3-8-2 Alkaline Basalts in the Periphery of Paraná Basin and Surrounding Ore showings

(1) Distribution and the Time of Intrusion of Alkaline Rocks in the Periphery of Paraná Basin

Alkaline intrusion such as kimberlite, carbonatite and phonolite is generally understood that often occurs in fractured upheaving belt in the Precambrian shield. By the information that alkaline intrusions also distribute in/around the flood basalt area such as Siberian trap and Deccan trap, some researchers become to consider that the intrusion may have a relationship to mantle plume arising (Superplume Work shop 2002, Tokyo).

Kimberlite distribution in Brazil was compiled and interpreted by DNPM/CPRM (1991, vol. IV, p.70). They explain that the kimberlite tend to distribute along three structures such as "125 degree Lineament" tending NW-SE, "Transbrazilian Lineament" of NNE-SSW and "Blumenau Lineament" tending NE-SW direction in the report (Fig. II-3-8-37(a),(b)).

Alkaline intrusions in Lages district are generally understood that are related to the Blumenau Lineament tending NE-SW. The faults in the intrusion area also intensively tend to NE-SW direction. The Lages alkaline intrusion has a dimension of 30 km x 30 km, is mappable in a geological map of 1/2,500,000 scale, is precisely described by Scheibe (1986).

Geological map of the Lages District by Scheibe(1986) is shown as Fig. II-3-8-38. K-Ar age data of the alkaline bodies are measured as 62.9 Ma (Janjão Kimberlite), 63.5 Ma (Olivine Melilitite), 65.7-74.2 Ma (Phonolites), 69.4-74.3 Ma (phlogopite in chimney breccia), 74.6-78.3 Ma (Nepheline syenite porphyry) by Scheibe (1986) and others.

Janjão Kimberlite contains some diamonds, and small-scale bauxite deposits are under excavation that is originated by weathering of phonolite intrusions.

(2) Mineralization in Lages District

Lages in Santa Catarina Province is situated on the southeastern edge of Paraná basin, and Paraná basalt isolatedly distributes just in the form of islands caused by erosion. A mineral showing of total of 300 g/ton of platinum and palladium is said to have been discovered in 1930s in the eastern area of Lages. It is known in addition that dendritic placer silver is found in the rivers situated between Lages and Painel. It is also said that some Americans conducted an investigation on PGE/Cu/Zn/Ag, etc. around the year 1973.

In 1986, Luiz Fernando SCHEIBE of São Paulo University published his dissertation (Scheibe, L.F., 1986) Geologia e petrologia do distrito alcalino de Lages, SC. Universidade de São Paulo instituto de geociencias; Tese de doutoramento, 224p). Further, in 1987 an American company enforced a geochemical prospect in Lages district referring to the

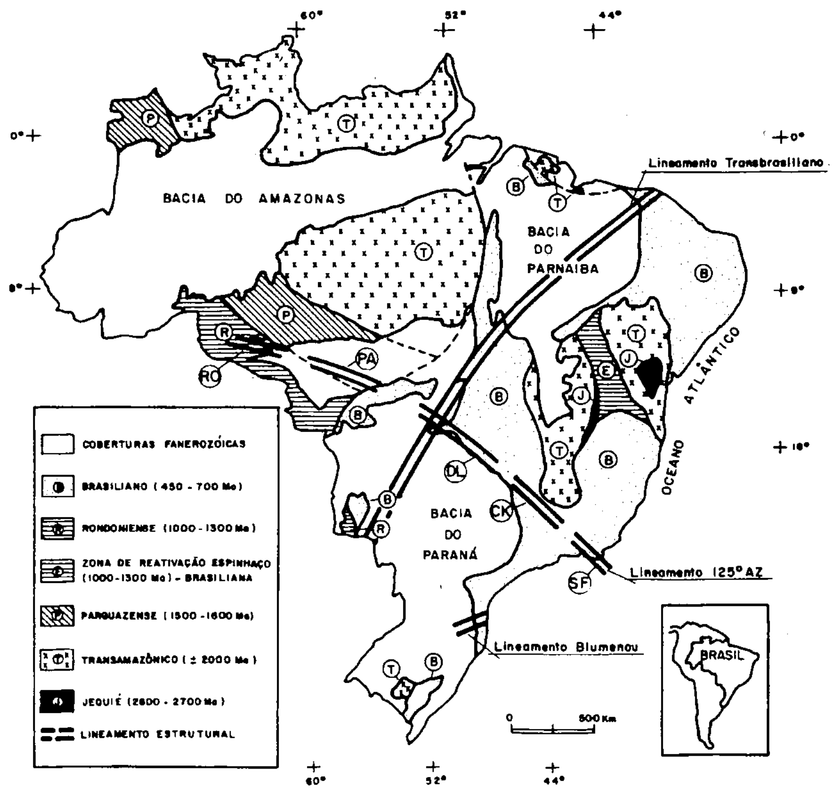
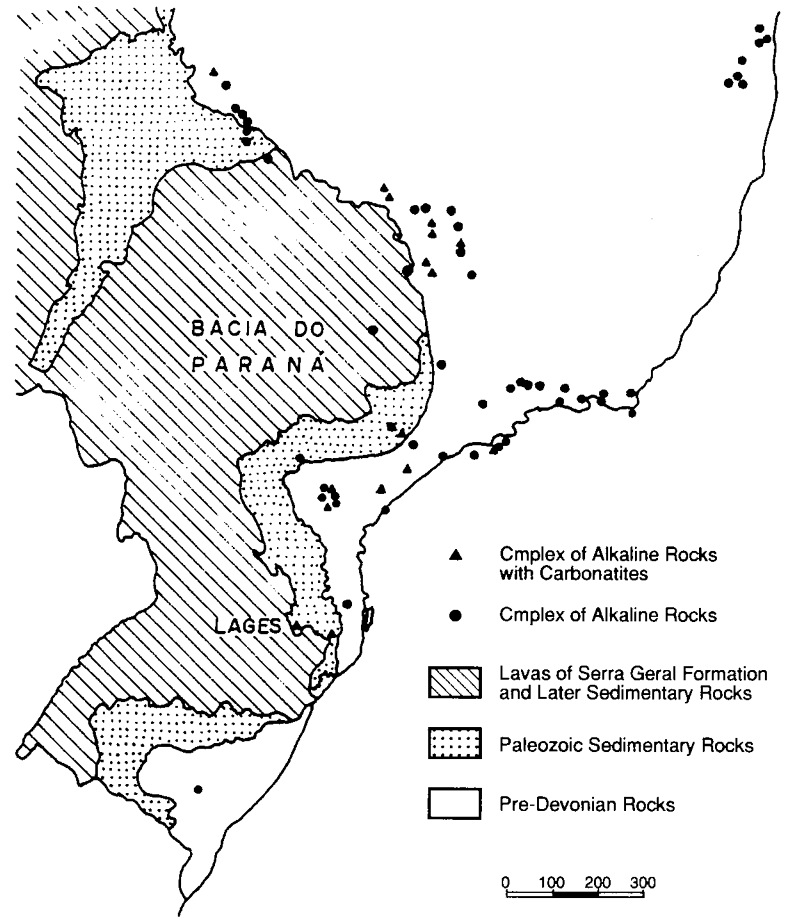


Figura 10 – Mapa do Brasil apresentando os lineamentos 125°AZ, Transbrasiliano e Blumenau, bem como os eventos termotectônicos e/ou tectono-magmáticos. Modificada de Schobbenhaus e Campos (1984). SF = segmento Brasiliano com predominância de rochas sieníticas e fonólitos; CK = segmento Brasiliano com predominância de carbonatitos e kimberlitos; DL = segmento Brasiliano com predominância de rochas ultrabásicas alcalinas e lamprófiros; PA = segmento Parguazense; RO = segmento Rondoniense.

(a) Map of Kimberlite Distribution along 125° Lirerament, Transbrasilian Lineament, and Blumenau Lineament (By DNPM/CPRM, 1991)



(b) Distribution of Alkaline Intrusions near Parana Basin (By Sheibe; 1986 after Ulbrich e Gomes; 1981)

Fig. II-3-8-37 Alkaline intrusion distribution in Brazil

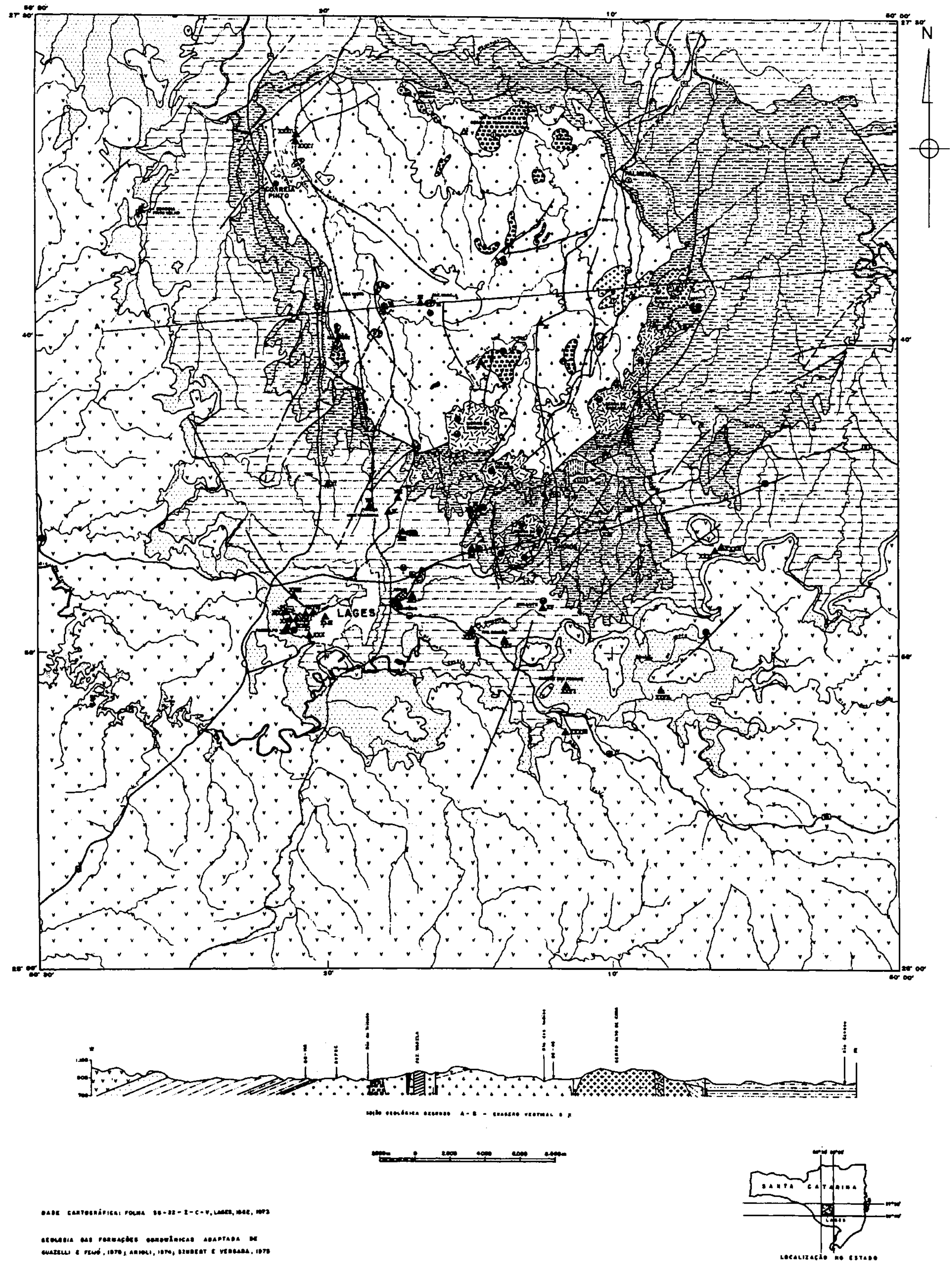


Fig. II-3-8-38　　Geological map of Lages district (by Sheibe, 1986)

COLUNA ESTRATIGRAFICA

PERIODO	GRUPO	FORMACAO/LITOLOGIA	SIMBOLO
TERCIARIO/ CRETACEO	DISTRITO ALCALINO DE LAGES	BRECHA DE CHAMINE	
		CARUONATITO	
		ANALCITA TRAQUITO	
		FONOLITO	
		FONOLITO PORFIRTICO	
		NEFELINA SIENITO PORFIRTICO	
		OLIVINA MELILITITO	
JURO-CRETACEO	SAO BENTO	SERNA GERAL	
		BOTUCATU	
PERMIANO	POSSA DOIS	RIO DO RASTO	
		TEREZINA	
		SERRA ALTA	
		IRATI	
PERMOCAR BONIFERO	GUATA		
	ITARARE		

CONVENCOES GEOLOGICAS

- CONTATO
- FALHA
- ZONA DE BRECHA
- PONTO DE AMOSTRAGEM

CONVENCOES TOPOGRAFICAS

- CIDADE
- SEDE MUNICIPAL
- SEDE DISTRITAL
- ESTRADA FEDERAL
- ESTRADA MUNICIPAL
- ESTRADA FERRO
- DRENAGEM

Fig. II-3-8-38 (continued) Legend of geological map of Lages district

dissertation written by Scheibe. The company is said to have made a conclusion that geochemical anomaly of Au and Ag occurred as a result of alkaline igneous activities (according to the hearsay from a Japanese researcher). During our investigation of this time, we noted that small-scaled but positive exploration activities were made in the site including establishment of private mine claims and probing.

a) Geochemical Anomalies in Paraná basalt

As mentioned above, anomalies of Au and Ag are said to exist in Lages district. However, such anomalies were discovered through investigation made personally or by private companies, and there is no record as the published paper. Although no geochemical prospection of stream sediment was done during our investigation in this time, our chemical analysis on rocks revealed high Au anomalies in some of Paraná basalt. As indicated in Table II-3-8-3, while the average Au value of both Gramado and Esmeralda types was only 3 to 4 ppb, the Au content of the rock specimen AS021 (Gramado Type) was Au: 69 ppb. The highest of all the anomalies in Au values is Au: 1000 ppb as a result of our project finding survey conducted in 2000 (MMAJ, 2000) obtained from the sample of the bottom of Lomba Grande picrite intrusion.

Since the detection limit of Ag is high, i.e. 5 ppm, it is unknown whether or not Paraná basalt in this district shows geochemical anomaly of Ag like that of Au.

Table II-3-8-3 Comparison of chemical composition between Lages basalts and average of some magma types

SAMPLE	SiO2	Al2O3	Fe2O3	MnO	MgO	CaO	Na2O	K2O	TiO2	P2O5	Total
	%	%	%	%	%	%	%	%	%	%	
Gramado average(56)	54.73	13.47	13.20	0.19	4.20	7.90	2.91	1.64	1.54	0.21	100.00
Esmeralda average (9)	52.31	13.31	14.33	0.21	5.04	9.41	2.66	0.97	1.57	0.19	100.00
Gramado-Esmeralda unclassified average(15)	53.85	12.99	14.73	0.21	3.91	7.90	2.83	1.61	1.73	0.24	100.00
AS021	54.52	13.84	12.37	0.18	5.15	7.77	3.33	1.47	1.21	0.17	100.00
AS023	53.02	12.59	15.90	0.22	3.92	8.24	2.99	0.89	1.98	0.25	100.00
AS024A	51.66	13.82	12.76	0.22	6.43	10.64	2.51	0.49	1.35	0.13	100.00

SAMPLE	LOI	Ag	Cu	Ni	Pb	Zn	S (3 dig	Pd	Pt	Au	Mg #
	%	ppm	ppm	ppm	ppm	ppm	%	ppb	ppb	ppb	
Gramado average(56)	0.80	-0.3	132	33	19	96	0.142	6	5	4	0.21
Esmeralda average (9)	0.76	-0.3	186	44	7	100	0.085	11	9	3	0.23
Gramado-Esmeralda unclassified average(15)	0.53	-0.3	186	27	18	105	0.031	11	14	4	0.19
AS021	1.15	-0.5	110	48	10	93	-	5	6	**69**	0.26
AS023	1.61	-0.5	214	40	11	130	-	14	15	6	0.18
AS024A	0.13	-0.5	140	63	-5	74	-	12	6	3	0.30

SAMPLE	Magma Type
Gramado average(56)	Gramado
Esmeralda average (9)	Esmeralda
Gramado-Esmeralda unclassified average(15)	Gramado-Esmeralda
AS021	Gramado
AS023	Esmeralda
AS024A	Esmeralda

Mg #: Magnesium Number   Minus value means under detection limit

b) Argillized Zone Accompanying Sulfide Minerals

In an area located in the eastern part from Lages where an ore showing is believed by local people to exist (the Fazenda do Fortunato situated 15 km to the south of Lages), as containing a total of 300 g/ton of platinum palladium. A pit survey was conducted on white argillized zone with dissemination and network of pyrite, and we had an opportunity to observe the site.

Location and Coordinate:

50 meters to the southwest along a bushy creek from the point where UTM shows 22J 583,981; 6,919,263; height: 1072 m.

Topography and Geology:

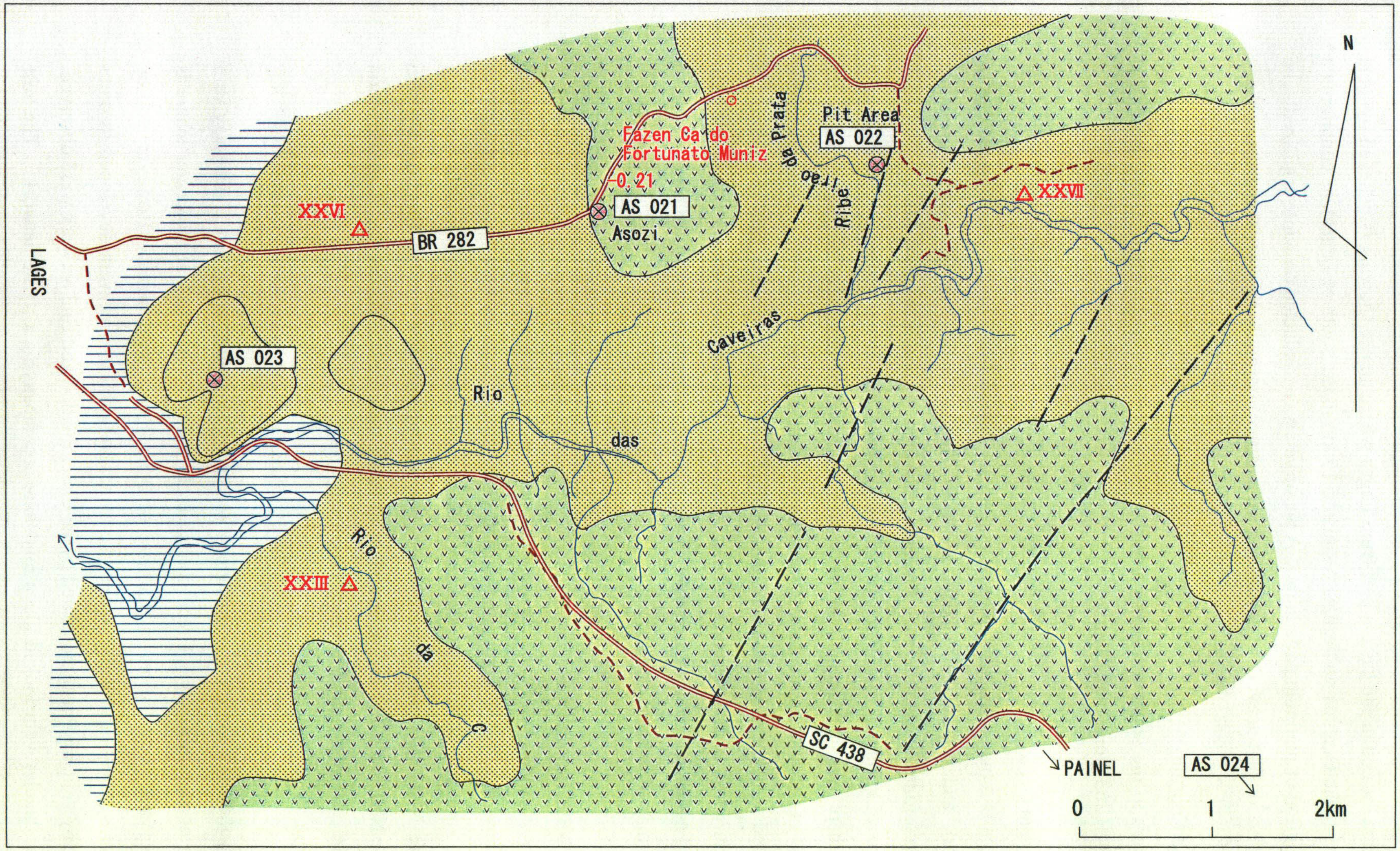
This area is situated on the southeast end of the Paraná flood basalt (showing the age of 130-137 Ma), and argillic vein exists in lower Aeolian sediments (Botucatu Formation, quartzose-sandstone). Alkaline rock (syenite, phonolite, kimberlite) of 70 Ma age had been intruded into this district for 30 x 30 km collectively, and lower Palaeozoic formation is distributed there like a window. In its vicinity, kimberlite chimneys are scattered in the southern half of the alkaline composite intrusions within a range of 10 km to its south. This area is located at 5 km to the south of the alkaline composite intrusions, and distribution of kimberlite chimneys in its vicinity has been recorded. Fig. II-3-8-39 shows a geologic map modified and added referring to the result of the site reconnaissance conducted on the basis of the geologic map of Scheibe (1986).

Size and Structure of Clay Vein:

With respect to the size of the clay vein, its strike is N30-40E, dip vertical and 5 m in width. The clay vein is distributed along small-scaled water stream with its total length estimated as 1.5 km. In an aerial photograph, the clay vein is identified as a clear lineament along the stream in the NNE-SSW direction. Two nearby lineaments in a similar direction are also shown. The NNE-SSW to NE-SW directions of these lineaments is concordant to the direction of the main fracture in the alkaline complex intrusive rock.

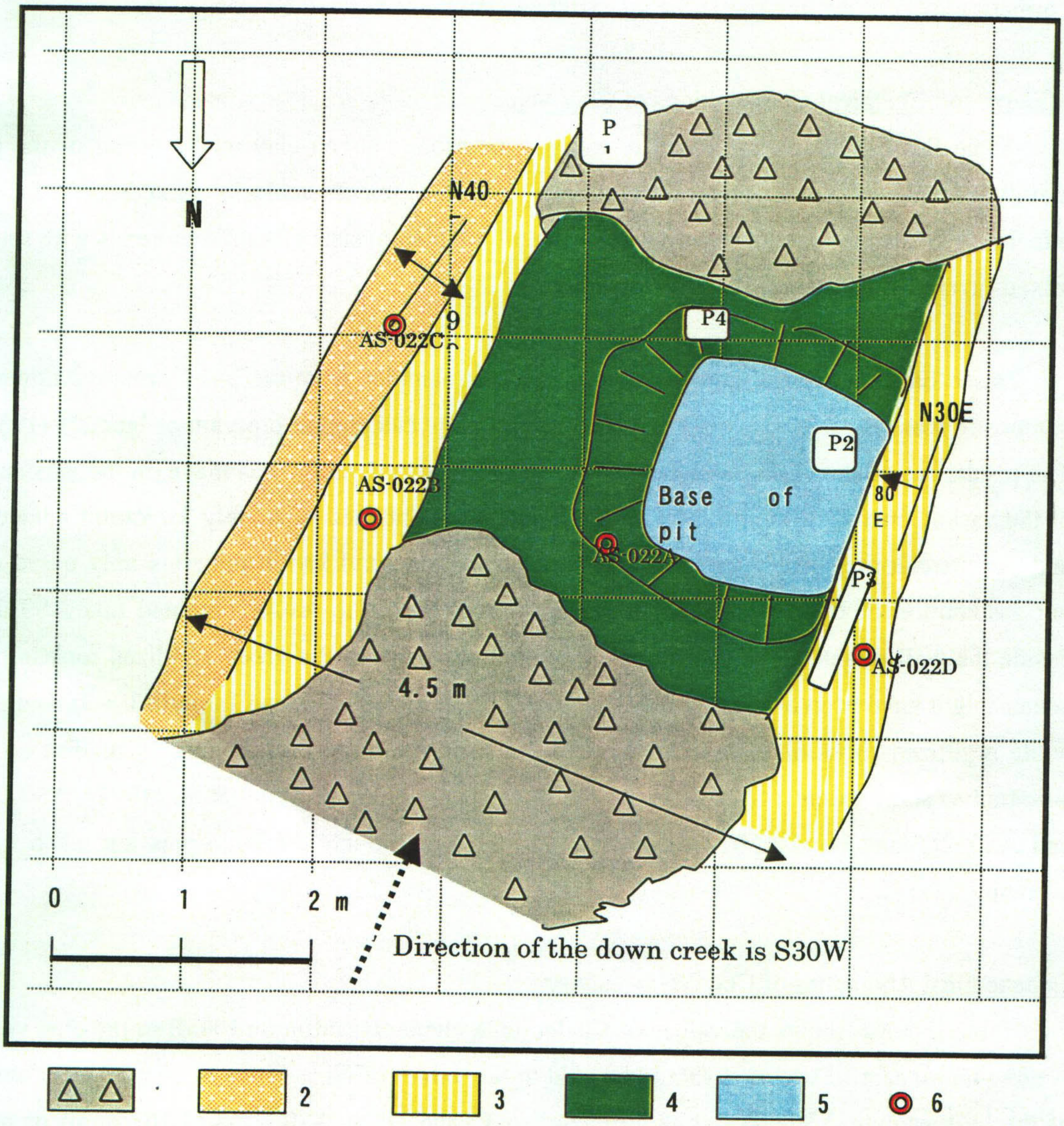
Form of Clay Vein:

Fig. II-3-8-40 is a sketch of a pit, which was being excavated at the site. The clay vein has a zoning of clay minerals. Green clayish rock of 3.0-3.5 m width at the center where is white phenocrystic texture/spots in diameter of 0.5-1.0 mm were noted. However, sulfide minerals were scarcely observed. White clay zones in width of 1 m were developed as outer zone of the clay vein, and medium-scaled pyrite dissemination and fine network were observed. In dry points, the clay vein looked like a mudstone accompanying a pyrite network. The host



Serra Geral Formation(Parana Basalt)
Botucatu Formation (Eolean sandstone)
Paleozoic Sedimentary Rocks
Kimberlite Chimney (number is same as in the text by Sheibe;1986)

Fig. II-3-8-39 Location of altered area and its surrounding geology (geological distribution is compiled after Sheibe; 1986)



1: Debris and waste by pitting, 2: Silicified eorian sandstone, Botu Catu Formation overlain by Paraná flood basalt, 3: White colored argilized zone with sulfide minerals, 4: Green colored argilized zone, 5: water pool at the bottom of the pit, depth from the top is 3 meters from the waste dump or 5 meters from topographic surface besides the creek, 6: Sample location

P1 to P4: Pan concentrated sample locations; (**P1** is taken from the deposited materials by waste water, **P2** is the deepest green argilized material in the pit, **P3** is trench sample on the west white clay wall, **P4** is taken from middle deep sample in green argilized zone.

Fig. II-3-8-40 Schematic sketch of the pit for argillized vein with sulfide minerals at the area in Fazenda do Fortunato Muniz in Lages district, Santa Catalina

rock near the wall observable on the eastern side consists of silicified sandstone (Botucatu Formation) accompanying pyrite, being extremely solid and stained by iron oxide.

Mineral and Chemical Compositions of Clay Vein:

Table II-3-8-4 shows the result of x-ray diffraction. Green clay in the center of the pit mainly consists of kaolin minerals (kaolinite) and the smectite/chlorite mixed-layered clay mineral. White clay on the eastern side of the pit mainly consists of kaolin minerals with same mixed-layered clay minerals in small quantities.

Based on the chemical composition of the four samples from the pit, Normative mineral composition as clay minerals were obtained using on the calculation program of Igarashi (1983). The results are as shown in Table II-3-8-5. Since no consideration was made on the existence of the various mixed-layered minerals, our results were obtained separately for kaolin minerals and sericite/chlorite, kaolin minerals and sericite/smectite, and kaolin minerals only based on our assumption of their existence. It was presumed from the results obtained that AS022C beside the wall might be the sandstone silicified and pyritized; the green argillized rock in the center might have been originated from the basalt of Gramado type (see Table II-3-8-3), and the white argillized rocks on both sides might have been the basic rock extremely oxidized and silicified to some extent. According to the distinction criteria of Peate et al. (1992), AS022A and AS022C may be classified as of Gramado types, although alteration was not taken into account.

Geochemical Anomalies of Clay Vein:

Table II-3-8-6 shows the values of Chalcophile elements, sulfur and PGE in the clay vein. Among them, careful attention should be paid to the values of Ni. From Ni content (400 ppm) of the bulk sample AS022B (white argillized rock) and Ni of AS022P-4 (1,161 ppm) of pan concentrated sample (heavy minerals in green argillized rock), it is noted that Ni contents have no relation with the sulfur contents. In other words, most of sulfur may probably be contained in pyrite, and no co-relationship with the Chalcophile elements is observed in most cases. However, on the assumption that Ni in the sample AS022P-4 is a heavy mineral, it may possibly be a sulfide or an arsenic compound. However, since PGE contents are small, i.e. Pd 5ppb and Pt 6 ppb, it may not be made subject to any exploration unless Ni in the unaltered rock shows a considerable grade.

Formation Model of Clay Vein:

- A basic rock of approximately 5 m in width (probably Paraná basalt) intruded as dyke into a

Table II-3-8-4 X-ray diffraction result of argillized samples

	Serial number	1	2	3	4
	Sample name	KN035C	AS022A	AS022B	AS028C
Silica minerals	Quartz	tr	tr	1	
	Cristobalite				
	Tridymite				
Feldspar	Plagioclace	5			1
	Potassic feldspar				5
	albite				
Clay minerals	Sericite				
	Chlorite				
	Kaoline minerals		1	5	3
	Smectite group	5 (Saponite)			1
	Broad sericite				
	Haloysite	tr			
	Sericite/Smectite				
	Chlorite/Smectite		5	3	
Zeolite minerals	Clinoptilolite				
	Mordenite				
	Lawmontite				
	Stilbite				
	Analcime				
	Wirakite				
Others	Hornblende				
	Augite				
	Biotite				
Sulfate minerals	Alunite				
	Gypsum				
	Barite				
	Jarosite				
Carbonate minerals	Calcite				
	Ankerite	tr			tr
	Siderite				
	Magnesite	tr			
Other minerals	Pyrite				
	Hematite				
	Anataze (TiO2)		1	3	
	Rutile (TiO2)				
	Goethite (alpha-FeOOH)				
	Marcasite (FeS2)				

5 : common 3 : medium 1 : little tr: trace ? : uncertain

Table II-3-8-5 Normative calculation of clay mineral assemblage for Lages argillized rocks

	AS022A			AS022B			AS022C			AS022D		
	Se/Ch	Se/Mo	Ka	Se/Ch	Se/Mo	Ka	Se/Ch	Se/Mo	Ka	Se/Ch	Se/Mo	Ka
Quartz	21.61	17.36	18.92	23.66	21.31	21.38	77.99	78.07	76.80	39.48	39.70	39.13
andalusite							1.25	1.26	2.15	2.87	3.87	2.71
microcline			0.30			1.18			3.31			0.06
albite	3.30		3.30	3.55		3.55	3.64	3.29	3.64	3.81	2.85	3.81
anorthite	2.96	2.96	2.96	1.81	1.81	1.81				0.17	0.17	0.17
kaoline	36.47	27.08	39.49	54.48	48.64	57.41	1.05	0.23	2.79	37.63	35.37	38.21
sericite	0.42	0.42		1.69	1.69		4.74	4.74		0.08	0.08	
montmorillonite		25.34			17.44			0.94			2.59	
chlorite	5.93			4.08			0.22			0.61		
limonite	20.02	20.02	20.02	5.21	5.21	5.21						
hematite							6.60	6.60	6.60	0.56	0.56	0.56
pyrite	0.03	0.03	0.03	0.11	0.11	0.11	0.01	0.01	0.01	0.06	0.06	0.06
ilmenite	1.54	1.54	1.54									
rutil	1.15	1.15	1.15	2.88	2.88	2.88	0.66	0.66	0.66	1.52	1.52	1.52
apatite	0.04	0.04	0.04	0.12	0.12	0.12	0.05	0.05	0.05	0.05	0.05	0.05
enstatite			5.36			3.69			0.20			
others	6.13	4.37	6.50	2.38	1.07	2.56	4.34	4.34	4.34	7.02	7.02	7.02
total	99.60	100.31	99.61	99.97	100.28	99.90	100.55	100.19	100.55	93.86	93.84	93.30

The calculation is resulted by Dr. Sudo H. in Geological Survey of Japan by using computer program by Igarashi(1
The calculation is independently done in each three cases such as Sericite/Chlorite mixed layer, Sericite/Montomorillonite mixed layer, and Kaolin only as clay mineral in each samples. The original program has not the case that mixed layered clay minerals exsised.

Table II-3-8-6 Assay results of bulk and pan concentrated samples at Lages area

SAMPLE	Cu	Ni	Pb	Zn	S	Pd	Pt	Au
Bulk Sample	ppm	ppm	ppm	ppm	%	ppb	ppb	ppb
AS022A	142	70	9	134	0.018	8	9	4
AS022B	251	400	18	138	0.246	14	11	5
AS022C	-10	-20	9	-30	4.295	2	2	3
AS022D	29	48	8	-30	7.055	4	5	3
Pan concentrates								
AS027P	68	45	7	68	0.006	1	1	
AS022P-1	79	51	6	75	3.966	-1	4	
AS022P-2	75	109	6	66	9.976	3	3	
AS022P-3	130	105	5	50	10.026	3	3	
AS022P-4	53	1161	14	86	3.192	5	6	

Sample location see on the pit skech

fault in quartz-sandstone as Aeolian sedimentary rock.

- In view of its high Ni content, the basalt intruded is presumed to be the basalt of high-magnesium type containing the following values:

High Magnesian rock average (33 samples)

Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
105	344	10	80

- Related to the igneous activity of Cretaceous alkaline rocks, argillization, pyritization, and silicification occurred mainly on kaolin and pyrite by acidic hydrothermal solution accompanying fault activity.

Chapter 4: Considering the Survey Results

This project started in anticipation of whether we can find Noril'sk type copper-nickel-PGE sulfide ore deposits in the Paraná flood basalt. In strict meaning, however, since no other Noril'sk type ore deposit has been found yet, this type of ore deposit could be exceptional. Studies on LIP (Large Igneous Province), including the flood basalt that formed ore deposit of this type, have just made rapid development since 1995. Because discussions are still on the progress on the characteristics and origin of LIP, researchers have naturally different opinions.

Under these conditions, this first phase project began, based on existing literature, to review the geochemical stratigraphy and structure of the Noril'sk ore deposits and the Siberian traps, in relation to the characteristics and the genesis of flood basalt around the world. Next, we analyzed major chemical constituents, trace elements including Pt, Pd, Au, and REEs of the rock samples, and isotope ratios that we gathered trough the local survey.

4-1 Theories of Flood Basalt and PGE Sulfide Ore Deposits

A number of theories exist concerning the formation of flood basalt, including a theory that supports active involvement of the mantle plume and a theory that emphasizes ascensions of the asthenosphere in continent divisions. However, there has been no established theory yet concerning the formation of flood basalt. Since 1995, a new theoretical model has been attracting researchers. According to this model, vast amounts of oceanic crust (slab) that subducted from continental margins deposited at the deep of the mantle, and ascended as heterogeneous mantle plume. The flood basalt magma characteristically erupted huge amounts of lava in a short period generally within 1 Ma or less. The heterogeneous plume that consists of basalt constituent having low melting temperature and peridotite constituent ascended from the mantle. In addition, magma activities of flood basalt vary depending on the location, so the theory of flood basalt formation does not necessarily lead to direct linkage to the existence of PGE ore deposits.

The continental crust that has been well differentiated contains poor platinum group elements (PGE) because most PGE were enriched in the core in the genesis of the Earth, and they are enriched naturally in solid phase. Consequently, it is appropriate to trace the origin of PGE in flood basalt to the mantle. During the formation of flood basalt, magma was generated in a larger quantity than during normal igneous activity, a large-scale melting occurred. As a result, a comparatively large quantity of PGE may probably be contained in the melt produced.

On these premises, it can be said that it is desirable that the origin magma of flood basalt, which causes mineralization of PGE, was from the mantle plume, and was generated by large-scale partial melting of the plume containing oceanic slab.

These are the characteristics of all type of LIP igneous activities, and more important matter for formation of PGE sulfide deposit would be such factors that affect the enrichment of PGE. These factors include supply of sulfur and silicate components due to crust contamination, and also local tectonic setting.

4-2 Guidelines for Cu-Ni-PGE Sulfide Deposit Prospecting

It is certain that the formation of Noril'sk ore deposits in Russia derived from flood basalt. Based on the hypnosis that some characteristics could be observed when we regard mineralization as an orthomagmatic ore deposit, we collected literature and interpreted the characteristics and the formation of orthomagmatic ore deposits. As the result, magma, which was concerned in the formation of Noril'sk ore deposit, is considered to be composed of picrite-basalt, rich in PGE and under saturated in sulfur. This magma was contaminated by crust materials, which caused immiscible sulfide* melt to be separated from silicate magma. It is considered to be the origin of the Noril'sk deposit that copper, nickel, PGE were condensed into immiscible sulfide melt because the separated sulfide melt reacted on a large quantity of silicate magma in the central zone of the magma activity. From the above, three points can be listed as the conditions of Noril'sk type ore deposit generation:

1) Generation of magma under saturated in sulfur and its rise to a shallow part of the crust,
2) Generation of immiscible sulfide melt due to contamination of crust materials, and
3) Reaction of the immiscible sulfide melt with a large quantity of silicate magma.

As the policy of propecting ore deposits that satisfy the above conditions, the following can be listed:

1) Existence of "Low-Ti" type, PGE-rich magma as lava or intrusive rock,
2) Existence of magma exhausted in PGE in influenced by crust material contamination as lava or intrusive rock,
3) Being the central area of volcanic activity that weak line of crust has developed and large quantity of silicate magma has supplied from the deep, and Existence of high temperature picrite magma that apt to cause contamination of crust material as lava or intrusive rock.

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* immiscible: At a fixed temperature and pressure condition, two separate phases are thermodynamically more stable than one phase of the solid solution or liquid.

Considering the fact that the large part of the magma involved in the formation of Noril'sk ore deposit was basaltic magma, it becomes questionable whether picritic magma had an indispensable role to play.

4-3 Geology and Geological Structure of the Paraná Basin

Based on the contraction rate of the lithosphere calculated from tidal gravity anomaly, the lithosphere of the Paraná basin is considered as thinner than the lithosphere of a craton and an orogenic belt. Its mantle plume is also considered as located at relatively shallow. An area along Paraná River in the NNE-SSW direction, which ranges from western Paraná Province to southwestern São Paulo Province through northwestern Paraná Province, has the thickest lithosphere in the region. The plume is considered to have intruded in the area along Paraná River. The lift belt, which is considered as the center of the extrusion, is thin in the thickness of lithosphere, indicating high gravity anomaly. This suggests that the high gravity area along Paraná River may have a large magma feeder.

4-4 Tectonics of Copper-Nickel-PGE Deposits Accompanied by Continental Flood Basalt

We considered the Duluth ore deposit in the United States, Noril'sk deposits in Russia, and the Paraná basin to examine the effects of a tectonic stress field on a series of geological phenomena, including flood basalt and copper-nickel-PGE sulfide deposits.

For the Duluth, the copper-nickel-PGE sulfide ore deposit was presumably formed when Duluth complex intruded in the tensional zone formed by the lateral movement of two transform faults.

The Noril'sk deposits are located along the Noril'sk-Kharayelakh fault in the NNE-SSW direction. The fault is considered as laterally shearing according to the shape of ore body. The Talnakh ore zone, located on the west side of the fault, forms a triangle area extending to northwestern direction. This is considered as the deposit is formed in the tensional zone. The Noril'sk and Talnakh deposits are also located at the crossing part of NNE-SSW and NNW-SSE structural directions. These deposits are situated at the thickest part of the related basalt lava pile, namely at the center of the extrusion.

When we regard the lineament in Paraná basin as a fault or fracture, the lineament could be interpreted as a tectonic stress field in the lift zone. Paraná river, in the center of the basin, flows from NNE to SSW direction. This direction matches the coastal line near the east of the basin, the line that is the tensional fracture between the South American and African continents. The lithosphere along Paraná River indicates high contraction rates, high gravity anomaly, and thick dolerite sill intrusion, and the basalt lava forms thickest piles in the region. All of these phenomena could be regarded as indicating that the NNE-SSW structure is a large tensional lift zone that leads to the mantle.

The structure of the NW-SE direction crosses over the NNE-SSW structure that estimated as a lift, and is considered as "transform fault." In particular, what are noteworthy are Ponta Grossa, Abreu Mourao, Rio Piquiri, and other zones where fractures are concentrated. This zone presumably formed a Cymoid loop by right lateral movement, allowing large volumes of sills and dykes to intrude in the zone. In this way, the cross-point between the transform faults and other structures may played the major role in forming the large Cymoid loop. Thus, the cross-point is considered to have been the center of the magmatic activities.

4-5 Satellite Image Analysis

Dykes of Ponta Grossa Arch are extracted as clear lineaments. We need to examine whether dykes are found in basalt platform, and preferably identify they are feeder dykes.

Lineaments in the NE-SW direction were extracted in the distribution area of basalt in the central area in this interpreted. These lineaments are not at all described in the geologic map and their geological meaning is unclear. Thus, we may need to examine them at next field survey. Concerning the lowland centering on Paraná River, the NE-SW horst and graben structures in the basement rock is estimated by airborne magnetic and gravity data. However, no corresponding lineaments have been extracted on SAR images. Since after flood basalt was erupted, no major tectonic movements have been observed.

4-6 Geochemical Characteristics of the Paraná Flood Basalt

Peate et al. (1992) newly classified the Paraná lavas to six types divided as "Low-Ti" type and "High-Ti" type. In our survey, we judged that Paranapanema and Ribeira have intermediate Ti contents, which are impossible to distinguish them from geochemical viewpoint. Thus, we reclassified transitional types of lava (Paranaanema-Ribeira) in the categories stated below. Ti contents among the three types are remarkably different, and indicate differentiation trends in the Mg#-TiO_2 diagram.

The geochemical result is summarized in Table II-4-6-1. According to the geochemical characteristics, each type of lava is considered as having the following origin and

Table II-4-6-1 Summary of geochemical interpretation

Lava type	Variation of major elements			Variation of minor elements		Spider diagram (chondrite normalized) of trace elements		Metallic elements		REE			Degree of partial melting from primitive mantle	Ta/Nb-Y/Nb and Zr/Nb-Y/Nb corelation		Nd, Sr Isotope ratio		
Plot-Diagram	Major elements	TiO2 content (wt %)		Nb,Zr,Y, Ba,Th,U-Mg#	Sr-Mg#	Light REE	Heavy REE	Ni-Mg#	Cu,Au,Pt,Pd-Mg#	LREE (La/Sm-Mg#)	HREE (Gd/Yb-Mg#)	Nb/Zr-Mg#	Ba/Ca-Sr/Ca	Ta/Nb-Y/Nb systematics	Zr/Nb-Y/Nb systematics	$^{143}Nd/^{144}Nd$-$^{87}Sr/^{86}Sr$	$^{87}Sr/^{87}Sr$-Mg#	$^{143}Nd/^{144}Nd$-Mg#
Urubicí	Elements (Al_2O_3, MgO, CaO) decreasing by differentiation Elements (TiO_2, K_2O, Na_2O) increasing by differentiation	>3.3	High-Ti	Increase by crystallization differentiation	Sr slightly increase by fractionation	Highest	stinctly lo	Decrease toward smaller Mg# side	Poor in Cu, Au, Pt, Pd	High	High	Medium	<5% ?	Nearest to enriched mantle source	Nearest to enriched mantle source	Low $^{87}Sr/^{86}Sr$ and high $^{143}Nd/^{144}Nd$ (on the lline conect MORB and OIB)	Low $^{87}Sr/^{86}Sr$	Medium $^{143}Nd/^{144}Nd$
Pitanga		>2.8				High	Almost same level			High	High (low partial melting)	High (low partial melting)	on 10% line					
Paranapanema-Ribiera		1.5-3.2	Inter-mediate-Ti		Sr decreasing may show plagioclase fractionation	Medium			Most enriched in Cu, Au, Pt, Pd	Medium	Medium	Medium	on 20%(15-25) line	Near to enriched mantle source	Near to enriched mantle source			
Esmeralda		1.1-2.0	Low-Ti		Almost same value in Sr	Low				Low and increase toward lower Mg# (near primitive magma)	Low (high partial melting)	Low (high partial melting)	on 30% line	Far from depleated mantle source	Far from depleated mantle source			High $^{143}Nd/^{144}Nd$ and narrow Mg# range
Gramado	Al_2O_3, CaO inclresing at high (75 to 70)Mg# range in Gramado type (olivine control)	0.7-2.0		Th, U Widely dispersing shows contamination by the crust		Medium		Very high at Mg# >70 side, and decrease at smaller Mg# side	Widely variable in Cu, Au, Pt, Pd on any degree of differentiation	Widely dispersed (Highest to Medium) (may be contaminated by the crust)	Medium to low	Medium to low	on 30% line	Far from depleated mantle source	Far from depleated mantle source	High $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ (may shows crustal contaminatio n)	High $^{87}Sr/^{86}Sr$ (crustal contaminatio n)	Low $^{143}Nd/^{144}Nd$ and wide Mg# range
Comment				Incompatible elements (Nb, Zr, Y, Ba, Th, U) having large ionic radius enrich toward crystallization differentiation.				This corresponds to crystallization differentation of olivine or pyroxene + plagioclase.	We have no answer why the intermediate magma type is enrich in PGE, Cu, Au.	Each magma type show different level of La/Sm ratio. High La/Sm ratio generally means high degree of crustal contamination. Gramado has wide variation of La/Sm ratio which means distinct crustal contamination.	Low Gd/Yb ratio may mean high degree of partial melting because Gd easily included in garnet at mantle.	Low Nb/Zr ratio means high degree of **partial melting.** May be caused by difference of fractionation coeficients for mantle and basalt magma	Degree of partial melting from primitive mantle	Parana basalts are nearer to MORB than OIB(Ocean Island Basalt). The systematics must be interpreted in future with other continental flood basalts and OIB.		$^{87}Sr/^{86}Sr$ ratio is high in granitic crust		High $^{143}Nd/^{144}Nd$ may mean near primitive mantle source.

characteristics:

a) Esmeralda contains a little light REEs and its neodymium isotope ratio is low. Thus, Esmeralda is considered as most primitive, having less influence from the contamination with crust and crystallization differentiation.

b) Gramado, classified into "Low-Ti" type, is relatively rich in Th, U, and Rb; high in strontium isotope ratio; and low in neodymium isotope ratio, suggesting the influence of granitic material of the upper continental crust. Contamination with the crust may be related with the distribution of lava in basement rocks in southern Paraná basin.

c) "High-Ti" type and Transitional type of magmas have small contamination with the upper continental crust, suggesting quick development of effusions so that the magma had no time to react with the crust. In other words, Paranapanema and Pitanga types of lava formed thick piles in the center of the Paraná basin, indicating the largest extrusion of lava in the Paraná basalt. When their extrusion/erution ages were precisely identified, the form and history of activities in the Paraná basalt will become clear.

d) It could be possible to say that three types of lava were formed by different partial melting degrees of mantle materials. "Low-Ti" type magma, having largest partial meting, is considered as assimilating materials at different levels in the upper part of the continental crust. However, we cannot exclude the possibility of different magma sources.

e) Paranapanema-Ribeira, classified into Transitional type, is richest in the PGE in the region. This type of lava contains 9.7 ppb and 15.5 ppb of Pt and Pd, respectively, on average. These contents are higher than the lava found in the Noril'sk area. Partial melting alone faces difficulties to explain why Paranapanema (-Ribeira) is rich in PGE. We will also have to consider that locations of magma sources may be different. If PGE depletion caused by the separation of immiscible sulfide melt in Transitional type Paranapanema-Ribeira is found, we may expect to find a PGE ore deposit.

f) "Low-Ti" type magma has high Pt and Pd contents, next to Transitional type magma. Gramado type magma, which is influenced by distinct crustal contamination, has the samples depleted in PGE. "High-Ti" type Pitanga is extremely low in the Pt and Pd contents, suggesting poor PGE in juvenile.

g) Geochemical anomaly of PGE, Ni, Cu, and other chalcophile elements, which resulted from stream sediment geochemical survey conducted by Mineropar, located in the western Paraná Province, may indicate the distribution itself of Paranapanema-Ribeira type lavas that has a high PGE content. Additional data is needed to decide the characteristics of the western

Paraná Province.

4-7 Intrusive Rocks Relating to Paraná Basalt

Constituent of sills is wide at the Lomba Grande area, consisting of picrite to dacite sills. Sills and dykes constituent in Ponta Grossa Arch are narrow and they are wholly made of basalt. Sills in Lomba Grande area are rich in Th, U, and Rb. The neodymium and strontium isotope ratios probably indicate crust contamination. Meanwhile, the sills in Ponta Grossa Arch have been formed presumably by the magma that is poorly influenced from crust materials.

A relatively high Pt and Pd contents (Pt 20 ppb or more at highest) in intrusive rock are observed in thick sills (basalt to andesite sills) in the northeastern to eastern Lomba Grande area, whereas the sills (picrite to basalt sill and andesite to dacite sill) in the central Lomba Grande area are depleted in Pt and Pd. The sills and dykes in Ponta Grossa Arch indicate uneven Pt and Pb contents, which range from almost none to 20 ppb of Pd.

The stated below are future subjects and survey methods we would like to propose.

- To establish the three-dimensional chemical stratigraphy of the entire Paraná basin mainly by drilling samples,
- To extract areas where contamination of crust materials and depletion of Cu-Ni-PGE are observed in individual types of lava,
- To obtain relational data and interpretation between amounts of sulfide minerals in lava and intrusion, variety of differentiation, sulfur isotope ratio and others,
- To know precise activity period of different magma types by accumulation of dating data and evaluation by existing dated results,
- To calculate eruption volumes and ratios of different types of magma,
- To examine/interprete geochemical data including other types of flood basaltin the world,
- To collect and discuss geochemical data of orthomagmatic Cu-Ni-PGE sulfide ore deposits including those of Noril'sk.