3-4 Geochemical Characteristics of the Paraná Flood Basalts

3-4-1 Geochemical Characteristics of the Paraná Flood Basalts

The Paraná flood basalts were divided into 3 magma types, "Low-Ti", "Intermediate-Ti", and "High-Ti" types. The geochemical study using trace elements and its ratios suggested that difference between these magma types was caused by the difference of degrees of partial melting of mantle. However this difference may be explained by the difference of source materials themselves. Therefore detailed study using larger number of samples is required.

The Esmeralda type which belongs to "Low-Ti" type is relatively the most primitive magma in all types, considering its contents of Th, Ta, Y, Zr, and isotopic $^{143}Nd/^{144}Nd$. The Gramado type which also belongs to "Low-Ti" type might have generated, assimilating larger amount of crustal materials, compared with other types, considering its higher $^{87}Sr/^{186}Sr$, non-linear differentiation trends of some elements, and dispersed concentrations of Th and U.

The Paranapanema-Ribeira which belongs to "Intermediate-Ti" type showed the highest concentrations of Cu, Au, Pt, and Pd, whereas "High-Ti" Pitanga type showed characteristically low concentrations of these elements. The Gramado type has 2 populations of fertile and depleted samples in these elements. The depleted population probably was formed by crustal contamination and sulfide segregation.

3-4-2 PGE Content of the Paraná Flood Basalts

As discussed in chapter II: 1-3, in order to yield economic orthomagmatic sulfide deposits, the generation of sulfur undersaturated magmas and its transportation into shallow crustal level are required. These magmas must have high concentrations of platinum and palladium.

Table II-3-4-1 shows Pt and Pd concentrations of lava samples collected in this fiscal year. Fig. II-3-4-1 illustrates Pt-Pd correlations in lava samples.

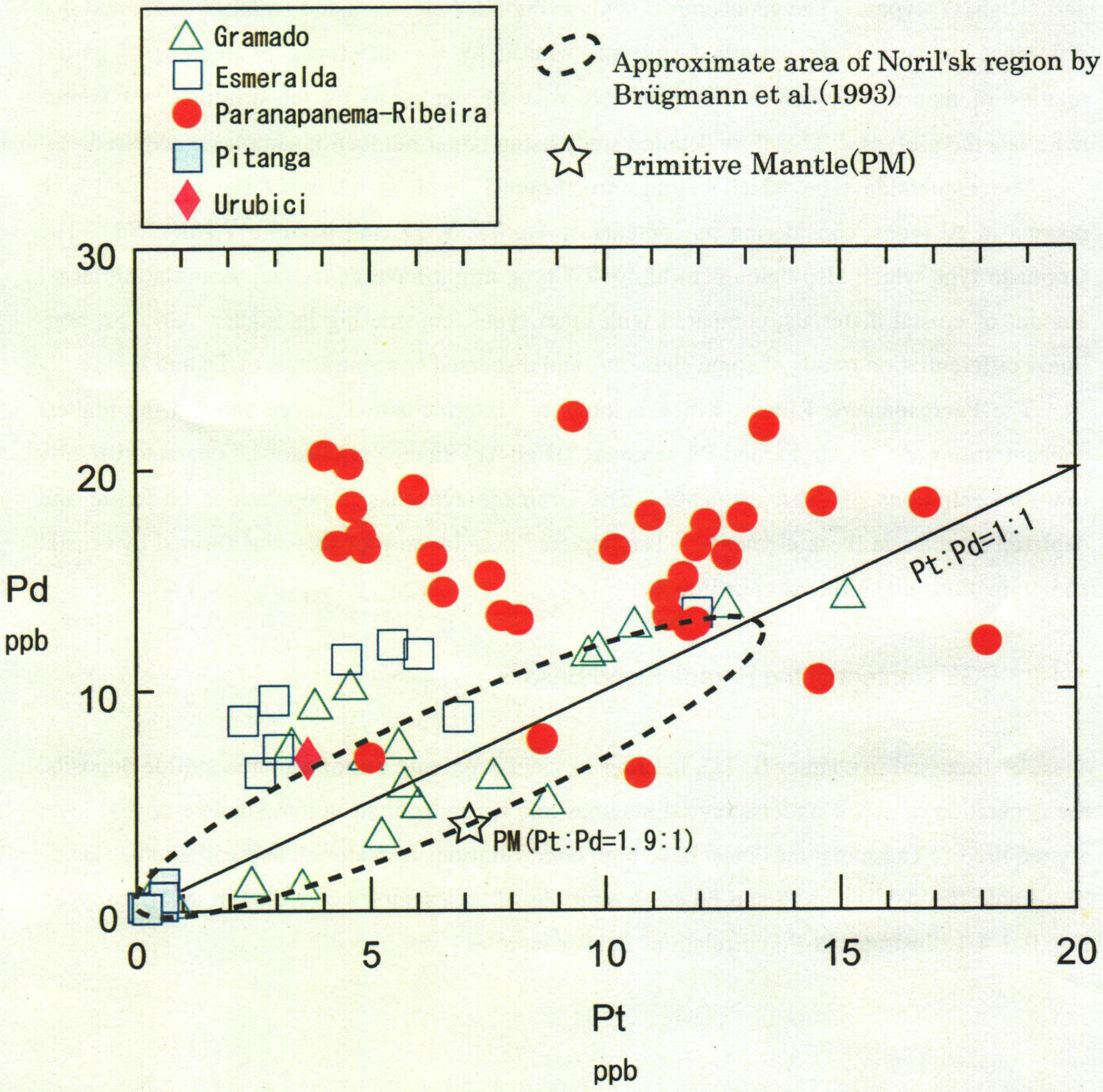


Fig. II-3-4-1 Pt-Pd correlation in lavas

Table II-3-4-1 Platinum and Palladium concentrations of lava samples

Lava	Type	Pt(ppb)			Pd(ppb)			number
		range		average	range		average	
Gramado	Low-Ti	0.3 ~	15.2	6.4	0.6 ~	13.7	7.0	19
Esmeralda	Low-Ti	2.3 ~	12.0	5.1	6.3 ~	13.5	9.9	9
Paranapanema-Ribeira	Intermediate-Ti	4.0 ~	18.1	9.7	6.2 ~	22.3	15.5	32
Pitanga	High-Ti	0.2 ~	0.6	0.4	0.1 ~	1.3	0.5	4
Urubicí	High-Ti	3.7 ~	3.7	3.7	6.2 ~	6.2	6.2	1
Tuklonsky(Noril'sk)*	Low-Ti	9.0 ~	13.0	11.2	9.0 ~	13.0	10.7	5

* The least PGE depleted lava of Noril'sk region (data from Brügmann et al.,1993)

The "Intermediate-Ti" type Paranapanema-Ribeira is the richest in Pt and Pd in all lava types. This type characteristically has high concentrations of Pd; the highest value is 22.3 ppb, and average value of 32 samples is 15.5 ppb. "Low-Ti" type Gramado and Esmeralda show the second highest Pt and Pd concentrations. These three types are thought to be fertile magmas. Particularly, the amount of Pt and Pd of Paranapanema-Ribeira reaches 25.2 ppb in average, exceeding 21.9 ppb of the Tuklonsky lava which is the least PGE depleted lava of the Noril'sk region. On the other hand, though the number of samples are only 4, "High-Ti" type Pitanga shows the lowest concentrations of Pt and Pd. The previous studies showed the "High-Ti" and "Low-Ti" types of lavas are distributed in the northern and southern Paraná basin, respectively. In this year only 4 Pitanga type basalts were collected in the survey area because the area was central to southern Paraná basin. Therefore, it is difficult to conclude that "High-Ti" type Pitanga has the lowest Pt and Pd concentrations in this stage. The Pt and Pd content of "High-Ti" type basalts remains an issue to be discussed next year.

As shown in Fig. II-3-4-1, Pt and Pd concentrations in the flood basalts of the Noril'sk region show close correlation, and the their Pt/Pd is approximately 1. This is lower than the chondritic ratio of 1.9. This means a Pt depletion relative to Pd. Such non-chondritic ratio of the magmas of the Noril'sk region is considered to reflect the source feature. The source material is probably the subcontinental lithosphere mantle or plumes originating in the lower mantle (Brügmann et al., 1993). The ratio of the Paraná basin basalts is less than 1. This means the magmas of the Paraná basin are of more depleted in Pt and non-chondritic compared with the magmas of the Noril'sk region. This is more remarkable in Paranapanema-Ribeira type. Therefore, the magmas of the Paraná basin basalts are thoughed to be non-chondritic as well as those of the Noril'sk region, and the depletion of Pt relative to Pd is larger.

The relation between Cu and Pd is shown in Fig. II-3-4-2. Although both elements have the nature to concentrate in sulfide melt, palladium is apt to concentrate further. The partition coefficient($D^{sulfide/silicate}$) is 600 to 1,000 for copper, and 10,000 to 100,000 for palladium. Therefore, palladium concentrates into sulfide melt 15 to 100 times more than copper. If the silicate magma is sulfur saturated and segregates a immiscible sulfide melt, both of Pd and Cu are depleted in the magma. The depletion of Pd is much larger than that of Cu. Therefore, the more sulfide segregation proceeds, the more Pd/Cu of the magma decreases.

Fig. II-3-4-2 shows that the data of each lava type is plotted on individual field. In five types, all data of "Intermediate-Ti" Paranapanema-Ribeira and "Low-Ti" Esmeralda lie within the sulfur undersaturated field, and exhibit high Pd concentrations. Particularly, Paranapanema-Ribeira basalts exhibit the highest concentrations of Pd and Cu. Although most of "Low-Ti" Gramado basalts lie within the sulfur undersaturated field, a few basalts of this type lie within the sulfur saturated field. Therefore the magmas of Paranapanema-Ribeira, Esmaralda, and Gramado are thought to have been sulfur undersaturated except same magmas of Gramado type. On the other hand, four basalts of "High-Ti" Pitanga type are depleted in Pd and lie within the sulfur saturated field. Therefore, it might be concluded that the magmas originated from "Low-Ti" and "Intermediate-Ti" types were sulfur undersaturated, but the magma originated from "High-Ti" type were sulfur saturated. However, with regard to the magma of "High-Ti" type, this conclusion is not definite due to a small number of samples. Further verification with more samples is necessary.

The Paraná basin flood basalts tend to be rich in Cu compared with those of the Noril'sk region. The magmas triggered the ores of the Noril'sk deposits are the magmas of the Tk type(see chapter II.1.3). These basalts are the most primitive and the least depleted in PGE among the magmas of Noril'sk (Pt and Pd concentrations range from 9-13 ppb according to Brügmann et al., 1993). On the other hand, the most primitive basalt type in the Paraná basin is Paranapanema-Ribeira, and the PGE content of this lava type exceeds that of the Tk lava of the Noril'sk region. Therefore, from a view point of fertility of magma in PGE, the magmas of the Paraná basin are almost equal to the magmas of the Noril'sk region, and satisfies the first requirements to generate the orthomagmatic sulfide deposits (Generation of sulfur undersaturated magmas and its transportation to shallow crustal level without reaching sulfur saturation) discussed in chapter II: 1-3. As a result, the magmas of the Paraná basin have a potentiality to generate the ore deposit if another requirements are satisfied.

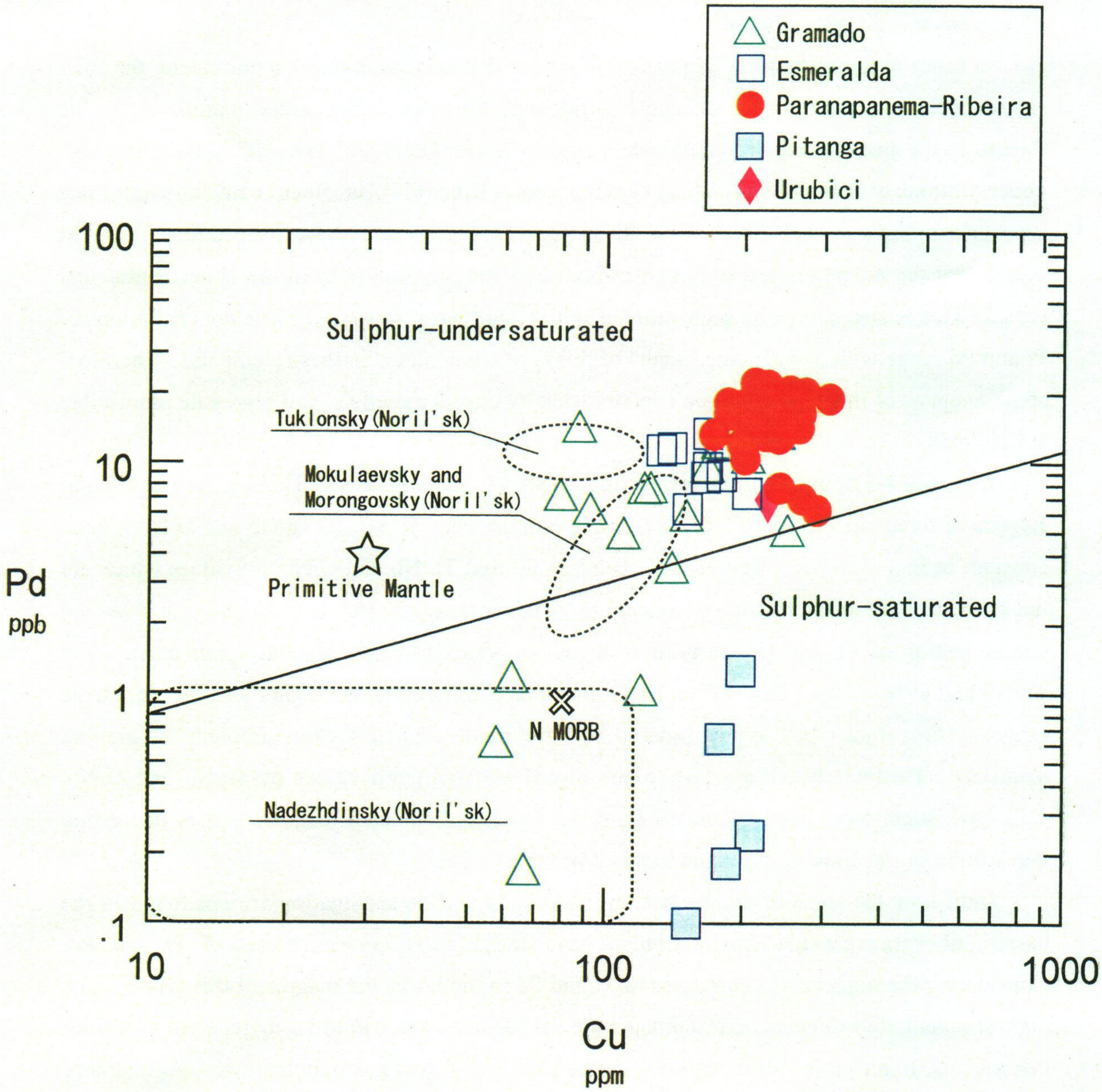


Fig. II-3-4-2 Cu vs. Pd discriminant diagram between the field of rocks formed by Sulphur-saturated magmas and the field of rocks formed by Sulphur-undersaturated magmas

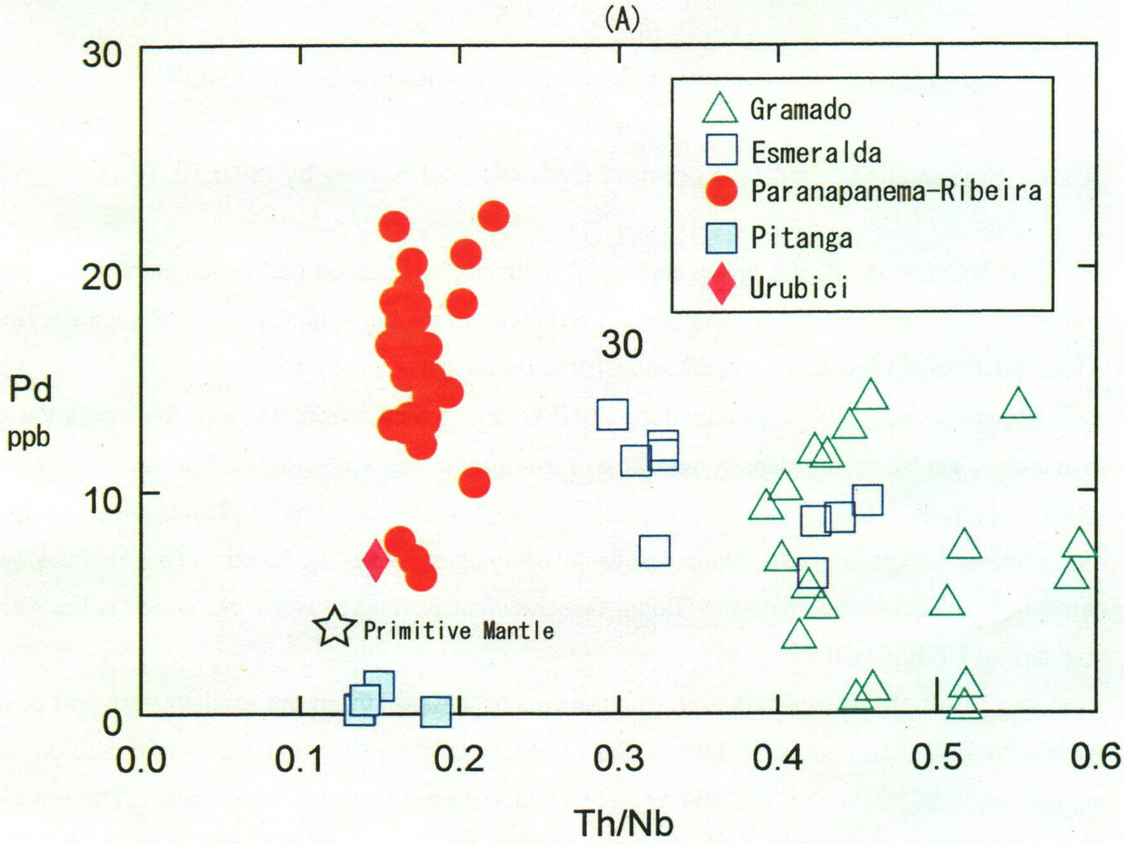
3-4-3 The Relation between Crustal Contamination and PGE Concentrations in Basalts

The relation between crustal contamination and the PGE concentrations in the lavas of the Paraná basin is discussed below.

In order to generate orthomagmatic sulfide ore deposits, as the next requirement, the PGE rich magmas must segregate immiscible sulfide melt by assimilating crustal materials. In the Paraná basin area the most contaminated magma is the Gramado type. This type has high concentrations of Pt and Pd as well as Paranapanema- Ribeira. The other characteristics of this type is exhibiting higher Th, U, and Rb concentrations compared with the other types. It means that the magma is probably contaminated by the granitic rocks of the upper continental crust. This is also shown by high value of initial $^{87}Sr/^{86}Sr$ of this type. The concentrations of Pt and Pd range widely and some basalts of this type are depleted in these elements. Therefore, some magmas of this type might be contaminated by crustal materials, and segregate immiscible sulfide melt.

Fig. II-3-4-3 shows Th/Nb vs. Pd and U/Nb vs. Pd diagrams. Though Paranapanema-Ribeira differentiates from 70.5 to 54.1 in Mg-number (Fig. II-3-3-2), Th/Nb and U/Nb remain constant in Fig. II-3-4-3. Therefore, it can be said that Th/Nb and U/Nb are values which are not influenced by differentiation of a magma. The increases of Th/Nb and U/Nb will show the contamination of Th and U rich granitic materials which form continental upper crust. The Th/Nb and U/Nb of the "Low-Ti" types, Gramado and Esmeralda, are higher and vary in a wide range. These two types are considered to have contaminated various amounts of granitic materials. Particularly, Gramado exhibits higher and scattered values of Th/Nb and U/Nb. This type might have been generated from the most contaminated magmas. It is interesting that sulfide segregation is suggested in this type.

Until now the signs of crustal contamination and sulfide segregation are not found in the basalts of Paranapanema-Ribeira, which have the highest concentrations of Pt and Pd. Considering the highest concentrations of Pt and Pd in the lavas, the magma of this type has the highest potentiality to generate orthomagmatic sulfide deposits. In order to generate ores from this magma, immiscible sulfide melt should be formed by crustal contamination. Furthermore the sulfide melt should react with voluminous silicate magma in a center of magmatic activity. Therefore, it is very important to hunt a volnanic center of each lava type including the Paranapanema-Ribeira. It is also needed to investigate whether the crustal contamination and the sulfide segregation are found or not there. To achieve this objective, investigation of the underground of the Parana basin area, for example, using existing drillings such as the Petrobras oil drillings, is highly required.



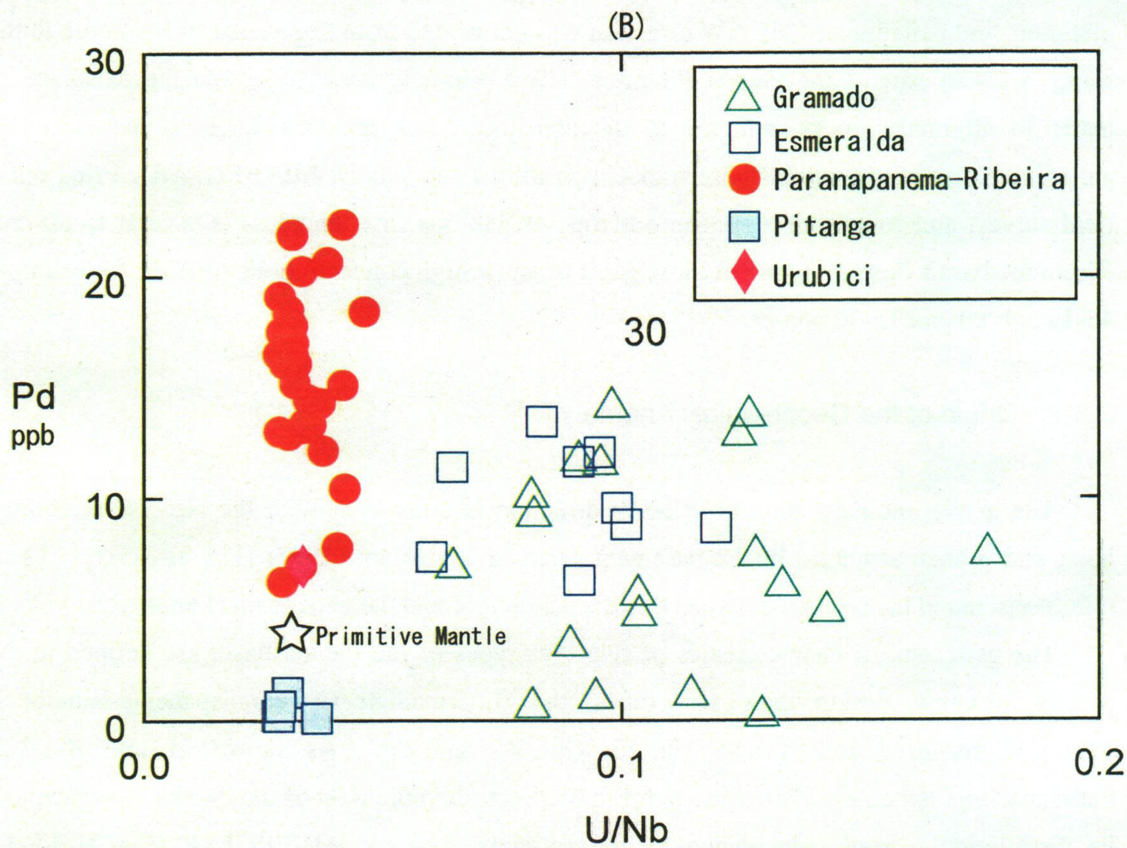


Fig. II-3-4-3 Th/Nb-Pd (A) and U/Nb-Pd (B) correlations in lavas

3-5 Study of the Stream Sediment Geochemical Anomaly by MINEROPAR

3-5-1 Review of the Stream Sediment Geochemical Survey by MINEROPAR

The MINEROPAR, the provincial agency for mining, carried out a reconnaissance multi-elements geochemical survey, using stream sediment and water samples, in the Paraná Province with IPARDES, IAPAER, EMATER and CPRM during 1994 to 1998.

The survey area was approximately 170,000 km^2, which covers 85 % of the whole Paraná Province. The sampling density was 26 km^2/sample to 238 km^2/sample, and the average was 225 km^2/sample. Totally 696 samples (696 drainages) were collected. Besides these samples, 40 samples, integrating 696 drainages to 40 drainages, were produced. The analysis was carried out in accordance with the Global Geochemical Reference Network, which is the world standard of UNESCO/IUGS.

As a result of this program, covering the area of 40,000 km^2 in the southwestern part of the Paraná Province, the high anomalies of Cu, Zn, Co, Ni, V, Ti, Cr, MgO, Pt, and Pd, and the low anomalies of SiO_2, Ba, Be, Sn, and W were extracted by the stream sediments. These multi-elements anomalies were thought to have related to the flood basalts activities (Fig. II-3-5-1). The geochemical anomaly zone that consists of chromium, nickel, copper, titan, vanadium, platinum, and palladium of NE-SW direction was delineated from Capanema to Mambore in the south- western part of the Paraná Province. This anomaly zone suggested the existence of mafic to ultramafic rocks, and led to the conclusion that the PGE such as platinum and palladium concentrate within those rocks. To follow the survey, MINEROPAR carried out a field survey, and found out a sixteen outcrops of gabbros (the thickness is several to 80 cm) within the basalt flows. Some of these gabbros show high concentrations of PGE, for example 46-48 ppb Pd and 15-20 ppb Pt.

3-5-2 Origin of the Geochemical Anomaly

The above anomaly zone of NE-SW direction is coincident with the NE-SW orientated horst and graben structure in the basement inferred by Milani (1997) (Fig. II-3-5-2). Licht (2000) discussed the relation between this deep structure and the geochemical anomaly.

The geochemical characteristics of five lava types of the Paraná basin are defined in the present survey. Within these five types, the "Intermediate-Ti" Paranapanema-Ribeira is relatively primitive and enriched in Ni, Cu, Pt, and Pd. As shown in Fig. II-3-3-1, Paranapanema-Ribeira is distributed in NE-SW direction in the west of the Paraná Province, and its distribution is well coincident with the anomaly zone by MINEROPAR (Fig. II-3-5-1). Surrounding Paranapanema-Ribeira, the sedimentary rocks overlying the flood basalts and

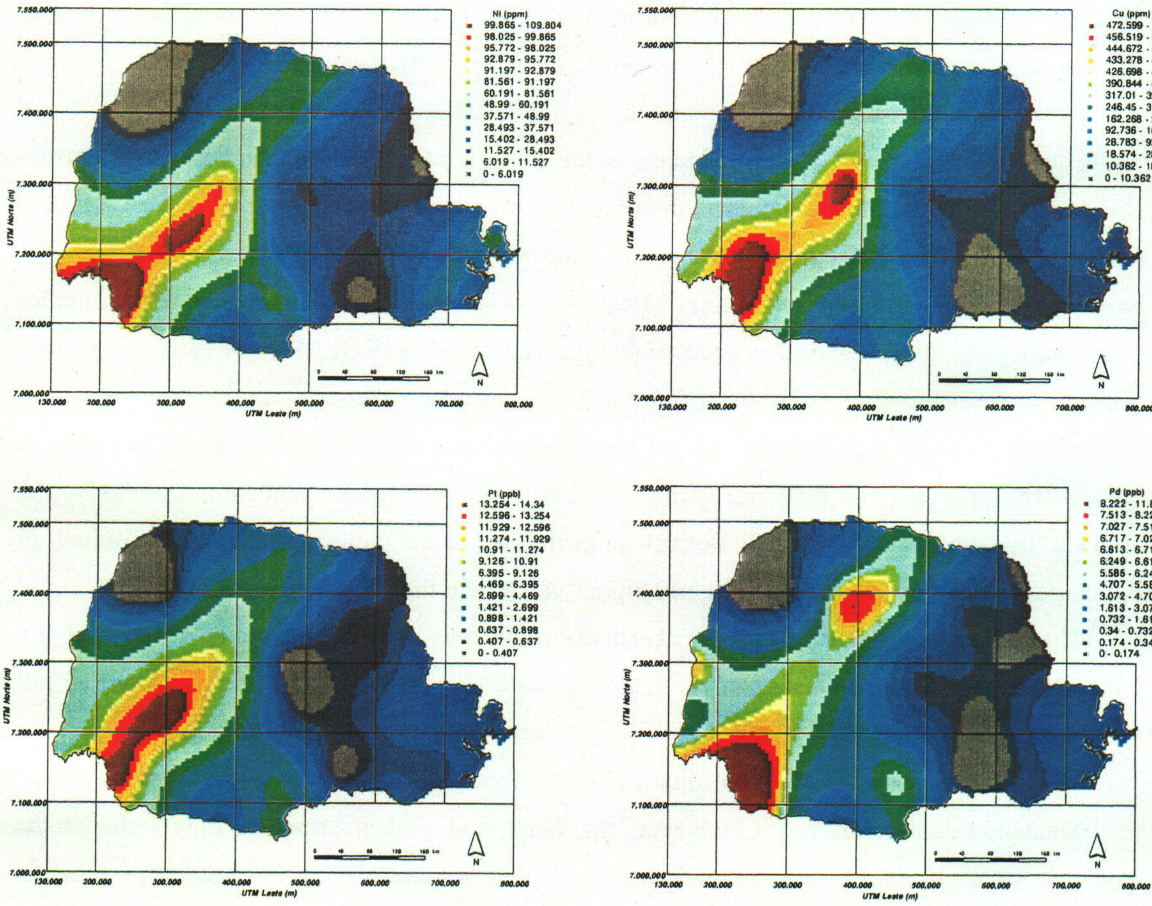


Fig. II-3-5-1 Stream sediment geochemical maps of Ni, Cu, Pt and Pd by MINEROPAR (Lichit, 2000)

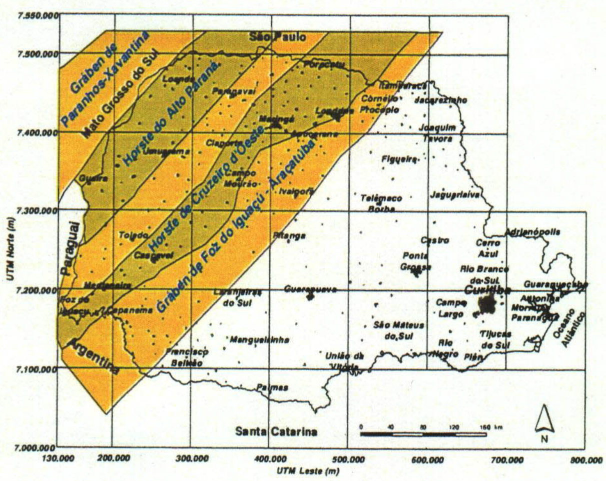


Fig. II-3-5-2 NE-SW trending horst and graben structure by Milani (1997) (Licht, 2000)

"High-Ti" Pitanga, both of which are poor in Ni, Cu, Pt, and Pd compared with Paranapanema-Ribeira, are distributed.

Therefore, the geochemical anomaly zone by MINEROPAR that suggested the existence of mafic to ultramafic rocks possibly indicates the distribution of Paranapanema-Ribeira itself, which is rich in these elements. Moreover the weak anomaly, which extends from the southern extremity of the Paraná Province to the north, indicates possibly the distribution of the "Low-Ti" type basalts (Gramado or Esmeralda). Therefore, it would be concluded that the anomalies extracted by the stream sediment geochemical survey by MINEROPAR have reflected surface geology very sensitively.

Fig. II-3-5-3 to Fig. II-3-5-6 are the distribution maps of Ni, Cu, Pt, and Pd contents in lavas. The area covered by Paranapanema-Ribeira has the highest concentrations of Pt, Pd, and Cu in lavas. However, Ni doesn't indicate the same pattern because Ni content of Paranapanema-Ribeira show only slightly higher value than that of other types.

The stream sediment geochemical survey indicates that these elements have higher concentrations toward the center of the anomaly zone (Fig. II-3-5-1). But this pattern is not described in lavas.

It is not clear now whether the distribution of Paranapanema-Ribeira has been controlled by basement structure or not. However, the horst and graben structure may indicate the existence of the fracture zone by tensional stress. If so, this structure might have acted as feeder of Paranapanema-Ribeira.

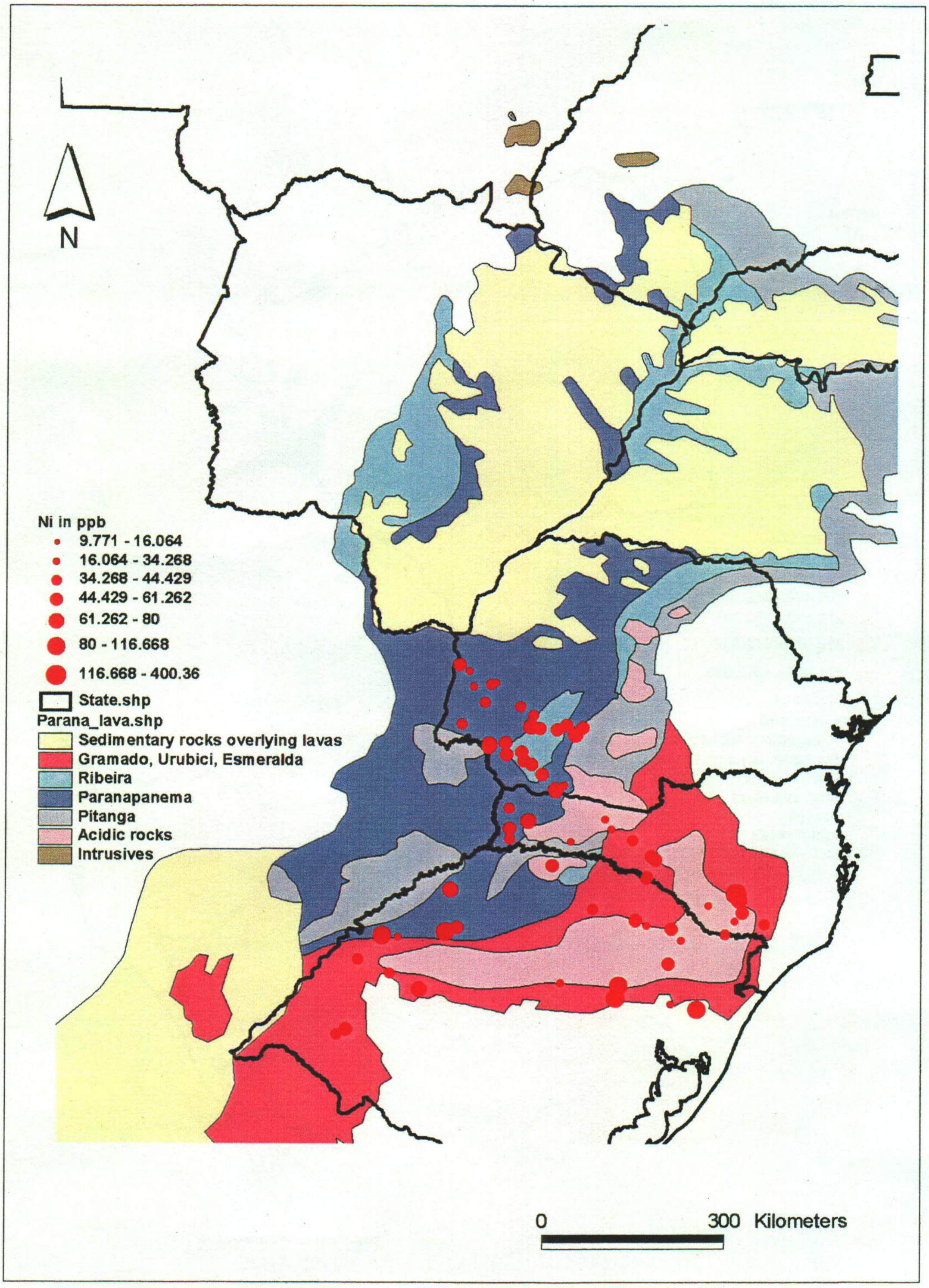


Fig. II-3-5-3 Distribution map of Ni content in lavas

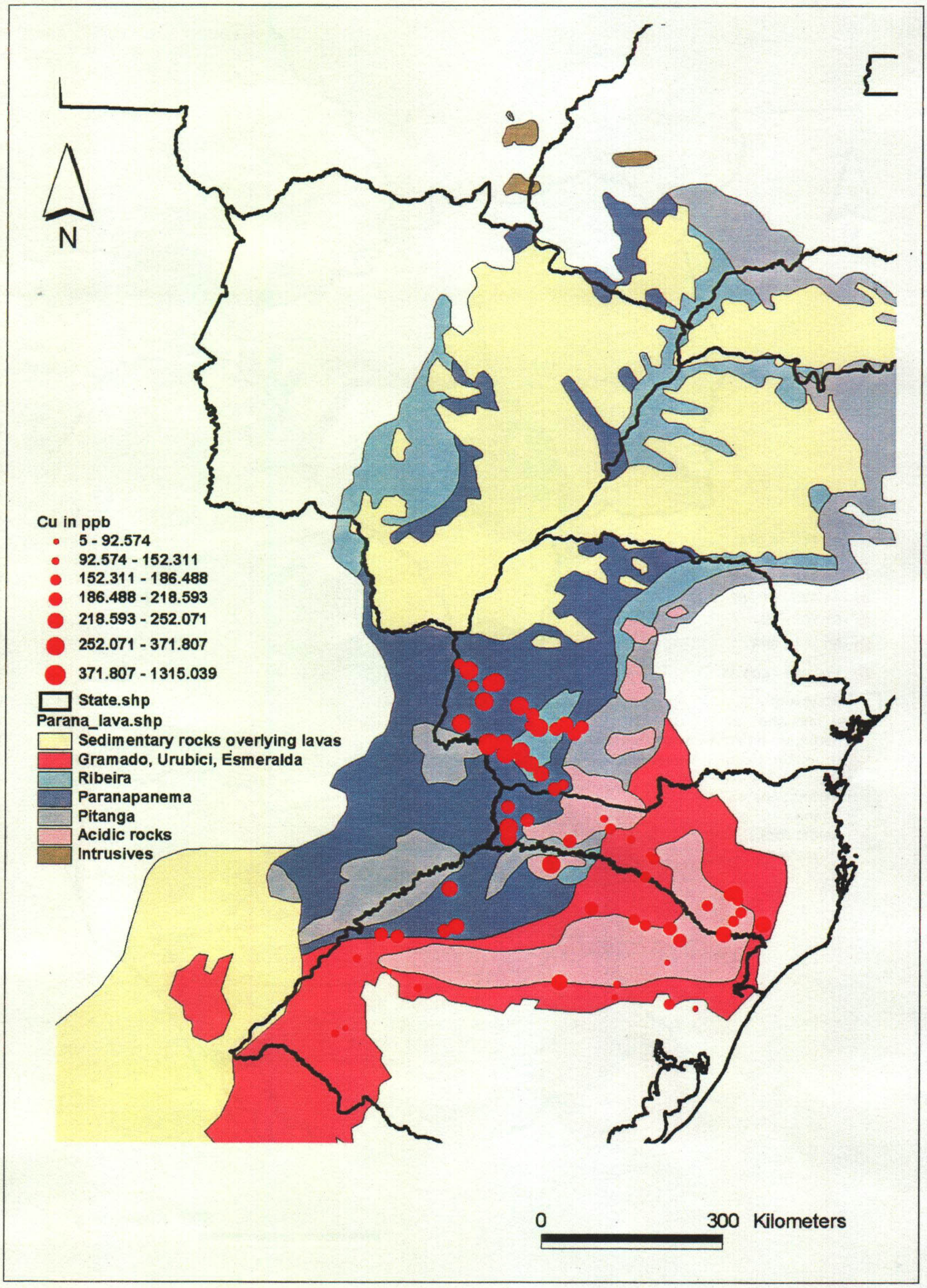


Fig. II-3-5-4 Distribution map of Cu content in lavas

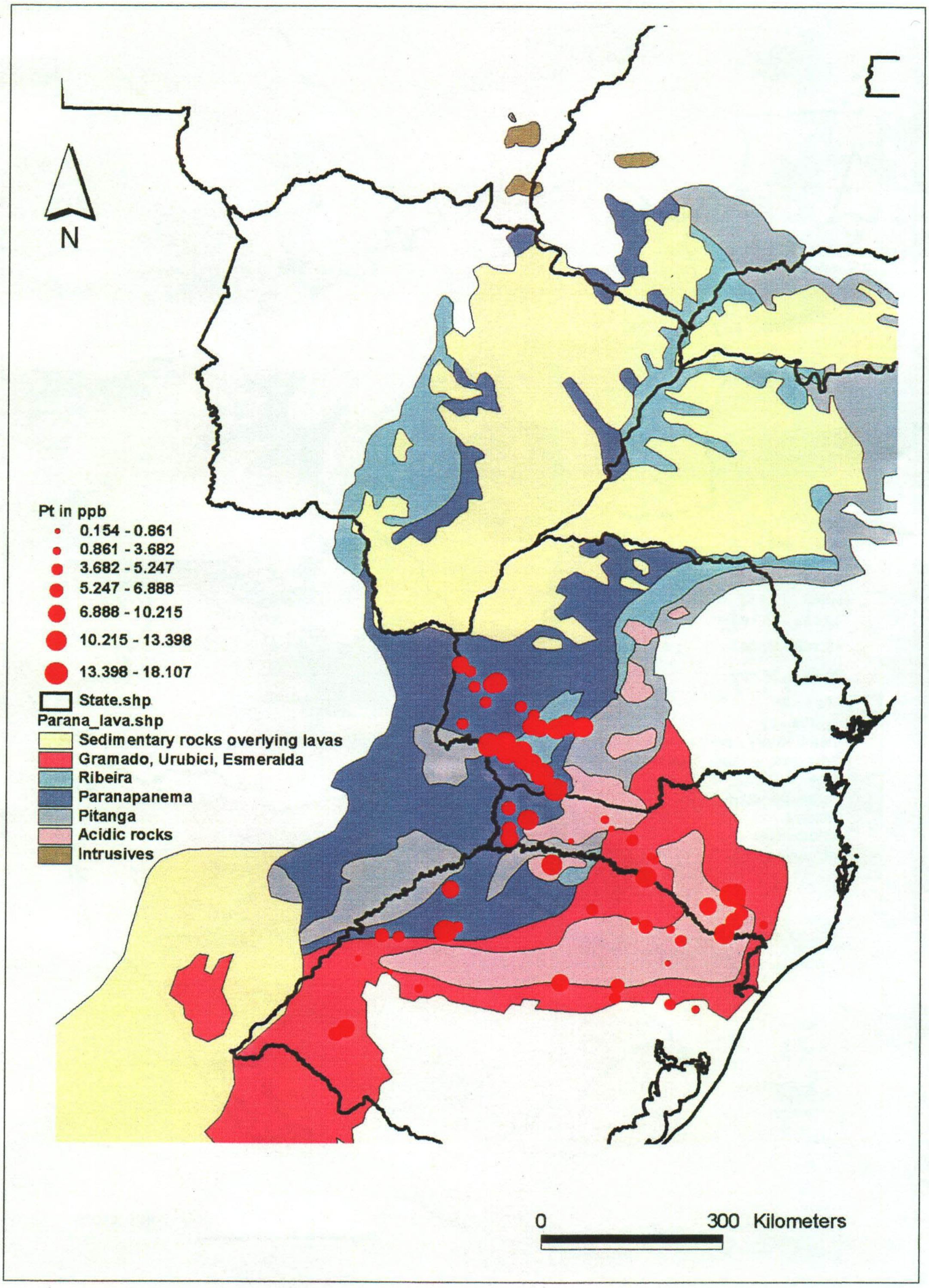


Fig. II-3-5-5 Distribution map of Pt content in lavas

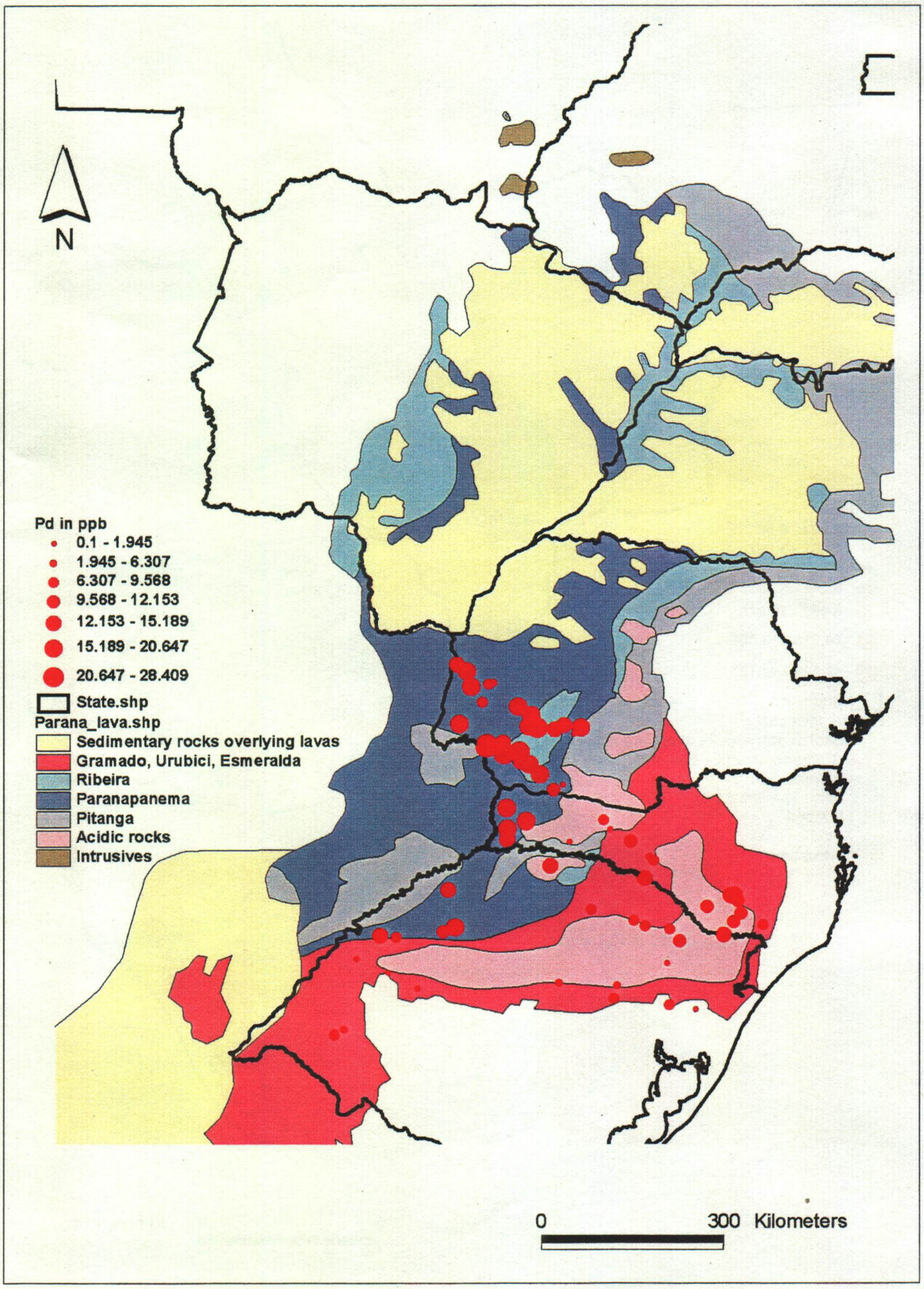


Fig. II-3-5-6 Distribution map of Pd content in lavas