures divide the cratons of the basement and the Brasilian- Pan African orogenic belts The fracture directions intersect with the σ_1 axis (NE-SW) at an angle of about 30 degrees. Judging from the secondary shear fracture directions in the basement rocks, the ENE-WSW trending direction is considered to be a sinistral strike- slip shear fracture. The shear fractures are not accompanied by doleritic sills and dikes.

Then, the NW-SE trending fractures are found in the Paraná basin. The fracture direction is perpendicular to the direction of the rift. The NW-SE trending fractures may be a transform faults such as those of the Duluth ore deposit,. It is accompanied by a large quantity of doleritic sills and dikes along the Paraná River and in Ponta Grossa Arch. Judging from the secondary shear fractures indicated by the dike swam in the basement rocks, the NW-SE trending fractures are inferred to be adextral strike- slip faults. The sense of the strike- slip direction coincides with the clockwise rotation of the Gondwana continent drift. The zone where many fractures such as Ponta Grossa, Abreu- Mourao, and Rio Piquiri concentrate, is the most noteworthy among the NW-SE direction shear fractures. This zone is a tensional fracture zone formed by the lateral movement and it is estimated that a large quantity of sills and dikes intruded in the zone. The tensional fracture zone in the western part of Paraná Province is formed at the intersection between the NE-SW rift and the NW-SE transform fault like and the tensional fracture zone in Ponta Grossa at the intersection between the ENE-WSW shear fracture and the NW-SE transform fault. As these examples, the intersection between the transform fault and other direction fracture may have played an important role in the formation of a large tensional fracture zone.

The NW-SE trending Tiete tectonic line is in the northern part of the Paraná basin and the NW-SE trending Torres Posadas tectonic line is in the southern part. The high ε zones and the high gravity anomaly zones are found around each tectonic line. But, both of them are small in scale.

As the fracture concentration zones of the Ponta Grossa arch, Abreu- Mourao, and Rio Piquiri have had stronger magmatic activities in the Paraná basin, the zones are more promising areas for Ni- Cu- PGE ore deposits. In particular, the sills and dikes concentration zone along the Paraná River (the rift zone) is expected as the first priority area for exploration of the ore deposit from the viewpoint of tectonics.

4-2 Analysis of Satellite Images

Digital mosaic images of the area, which crosses the central part of Paraná basin from east to west, were prepared using JERS-1/SAR(Synthetic Aperture Radar) data, and the geological structure was interpreted and analyzed. To cover the survey area of about 500,000 km^2, JERS-1/SAR data in 131 scenes was used. Most of the survey area, crossing Paraná basin from east to west, is extensively covered by flood basalts that erupted from the Jurassic to the Cretaceous. In the northeast part of the area, sedimentary rock of the Palaeozoic and basement granitic rocks are distributed. To interpret and analyze the geological structure, lineaments (including faults) and circular structures were extracted.

In the Ponta Grossa Arch, which is the northeast part in the survey area, sedimentary rock of the Palaeozoic and the basement granitic rocks are distributed, and also exist a lot of dolerite dikes, which are considered to have been the feeder of the flood basalts. The dikes extend as long as maximum 80 km in NW-SE direction. They are identified clearly as lineaments on the interpretation image. It is considered to be the reason for this that dikes in sedimentary rocks, which are relatively weak in resistance to erosion, form a continuously ridging topographical feature. However, no dike has been identified in the basement region. It is considered to be the reason for this that dikes do not form a ridge because the dikes and granite are not much different in erosion resistance. In the flood basalts area, a considerable amount of lineament groups in the NE-SW direction was extracted in the center of the survey area. These lineament groups, which have not been described on the existing geological map, are noteworthy. The lineament density in the flood basalt distribution area is extremely low compared with the sedimentary rock area. In particular, in the low land around Paraná River in the survey area, a horst and graben structure in NE-SW in the basement was estimated through airborne magnetic survey and gravity prospecting. However, no lineament corresponding to this has been identified on SAR image. This may indicate that the basement structure has not given significant structural influence on the distribution of flood basalts, and no large structural movement has taken place in this area since the eruption of flood basalts.

As to circular structure, a alkaline complex existing in the Lages area are clearly extracted as corresponding to circular structure on geologic map definitely.

The Paraná River, which flows through the center of the basin, is very linear, and by the supra-regional image analysis using Landsat TM data, the lineaments of NNE-SSW direction along the Paraná River were extracted. Therefore, the Paraná River itself possibly represents a large-scale fracture zone.

4-3 Geological Survey

Peate et al. (1992) divided the Paraná basin flood basalts into two magma types, "Low-Ti" and "High-Ti". The former consists of lava types of Gramado, Esmeralda, and Paranapanema, and the latter consists of Pitanga, Urubicí, and Ribeira.

In the present survey, Paranapanema and Ribeira indicated "intermediate-Ti" content between " Low-Ti" and "High-Ti", and these types could not be classified geochemically. Therefore, we divided the flood basalt samples collected into following three types.

	Peate et al.(1992)	Present Survey
Low-Ti type	Gramado	Gramado
	Esmeralda	Esmeralda
	Ribeira	
Intermediate-Ti type	—	Paranapanema-Ribeira
High-Ti type	Paranapanema	Pitanga
	Pitanga	Urubicí
	Urubicí	

The "Low-Ti", "Intermediate-Ti, and "High-Ti" types have the following geochemical characteristics.

(1) Esmeralda, which belongs to "Low-Ti", is the most primitive magma type according to its contents of Th, Ta, Y, and Zr, and neodymium isotope ratios.

(2) Gramado and Esmeralda, which belong to "Low-Ti" type, contain more crustal components such as Th, U, and Rb than the other types. Gramado is particularly prominent in this regard. It can be inferred that the magmas of "Low-Ti" type have been more or less influenced by the upper continental crustal materials. Magmas of Gramado mostly have had this influence, and this is also indicated by the strontium and neodymium isotope ratios.

(3) As for the magmas of "High-Ti" and "Intermediate-Ti" types, we have concluded that the influence of the crustal contamination was weak. It may be possible that the magmas had

directly extruded from the mantle to the earth's surface.

(4) The difference between "Low-Ti", "Intermediate-Ti", and "High-Ti" types probably attributed to the difference of degrees of martial melting. "Low-Ti" type magmas, which might have been generated by larger degrees of partial melting, are thought to have assimilated various degrees of upper continental crustal materials. However this difference may be explained by the difference of source materials themselves. Therefore, detailed study using larger number of samples is required.

(5) As for the PGE content, Paranapanema-Ribeira of "Intermediate-Ti" type indicates the highest content. The average contents of Pt and Pd in this type are 9.7 ppb and 15.5 ppb, respectively. These values are higher than those of the lavas richest in PGE in the Noril'sk region. "Low-Ti" type Gramado and Esmeralda have the second highest contents of Pt and Pd. As for Gramado, which is mostly influenced by crustal contamination, there are two populations of samples, depleted or not depleted in PGE. On the other hand, Pitanga of "High-Ti" type indicates very little contents of Pt and Pd. Therefore, it is concluded that the magmas of "Low-Ti" and "High-Ti" types satisfy the primary requirement for the genesis of the Nori'sk style deposit (generation of sulfur undersaturated magma and their transportation to shallow crustal level), which was discussed in the existing data analysis.

As discussed above, the geochemical study of lavas revealed the existence of PGE rich magmas, which can generated the Noril'sk style orthomagmatic sulfide deposits, in the Paraná basin area.

According to the examination of the result of the stream sediment geochemical survey in the Paraná Province conducted by MINEROPAR, the geochemical anomaly zone that suggested the existence of mafic to ultramafic rocks were thought to have indicated the distribution of Paranapanema-Ribeira itself that had higher concentration of PGE compared with the surrounding rocks.

Regarding the intrusions distributed in the eastern margin of the Paraná basin, the geochemical investigation was conducted on the sills exist in the Lomba Grande area, in the southern part of the survey area, and sills and dikes exist in the Ponta Grossa Arch, in the northern part of the survey area.

An analysis of the major and trace elements has revealed the wide range of chemical compositions of sills in Lomba Grande area(picritic to dacitic), while the range of sills and dikes in the Ponta Grossa Arch was entirely basaltic, concentrating in a narrow region. According to the variation of TiO_2 with Mg number, the former and the latter were respectively classified into "Low-Ti" and "High-Ti" types as in the case of lavas. The sills in the Lomba Grande area are rich in Th, U, and Rb compared with those of the Ponta Grossa Arch. These features in the intrusions are same as those observed in corresponding lavas. Therefore, except for the picritic sills, it is considered that the sills of the Lomba Grande area have had the influence of continental upper crust contamination. This is in harmony with the distribution of Gramado type lavas and acidic rocks in the Lomba Grande area. On the other hand, the sills and dikes in the Ponta Grossa Arch are considered to have been generated from the magmas that had little influence of crustal materials. The influence of crustal materials on the magmas of intrusions was also shown by strontium and neodymium isotope ratios.

As for the Pt and Pd concentrations in the intrusions, two big sills of basaltic to andesitic compositions with the thickness of more than 130 m, which located in the northeastern and eastern parts of the Lomba Grande area, indicated relatively high Pt and Pd concentrations. In particular, some samples from the sill in the northeastern part indicated high values of Pt, exceeding 20 ppb. On the contrary, the sills in the central part of the Lomba Grande area are of picritic to basaltic and of andesitic to dacitic. These sills are depleted in Pt and Pd. Particularly the andesitic to dacitic sills showed very little contents of Pt and Pd. The Pt and Pd contents of the sills and dikes in the Ponta Grossa Arch vary in a wide range. Some of them contain more than 20 ppb Pd but others are depleted in Pd.

As mentioned above, the geochemical investigation of lavas and intrusions conducted in the present survey revealed the presence of the PGE rich magmas (Paranapanema-Ribeira etc.), which can generate the Noril'sk style deposits, in the Paraná basin area. Furthermore, the crustal contamination and depletion in PGE were found in some samples of the Gramado of "Low-Ti" type. The depletion in PGE was also found in some dikes and sills of the Ponta Grossa Arch although crustal contamination was not clear there.

The EPMA test revealed that sills and dikes of the Ponta Grossa Arch and the sill of the northeastern part of the Lomba Grande area contain a trace of chalcopyrite. In particular, a trace of sphalerite and cobalt-arsenic mineral containing nickel were found in a sill sample of the Ponta Grossa Arch, which is interesting.

As for the future survey program, it will be important to locate a volcanic center of each lava type, and investigate whether the crustal contamination and depletion in PGE are found or not there.

Chapter 5: Conclusion and Proposal

5-1 Conclusion

Analysis of existing data, analysis of satellite images, and a geological survey were conducted in this fiscal year for regional survey of Ni-Cu-PGE ore deposit accompanied with the Paraná flood basalt. The analysis of existing data covered flood basalt volcanism in the world, the Noril'sk ore deposit and geology of the Paraná basin, while the analysis of satellite images focused on JERS-1/SAR images. The geological survey included mainly whole rock analysis, geochemical analysis of trace elements and isotope analysis of the Paraná flood basalt.

5-1-1 Analysis of Existing Data

Flood Basalt : The well differentiated continental crust contains little platinum group elements (PGE) because the PGE was enriched in the core in the genesis of the Earth, and they are enriched basically in solid phase. Consequently, it is appropriate to trace the origin of the PGE in flood basalt to the mantle. Since a magma of flood basalt generates in a larger quantity than magmas of normal igneous rocks, a large-scale melting occurred. As the result, a comparatively large quantity of PGE what is enriched generally in solid phase may probably be contained in the melt produced. On these premises, it can be said that it is desirable that the origin of flood basalt magma, which causes PGE mineralization, was derived from the mantle plume, and was generated by large-scale partial melting of the plume and mantle materials surrounding the plume. These premises concern large igneous province (LIP) in general. Such factors that affect the enrichment of PGE such as supply of sulfur and silicate components due to crust contamination and also local tectonic setting would be more important for formation of PGE ore deposit,

Noril'sk ore deposit : The magma which genarated the deposit is considered to have been picritic to basaltic, PGE-enriched and sulfur-undersaturated. The magma was contaminated by crustal material, which caused the separation of the immiscible sulfide melt from the silicate magma. The immiscible sulfide melt dissolved much PGE reacting with a large amount of silicate magmas in the center of magmatic activity. These events are considered to be the origin of the Noril'sk ore deposit. From the above, three points can be listed as the requirements of the Noril'sk type ore deposit generation: (1) generation of sulfur-undersaturated magma and the ascending to a shallow crustal level, (2) generation of immiscible sulfide melt due to crustal contamination, and (3) reaction of the immiscible sulfide melt with a large quantity of silicate magma.

Furthermore, As the key factors of the exploration that satisfy the above requirements, the followings can be listed: (1) existence of "Low-Ti" type and PGE-rich magma as lavas or intrusions, (2) existence of magmas depleted in PGE and contaminated by crustal matrials as lavas or intrusions, (3) being center of volcanic activity where crustal suture has developed and large quantity of silicate magmas ascended from the mantle, and (4) existence of high temperature picrite magma which apt to cause contamination of crustal materials as lavas or intrusions. ·

Paraná basin : it is one of the continental inland basins formed in the western part of the Gondwana paleo-continent. The lithosphere of the basin is thinner inferred by analysis of tidal gravity anomaly and the mantle plume is located more shallowly than those of cratons and orogenic belts. Paraná basin deposited from the late Ordovician to the late Cretaceous. The sequences are divided into the Rio Ivai, Paraná, Gondwana I, Gondwana II, Gondwana III, and Bauru Supersequences. The Gondwana I supersequence was formed immediately after the Hercynian orogeny while the Gondwana III supersequence is a thick flood basalt lava pile. The sedimentary sequences deposited more thickly along Paraná River from the western part of Paraná province to the southwestern part of San Paulo province.

It is considered that, when a mantle plume enters into the lithosphere of the intracratonic basin, the lithosphere shrinks instantly, subsides by the weight of the plume, and the sedimentation of the basin starts. The attenuation factor (e) of lithosphere has been calculated from the analysis of drilling data etc. High e zones are observed along the Paraná River in the NE-SW direction, extending from the western part to the northwestern part of the Paraná province, then to the southwestern part of San Paulo province. In these areas, intrusions of numerous dolerite sills and dikes, thick basalt lava pile, and normal sediment deposits are observed. Gravity anomaly becomes high due to the thinner lithosphere of intracratonic basin such as in the Midcontinet rift in the United States. In Paraná basin, high residual gravity anomaly is often observed in high e zones such as that along the Paraná River.

Tectonics of the Paraná basin: Relationships between regional stress fields and ore deposits were examined about the Noril'skore deposit, Duluth ore deposit and the Paraná basin. Conjugate shear fractures form diagonal secondary shear fractures like echelon inside them as a lateral movement progresses (Cymoid Loop) and a shear fracture of conjugate shear fractures is developed to a rift while the other is developed to a transformed fault. In the Duluth ore deposit, it is considered that the Duluth complex intruded into the tensional fracture formed by the lateral movement of two parallel transform faults, and the Ni- Cu- PGE ore deposit was formed there based on the anomalies of gravity and airborne magnetic anomalies. From the above, The principal maximum compressive stress axis (σ_1) is the NE-SW direction and the principal minimum compressive stress axis (σ_3) the NW-SE direction in the regional stress field.

The Noril'sk ore deposit is controlled by the Noril'sk-Kharayelakh dextral strike- slip shear fault in the NNE-SSW direction and the Kayerkansky- Pyasinsky anticline in the NNW-SSE direction. Since the NNW-SSE direction coincides with that of Gydansk-Omsk rift, it is presumed to be the direction of $\sigma 1$. From the direction of $\sigma 1$, the $\sigma 3$ is presumed to show the ENE-WSW direction perpendicular to the Kayerkansky- Pyasinsky anticline. The Talnakh ore deposit of the west of the fault in the shape of a triangle stretching to the northwest is considered to have been formed in the tensional fissure zone. The Noril'sk ore deposit are located at the crossing of both NNE-SSW direction and NNW-SSE direction and, at the same time, they are located at the thickest part of the Nadezhinsky basalt lava unit, i.e. at the volcano-center.

A series of faults and fractures in the Paraná basin can be interpreted as a regional stress field in the rift zone. The high ε zone, the high gravity anomaly zone, and the thick doleritic sills and dikes are found in the NE-SW direction along the Paraná River from the western part of the Paraná province to the southwestern part of the San Paulo province. These events suggest that the zone was a rift. Assuming that the rift has the NE-SW direction, the stress axis in the NE-SW direction will be the $\sigma 1$ and the NW-SE direction perpendicular to the rift will be the $\sigma 3$ and a dextral transform fault. The zone where many fractures such as Ponta Grossa arch, Abreu- Mourao fault, and Rio Piquiri fault concentrate, is the most noteworthy among the NW-SE direction shear fractures. The zone is a tensional fracture zone formed by the lateral movement and it is estimated that a large quantity of sills and dikes intruded in the zone. The tensional fracture zone in the western part of Paraná Province is formed at the intersection between the NE-SW rift and the NW-SE transform fault and the tensional fracture zone in Ponta Grossa arch at the intersection between the ENE-WSW shear fracture and the NW-SE transform fault. It is proposed that they are the first priority exploration targets of Ni-Cu-PGE ore deposit. Then, The ENE-WSW trending fractures also predominate in the Paraná basin. The fractures divide the cratons of the basement and the Brasilian- Pan African orogenic belts. The fracture directions intersect with the $\sigma 1$ axis (NE-SW) at an angle of about 30 degrees and be sinistral strike- slip shear fractures. They are not accompanied with doleritic sills and dikes.

5-1-2 Analysis of Satellite Images

Digital mosaic images of JERS-1 Synthetic Aperture Radar (SAR) data were read and analyzed for area where crosses the central part of Paraná basin from east to west from the viewpoint of geological structures. The survey area covers about 500,000 km^2 where corresponds to JERS-1 / SAR data in 131 scenes. Most of the survey area crossing Paraná basin from east to west is extensively covered by flood basalt that erupted from the Jurassic to the Cretaceous. In the northeast part of the area, sedimentary rocks of the Palaeozoic and granitic rocks of the basement are distributed. To read and analyze the geological structure, lineaments (including faults) and circular structures were extracted.

In Ponta Grossa Arch where is situated at the northeast part of the survey area, sedimentary rocks of the Palaeozoic and granitic rocks of the basement are distributed, and also exist a lot of dolerite dikes, which are considered to be the feeder of the flood basalt. The dikes extend as long as maximum 80 kilometers in NW-SE direction. They are identified clearly as lineaments on the interpretation images. It is considered to be the reason why dikes in sedimentary rocks which are relatively weak in resistance to erosion form a continuously ridging topographical feature. However, no dike has been identified in the basement. It is considered to be the reason why dikes do not form a ridge as the dikes and granite are not much different in erosion resistance. In regard to flood basalt distribution, large lineament groups were identified in the NE-SW direction in the central part of the area. It should be noted that these lineament groups are not indicated in existing geologic maps. The lineament density in the flood basalt distribution area is extremely low compared with the sedimentary rock area. In particular, in the low land around Paraná River in the survey area, a horst and graben structure in NE-SW in the basement was estimated through airborne magnetic survey and gravity prospecting. However, no lineament corresponding to this has been identified on SAR images. This may show that the basement structure has not given significant structural influence on the distribution of flood basalt, and no large structural movement has taken place in this area since the eruption of flood basalt.

As to circular structure, alkaline composite rock bodies existing in Lages area are clearly extracted as corresponding to circular structure on geologic map definitely.

5-1-3 Geological Survey

The current survey revealed that the Paraná basin flood basalt was classified into three types: a "Low-Ti" type (Gramado and Esmeralda), a transitional type (Paranapaneme-Ribiera), and a "High-Ti" type (Pitanga and Urubicí). The three types of lavas have the following geochemical features.

(1) Judging from the Th, Ta, Y, and Zr content and the Nd isotopic ratio, the Esmeralda of "Low-Ti" type is the least undifferentiated. (2) The Gramado and Esmeralda of "Low-Ti" type contain a relatively large quantity of crustal enriched elements such as Th, U, and Rb. This tendency is particularly conspicuous in Gramado. This was also confirmed from the isotopes of strontium and neodymium. (3) The magmas of "High-Ti" type and "Intermediate-Ti" type may have been little affected by the upper continental crustal material, originated from the mantle, and probably erupted directly to the surface of the earth. (4) Each type of magma was probably generated by a difference in degree of partial melting. Among these, the magma of "Low-Ti" type has the largest degree of partial melting and may have assimilated the upper

continental crustal material in varying degree. (5) The average content of Pt of the Paranapanema-Ribeira flood baslt of "Intermediate-Ti" type is 9.7 ppb and that of Pd is 15.5 ppb. The "Intermediate-Ti" type shows the highest Pt and Pd contents of all the types. These content values are higher than those of the lava richest in PGE of the Noril'sk ore deposit. The magma of "Low-Ti" type (Gramado and Esmeralda) is the second highest in content of Pt and Pd. For the Gramado magma, which was greatly affected by the crustal contamination, some samples are depleted of PGE and others are not depleted of them. On the other hand, the Pitanga magma of "High-Ti" type is very low in content of Pt and Pd. The study of the chemical composition of lava revealed that magma having a high content of PGE which may generate an orthomagmatic sulfide ore deposit of Noril'sk type would exist in the Paraná basin area.

The analysis of major components and trace elements of the intrusive rock showed the wide variety of sill composition (picritic ～ dacitic sill) in the Lomba Grande area. On the other hand, it was clarified that the variety of composition of the Ponta Grossa Arch sills and dikes is limited and all of them are basaltic. Like the lava, the former is richer in Th, U, and Rb than the latter. This agrees with the features of the magma of "Low-Ti" type shown by the lava. The 130m thick large-scale sill (basaltic ～ andesitic) that exists in the northeastern part and eastern part of the Lomba Grande area shows a relatively high content of Pt and Pd. In particular, some samples that contain more than 20 ppb of Pt were found in the sill of the northeastern part. In contrast to this, the picritic ～ basaltic and andesitic ～ dacitic sills that exist in the central part of the Lomba Grande area are depleted of Pt and Pd. In particular, the andesitic - dacitic sill contains little Pt and Pd. The content of Pt and Pd of the sills and dikes in Ponta Grossa Arch varies. Some of them contain more than 20 ppb of Pd, but others are depleted of Pd.

As described above, the geochemical study of the lava and intrusive rock conducted in fiscal 2001 clarified that magma (Paranapanema-Ribeira etc.) with a high content of PGE that may generate an orthomagmatic sulfide ore deposit of Noril'sk type exists in the Paraná basin area. The crustal contamination and the depletion of PGE were found in some samples of the Gramado of "Low-Ti" type. Also, although the crustal contamination is not clear, the depletion of PGE was recognized in some dikes and sills of Ponta Grossa Arch.

The EPMA revealed that sills and dikes of the Ponta Grossa Arch and the northeastern part of the Lomba Grande area contain a trace of chalcopyrite. In particular, we detected a trace of sphalerite and a cobalt arsenic mineral containing nickel from sills and dikes of Ponta Grossa Arch, which are interesting.

5-2 Suggestion for Phase II Survey

In Phase I survey, we carried out a survey mainly in the central part of the flood baslt distribution area. Analyses of lava and intrusive rocks of flood basalt based on Phase I survey clarified geochemical features of the magmas. We also examined what kind of magma and geological conditions would cause the occurrence of a Ni-Cu-PGE ore deposit, taking the Noril'sk ore deposit and Duluth ore deposit as an example.

We are planning to conduct Phase II survey of the entire survey area, following Phase I survey. We will carry out a geological survey and collect analysis samples, particularly in the northern and southern parts of the survey area where enough analysis samples have not been obtained yet. The samples of lava and intrusive rock will be obtained from the ground surface and coal exploration drilling. The contents of analysis items and elements will be almost the same in order to maintain consistency with Phase I survey.

MINEROPAR in the Paraná province and CPRM in Rio Grande do Sul have conducted geochemical prospecting of stream sediment. The analyzed values of both prospectings reflect the own chemical composition of flood basalt relatively well. A geochemical prospection of stream sediment may be effective for an area where there is little outcrop of flood basalt sequences and will be conducted as a supplementary means to an outcrop survey as appropriate.

The survey of the geology and geological structure of the Paraná basin and basement rock revealed that the activity of flood basalt is controlled by a regional stress field. We will continue the survey of the geological structure of basin sediment and basement rock to determine the eruption sites of flood basalt where the occurrence of the ore deposit is expected.

We will also continue to analyze the SAR and TM images obtained through JERS-1 in order to clarify the geology and geological structure of the Paraná basin.
We will keep appealing to organizations concerned to obtain the data on drilling cores and a geophysical prospecting possessed by PETROBRAS.

We will bring together the Phase I and II survey results to make an analysis in a comprehensive manner, and eventually examine the potential for the occurrence of the Ni-Cu-PGE ore deposit in the Paraná basin, present the guidelines for the exploration, and extract promising areas for the exploration.