

## **Geochemical survey of the Sanage-yama area in Aichi Prefecture for environmental assessment**

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### **ABSTRACT**

Stream sediments in the Sanage-yama area, Aichi Prefecture were examined for the environmental assessment of the area. A total of 128 samples were analyzed for sixteen elements including Al, Ca, Ce, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Ti and V with ICP atomic emission spectrometry and atomic absorption spectrometry. Areal distributions and cumulative frequency distributions of the elements were discussed in view of sources for the elements. Samples from the area where granitic rocks are exposed are rich in Al, Ca, Na and Sr. On the contrary, Co, Cr, Fe, Ni and V are enriched in samples from the area underlain by Tertiary sediments. The distributions of these nine elements are considered to be closely related to the exposed rocks. Concentrations of Cu, Fe, Mn, Ni, and P are high in samples from some places without any correlation to the geology. Natural backgrounds of the elements seem to be overlaid with the elemental dispersion due to human activities. Drainages from human activities and many china-ware factories in and around Seto City are the main sources for some elements such as Cu and P. Correlation coefficients higher than 0.7 are observed between abundances of Ti-Ce, Fe-Mn, Ti-V, Ce-V, Ca-Sr, Na-Ca, Na-Al and Fe-V. The Ti-Ce correlation is found to have originated from sphene, a Ti-bearing mineral. The Fe-Mn-V correlation is considered to have come from iron oxides and Fe-Mn deposit in river bottoms. The correlation among Ca-Sr-Na may reflect compositional variations in a rock-forming mineral, plagioclase.

A clear distinction of a dispersed element by human activities in the natural background is the fundamentals for environmental assessment. The geochemical map is found to be a potentially important tool to clarify various sources of elements distributed in the geosphere.

### **INTRODUCTION**

The environment of a given area on the earth can be assessed from various data based on physics, chemistry, biology and geology. Maps showing areal

distributions of these data are useful for environmental assessments. For example, topographic maps provide geo-information standing on physics. Position, elevation and direction are the physical variables of geosphere. Similarly, geological and vegetation maps are the representatives of geo-information standing on geology and biology, respectively. Geochemical maps examined here provide fundamental geo-information in terms of chemistry.

The geochemical maps presented in the previous studies were examined mainly from an interest in resources, and thus the regional coverage of the geochemical map was not necessarily wide. In recent years, many geochemical maps which cover wider regions have been published for the purpose of environmental assessments. In these studies, many elements other than the elements as resources were examined. The environmental assessments by geochemical maps have been developed in Western Europe and North America. In England (Webb et al., 1978), Alaska (Weaver et al., 1983), Germany (Fauth et al., 1985), Finland (Kautsky and Bolviken, 1986) and Austria (Thalmann et al., 1988) the geochemical survey was already completed, and the geochemical maps which cover the whole country were published. Their geochemical maps have provided many fruitful aspects of chemical information of their countries and have contributed to the improvement of their environments (e.g. Webb et al., 1978). Shiikawa et al. (1984), Itoh et al. (1991) and Kamioka et al. (1991) reported pioneer geochemical surveys in Akita Prefecture and in the Northern Kanto area in Japan.

In the Sanage-yama area in northern central Aichi Prefecture, granitic and sedimentary rocks are exposed as natural sources of chemical elements. Human and industrial activities in and around Seto City are likely to be artificial sources of various elements. Therefore, the area is a good field to study how the conventional techniques are useful to identify the natural and artificial sources of elements. An international exposition is scheduled in this area in the year 2005. Large modification of the geosphere will be expected. It is important to have geochemical data before the modification as well as the environmental assessment after the development. We here present the results of the geochemical survey of the Sanage-yama area, Aichi Prefecture.

## **SAMPLES AND ANALYTICAL METHODS**

Geological features of the area are shown in Fig. 1. A hornblende-bearing biotite adamellite (Inagawa Granite) is exposed from the central to southeastern part of the area. Biotite adamellite (Naegi-Agematsu Granite) is exposed in the northern part of the area. Both granitic bodies were emplaced about 70 Ma ago and are classified as members of the Ryoke Granite. The western and southern parts are covered with the Pliocene Seto Group and the Miocene Mizunami Group. Many porcelain-clay quarries are present in the areas corresponding to the former group. There are many china-ware factories in and around Seto City, with population of 130,000; a part of drainages is discharged into some rivers of the area.

Stream sediments, which were chosen as samples for our study of geochemical mapping, reflect the chemical composition of surface materials exposed at their upstream area. The samples were collected at the exits of drainage basins over the area. Fine sediments were sieved with stream water at each sampling site using an 80 mesh ( $180\mu\text{m}$ ) sieve. After sampling, they were dried at room temperature. One-hundred and twenty-eight samples were collected in April 1994 from an about  $150\text{km}^2$  area shown in Fig. 2.

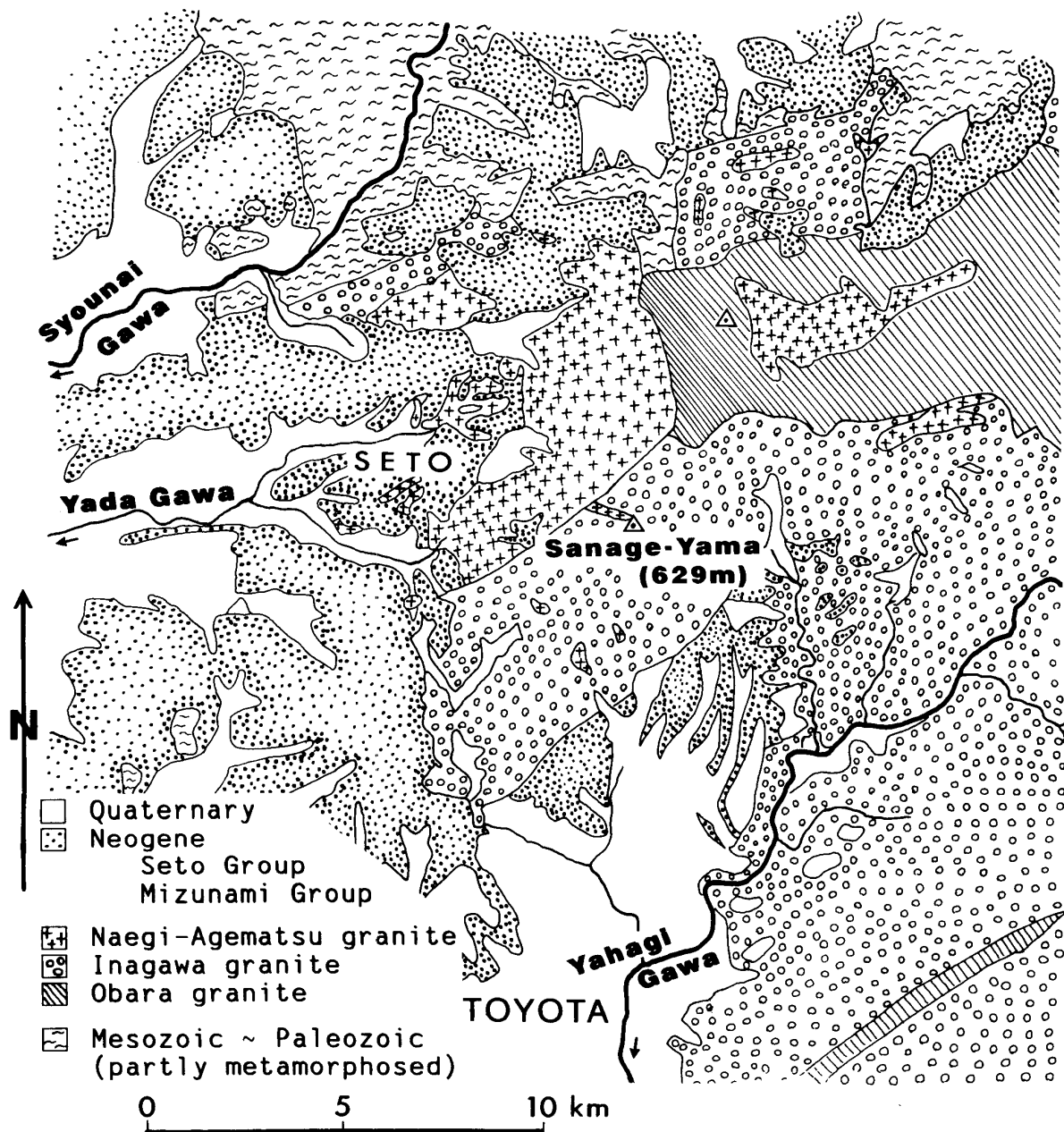


Fig. 1. Geological map of the studied area. The map is modified from 1/200000 Geological Map "Toyohashi" (Yamada et al., 1987).

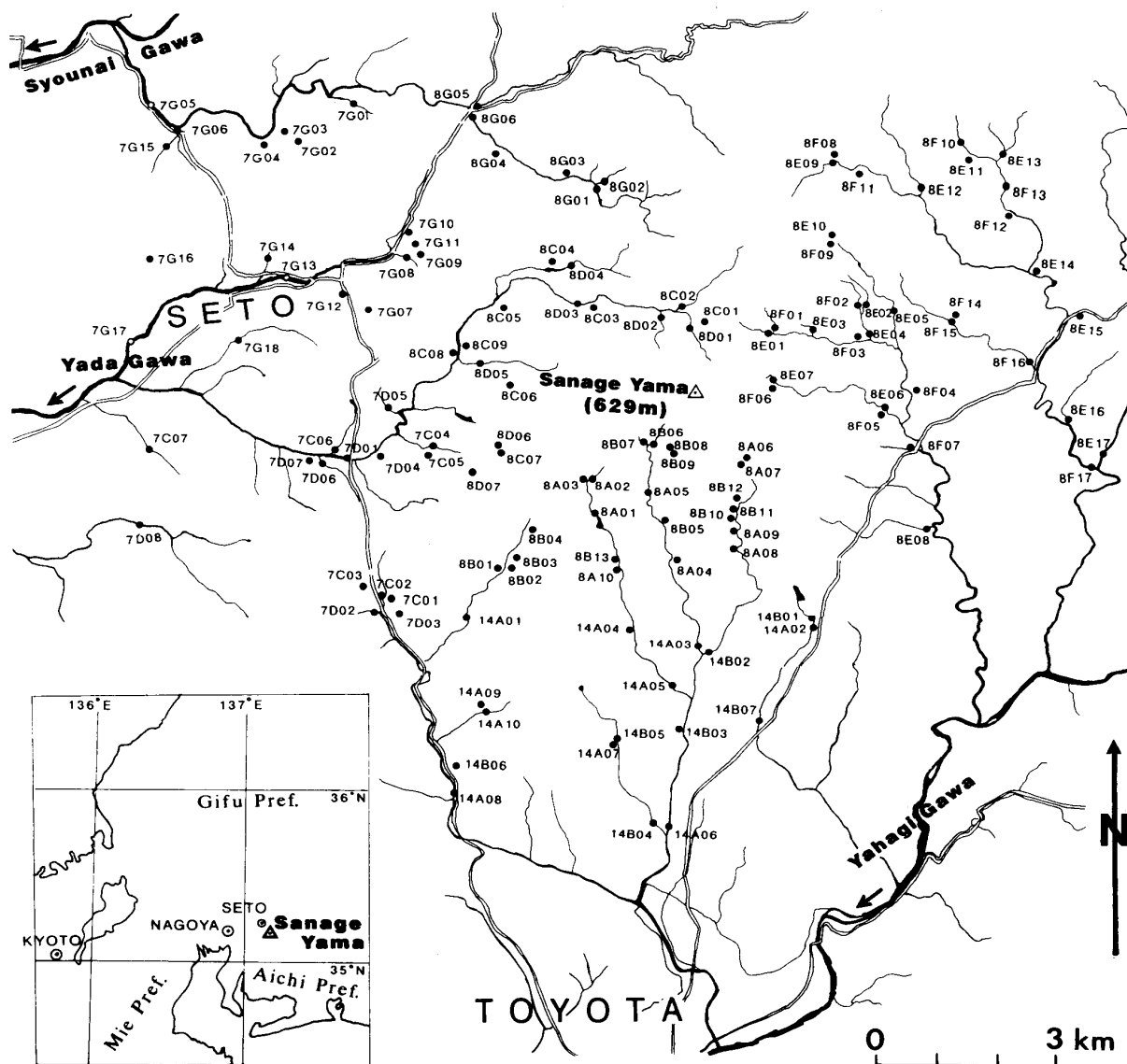


Fig. 2. Sampling localities. Under 80 mesh ( $180\ \mu\text{m}$ ) sediments were collected at every exits of drainage basins.

About 500mg of each sample is weighed in a teflon beaker. Concentrated nitric acid (4ml), perchloric acid (3ml) and hydrofluoric acid (10ml) are added on the sample powder for decomposition. The sample is stirred occasionally and evaporated to dryness on a hot plate. The residue is dissolved in 5ml of ca. 2N HCl and diluted to 50ml with 0.6N HCl.

Al, Ti, P, Ni, Ce, Cu, Co, V, Sr and Cr are analyzed by ICP atomic emission spectrometer (SEIKO SPS-1500R). Na, K, Mg, Ca, Mn and Fe are analyzed by atomic absorption spectrometer (HITACHI 180-30). Two aliquots of JG-1a (one of the rock reference samples issued from the Geological Survey of Japan) are analyzed simultaneously to check the accuracy of the analytical methods.

## RESULTS AND DISCUSSION

Analytical results are shown in Appendix A. The results of JG-1a are also shown in Appendix A with 1988 values for GSJ rock reference samples by Ando et al. (1989). These both values agree within  $\pm 30\%$  for most of the elements examined in this study. Although our values for Ce and V are lower than the 1988 values by 26 and 38%, respectively, the following discussion will not be altered by such differences. Areal distribution of Al, Ca, Ce, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Sr, Ti and V and the cumulative frequency distributions of their contents are shown in Appendix B, C, D, E, F, G, H, I, J, K, L, M, N, O, P and Q, respectively. Detailed descriptions for each element are as follows:

### *Aluminum (Appendix B)*

Most of Al contents determined in this study range from 1.6 to 8.8% (wt). The smaller values are observed in the western and southern areas where Tertiary sediments are exposed. Plagioclase, K-feldspar, muscovite and biotite are the possible major minerals loading Al. The cumulative frequency distribution of Al in Appendix B, however, shows a straight pattern. The straight pattern suggests that the observed element distribution in the area may be the result of an abundance variation of a single host phase.

### *Calcium (Appendix C)*

The abundance values of Ca range from 0.1 to 3.4% (wt). The cumulative frequency distribution of Ca can be separated into three parts; i.e. less than 0.2%, 0.2 to 2.2% and more than 2.2%. Higher values are observed in the area where granitic rocks are distributed, whereas lower values are distributed in the area of Tertiary sediments. A similar correlation between Ca abundance and the type of exposed rocks is observed in the Northern Kanto area (Itoh et al., 1991).

### *Cerium (Appendix D)*

The abundance values of Ce range from 15 to 360ppm. The cumulative frequency distribution of Ce consists of three segments. The first segment covers from 15 to 25ppm. The samples which form first segment are distributed over the area of Tertiary sediments. The second segment covers from 25 to 60ppm. This corresponds to the Ce abundance in the area of granitic rocks. These two abundance ranges and the correspondence to the exposed rock agree well with those of the Northern Kanto area by Itoh et al. (1991). The third segment covers more than 60ppm. The segment shows slope different from the former two segments. The different slope indicates a different controlling factor for Ce distribution from the other two segments. The details will be discussed in the later section.

*Cobalt (Appendix E)*

The abundance values of Co range from 1 to 78ppm. The median value 3ppm is somewhat lower than that (15ppm) of the Northern Kanto area by Itoh et al. (1991). Much more higher Co values are distributed in the area of the Tertiary sediments. It seems that the human activities other than the natural background are responsible for the Co abundance.

*Chromium (Appendix F)*

The abundance values of Cr range from 1 to 130ppm. The median value is 9ppm. The value is apparently lower than that of the Northern Kanto area (49.8ppm; Itoh et al., 1991). Itoh et al. (1989) suggested that Cr-spinel may not be decomposed completely by HF-HClO<sub>4</sub>-HNO<sub>3</sub> decomposition in an open beaker. Neutron activation analysis (NAA) can analyze the whole samples without decomposition. All the data of the Northern Kanto area are normalized to the value of NAA (Itoh et al., 1989). Although our data for JG-1a agree well with 1988 value by Ando et al. (1989), some Cr-spinel in our samples of the stream sediments might not be completely decomposed.

*Copper (Appendix G)*

The abundance values of Cu range from 1 to 130ppm. The median value is 9ppm. Large Cu abundances are seen in the area of Tertiary sediments. The large Cu abundances in the Northern Kanto area are observed only around mineralization area the Hitachi and Takatori mines and around Mito City. The values higher than 60ppm in this area indicate the presence of an additional source. In the Sanage-yama area, however, no Cu mineralization has been reported. The large Cu abundance in this area might be a result of human activities.

*Iron (Appendix H)*

The abundance values of iron range from 0.2 to 6.7% (wt). The median of the values is 1.2%. The cumulative frequency distribution of Fe consists of two segments (0.2%~1.5% and 1.5%~3.0%) and three data points. Three data with large Fe abundance can not be distinguished geologically from the other data. Mn abundance in these three samples are also large (see Appendix K). Geochemical coincidence between Fe and Mn might be a result of co-precipitation by oxidation similar to Fe·Mn-nodule formations in the bottom of deep sea.

*Potassium (Appendix I)*

The abundance values of K range from 0.7 to 4.4% (wt). A smooth rounded curve of cumulative frequency distribution pattern shows the continuous variation of several host phases of potassium.

*Magnesium (Appendix J)*

The abundance values range from 0.03 to 0.64% (wt) and the median value

is 0.17%. These values are apparently lower than the median value of 1.04% of the Northern Kanto area (Itoh et al., 1991). Many mafic igneous rocks and andesitic tuffs are likely to be the reason for higher Mg abundance in the Northern Kanto area than in the Sanage-yama area.

#### *Manganese (Appendix K)*

The abundance values of Mn range from 0.01 to 0.34% (wt) and the median value is 0.045%. No clear difference is observed in the abundance between the areas of granitic rocks and Tertiary sediments. Five higher extremes are observed, and the abundance values are correlated with those of Fe. Details on the correlation will be discussed in the later section.

#### *Sodium (Appendix L)*

The abundance values of Na range from 0.1 to 4.1% (wt) and the median value is 2.0%. The cumulative frequency distribution of Na abundances consists of two distinctive lines, showing that two different factors of Na distribution exist. As shown in Appendix L, Na abundances are high in the area of the granitic rocks, and low in the area of the Tertiary sediments.

#### *Nickel (Appendix M)*

The abundance values of Ni range from 0.5 to 150ppm and the median value is 3ppm. The value is far smaller than that of the Northern Kanto area (22.7ppm). It may be caused by absence of mafic rocks in the Sanage-yama area. The cumulative frequency distribution of Ni abundance can be divided into two parts, 0.5 to 2ppm and more than 2ppm. The samples which show lower Ni abundances are found over the area of granitic rocks. The higher values are distributed over the area of sedimentary rocks. Two data points show extremely high Ni abundance in the area. However, these two values (48.4ppm and 147.8ppm) are not unusual ones compared with data of the area where mafic rocks are distributed (Itoh et al., 1991).

#### *Phosphorus (Appendix N)*

The abundance values of P range from 0.01 to 0.32% (wt) and the median value is 0.02%. The values are high in the area of the Tertiary sediments and low in the area of the granitic rocks. Kamioka et al. (1991) found the high phosphorus abundance in the eastern part of Tochigi Prefecture, and pointed out the possibility of an environmental pollution from phosphatic manure. In the Sanage-Yama area, the high abundance of phosphorus does not seem to be related with the agricultural field.

#### *Strontium (Appendix O)*

The abundance values of Sr range from 21 to 146ppm. Higher values are observed in the area of granitic rocks, especially in the area of Inagawa granite, and lower values are seen in the area of Tertiary sedimentary rocks. The cumulative frequency distribution of Sr abundance shows a monotonous line,

suggesting that the unique component, probably plagioclase, controls the whole distribution.

#### *Titanium (Appendix P)*

The abundance values of Ti range from 0.03 to 4.5% (wt), with the median value of 0.12%. The data can be classified into two groups according to the cumulative frequency distribution pattern; i.e. less than 0.5% and more than 0.5%. The correlation between Ti and Ce will be discussed later.

#### *Vanadium (Appendix Q)*

The abundance of V ranges from 5 to 123ppm. The higher values are observed in the area of the Tertiary sediments, and lower values are seen in the area of the granitic rocks. V abundances are strongly correlated with Fe abundances in the Northern Kanto area and the combination of these elements indicates that magnetite (+ilmenite) controls the elements (Itoh et al., 1991). In the Sanage-yama area, however, the V abundance (median = 18ppm) which correlates strongly with Ti is lower than that of the Northern Kanto area (median = 130ppm). This suggests that ilmenite may be the major phase that controls the Ti and Fe abundances in the Sanage-yama area.

#### *Correlations among elemental abundances*

The correlation coefficients among elements analyzed in the present study are listed in Table 1. Ti-Ce, Fe-Mn, Ti-V, Ce-V, Ca-Sr, Na-Ca, Na-Al and Fe-V show strong correlation coefficients higher than 0.7. The strongest correlation 0.920 is found between Ce and Ti. The strong correlation, however, comes "mathematically" from seven Ti-enriched samples in Fig. 3. The other many points are clustering in the proximity of the origin of diagram. A resemblance between the elemental distribution maps in Appendix D (Ce) and O (Ti) is

Table 1. Correlation coefficients among the elemental analyses.

Na																			
0.102	K																		
0.001	-0.171	Mg																	
0.734	-0.161	0.498	Ca																
0.712	0.220	0.221	0.616	Al															
-0.110	-0.170	0.411	0.036	0.193	Fe														
-0.015	-0.097	0.217	0.024	0.232	0.868	Mn													
-0.324	-0.167	-0.053	-0.254	-0.257	0.541	0.503	Ti												
-0.303	-0.185	0.381	-0.090	-0.008	0.280	0.125	0.022	P											
-0.208	-0.178	-0.022	-0.163	-0.090	0.610	0.618	0.920	0.072	Ce										
-0.294	-0.065	0.330	-0.216	-0.055	0.563	0.502	0.204	0.319	0.223	Co									
-0.566	-0.192	0.417	-0.333	-0.362	0.200	0.082	0.217	0.307	0.159	0.333	Cr								
-0.473	-0.148	0.337	-0.289	-0.218	0.209	0.038	0.073	0.617	0.092	0.377	0.552	Cu							
-0.361	-0.121	0.377	-0.211	-0.153	0.100	-0.005	0.047	0.474	0.035	0.343	0.594	0.648	Ni						
0.604	-0.160	0.392	0.743	0.569	0.067	0.064	-0.206	-0.053	-0.118	-0.138	-0.219	-0.127	-0.135	Sr					
-0.432	-0.241	0.373	-0.162	-0.221	0.705	0.542	0.829	0.329	0.752	0.452	0.403	0.344	0.235	-0.065	V				



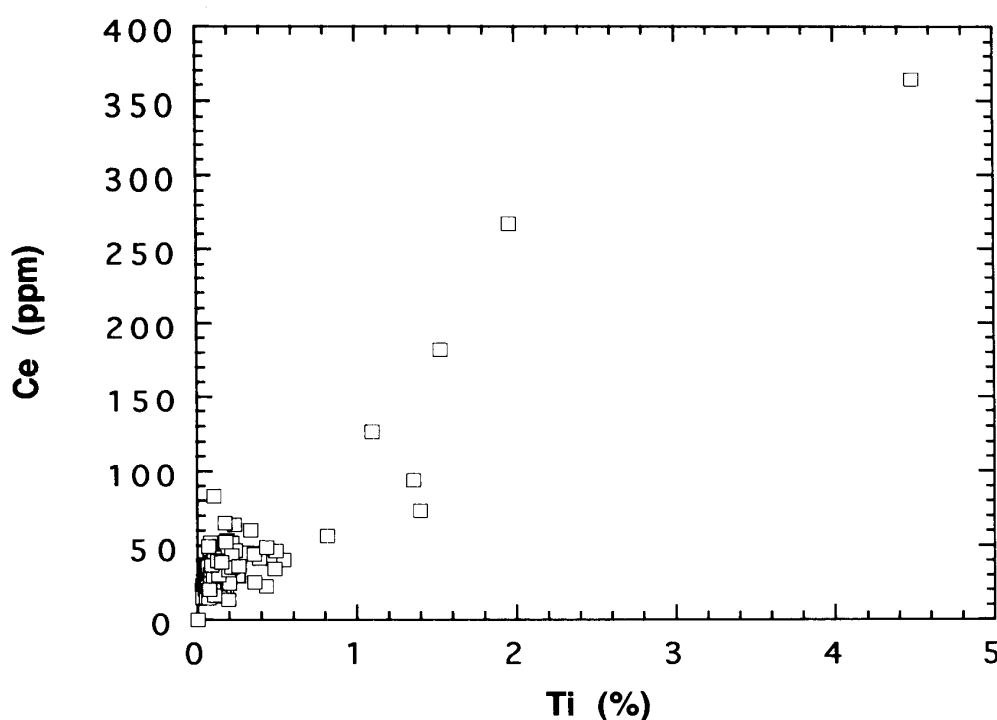


Fig. 3. A correlation diagram between Ti and Ce analyses. Although the correlation coefficient 0.920 is apparently high, the coefficient is found to have been derived from only seven Ti-Ce rich points. Points other than the 7 points do not show any close correlation.

visually emphasized by the presence of seven points.

It is important to judge whether these high Ce-Ti abundances are originated from natural background or affected by human activities. If the former is the case, the chondrite-normalized REE pattern of the sediments must be a smooth pattern. If the latter is the case, the REE pattern of the sediments is expected to be enriched only with Ce due to the industrial demand. Chondrite-normalized REE patterns for two extreme samples are shown in Fig. 4. Since the patterns appear to be the natural ones, it can be regarded that high Ti and Ce abundances have been affected by REE-rich sphene from the Naegi-Agematsu granite.

The elemental abundances Fe and Mn show a simple correlation with  $Mn/Fe = 0.05$  (Fig. 5), which agrees well with those of Japanese typical felsic igneous rocks. This suggests that the stream sediments just keep the values of igneous rocks without fractionation between Fe and Mn. From this point of view, the two relatively Mn-rich samples in the Fe-Mn diagram in Fig. 5 may indicate some uncommon environments.

Ti and V also show a high correlation coefficient 0.829. The correlation pattern in Fig. 6 forms two correlation arrays A and B. A shows  $V = 0.023 \cdot Ti$  and B shows  $V = 0.0028 \cdot Ti$ . Each of the correlation arrays A and B may correspond to a line controlled by a specific mineral.

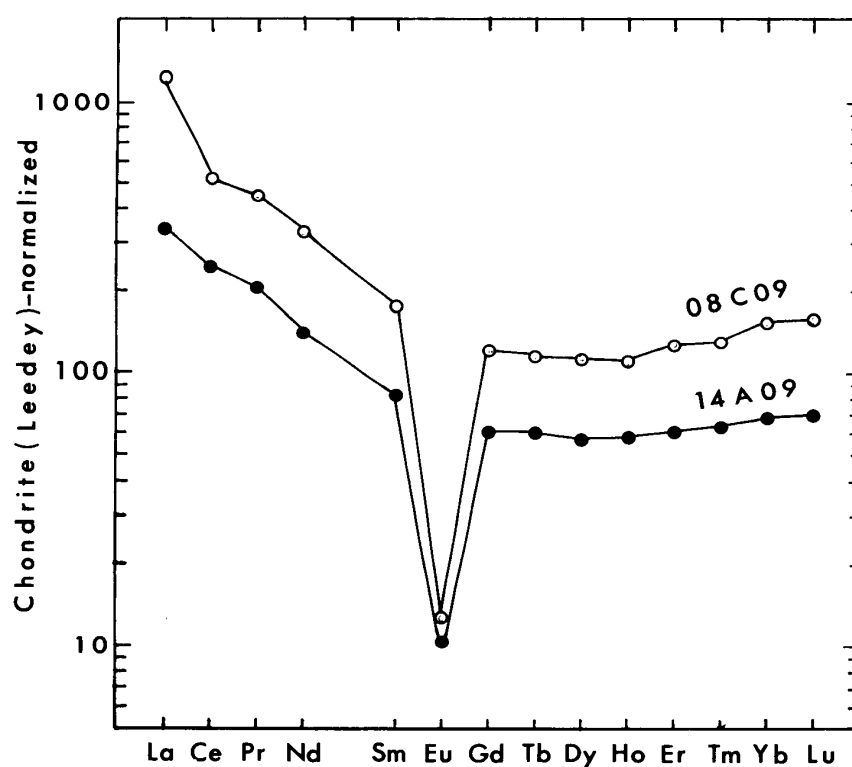


Fig. 4. Chondrite-normalized REE pattern of Ce- and Ti-rich samples. The abundance patterns are smooth, and specific element that is expected for industrial demand is not concentrated.

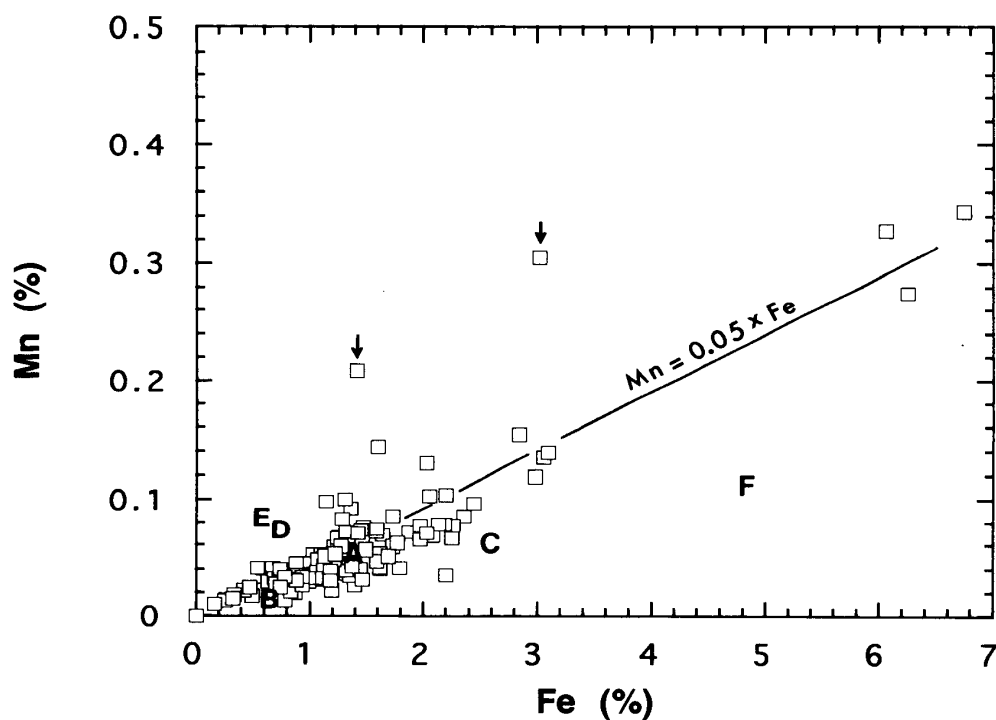


Fig. 5. A correlation diagram between Fe and Mn analyses. Letters A, B, C, D, E and F show the points for GSJ rock reference samples JG-1, JG-2, JG-3, JR-1, JR-2 and JA-1, respectively (Ando et al., 1989). Data indicated by arrows deviate from the correlation (see text).

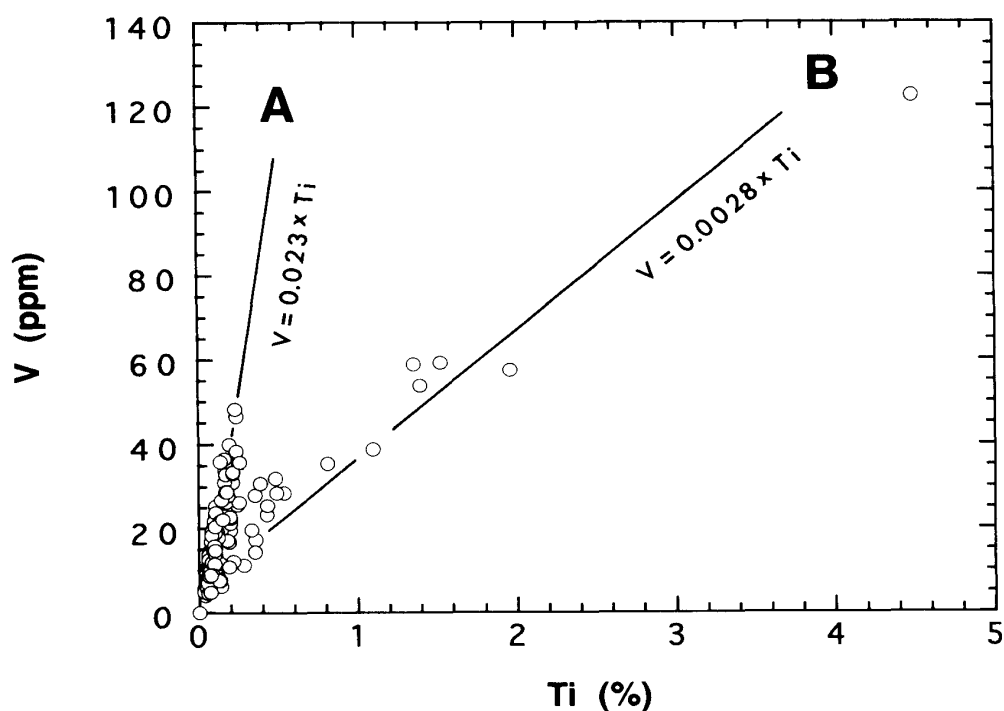


Fig. 6. A correlation diagram between Ti and V analyses. Two correlation arrays A and B are recognized.

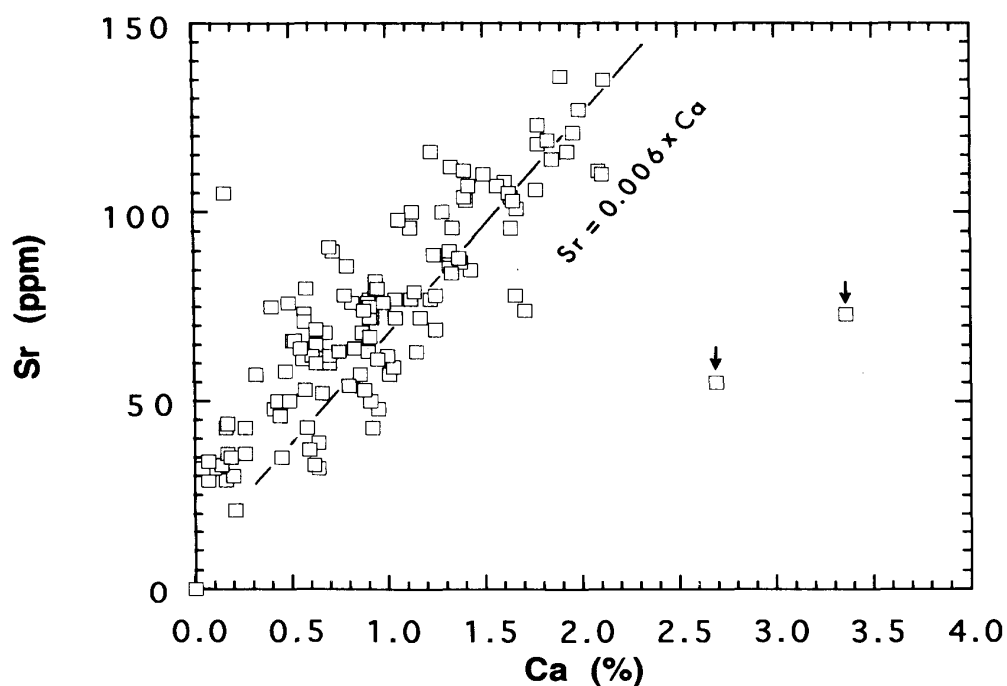


Fig. 7. A correlation diagram between Ca and Sr analyses. The correlation  $Sr = 0.006 \cdot Ca$  shows that it is formed by plagioclase. Two points with arrows deviated from the correlation seem to have suffered from some artificial addition of Ca (see text).

Ca and Sr show a sharp correlation, that is  $Sr = 0.006Ca$  (Fig. 7). The average abundances of Ca and Sr in plagioclase are 15% and 1000ppm, respectively (Philpotts and Schnetzlar, 1970). The Sr/Ca ratio is 0.006, which agrees well with the above correlation factor. Therefore, the correlation in Fig.3 is thought to be controlled by the amount of plagioclase. Two points that deviate largely from the correlation might have been affected by some other sources.

### SUMMARY

We have started the geochemical survey of the Sanage-yama area for the environmental assessment, and 128 stream sediments were examined. Although the number of samples is not so large, the samples reflect well the geochemical environments of the area. Chemical elements examined in this study are classified into two groups; i.e. the elements derived mainly from the exposed rocks of the area and the ones overlaid with the elemental dispersion resulting from human activities. Al, Ca, Na and Sr are rich in the area where granitic rocks are exposed. On the contrary, Co, Cr, Fe, Ni and V are found more abundant in the area where Tertiary sediments are exposed. These nine elements are considered to be derived from the natural background. Some data for Cu, Fe, Mn, Ni and P are extremely higher than the rest of the data. Natural abundance of the elements seems to be overlaid with the elemental dispersion owing to human activities.

A very strong correlation between Ce and Ti is observed. Although Ce pollution from pottery factories was considered at first, the correlation seems to have been made by nature. Chondrite-normalized REE patterns of the high Ce sediments are not artificial but are natural REE patterns. The Naegi-Agematsu Granite is rich in accessory minerals like sphene which concentrates the rare earth elements and Ti. The area of the high Ce concentration is located just on sides of the granite body.

For more precise assessment of geochemical environments, multi-element correlations will provide strong constraint to evaluate the sources for elements. The geochemical behaviors of chalcophile elements such as Cd, Hg, Ga, Ge, Pb, As and Sb are also important for the environmental assessment. More elements for more numbers of samples will be examined to clarify the geochemical environment of Aichi Prefecture and its adjacent regions in the future.

### ACKNOWLEDGMENT

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Appendix A. Analytical result of the stream sediments from the Sanage-yama area and JG-1a Geological Survey of Japan Rock Reference Sample.

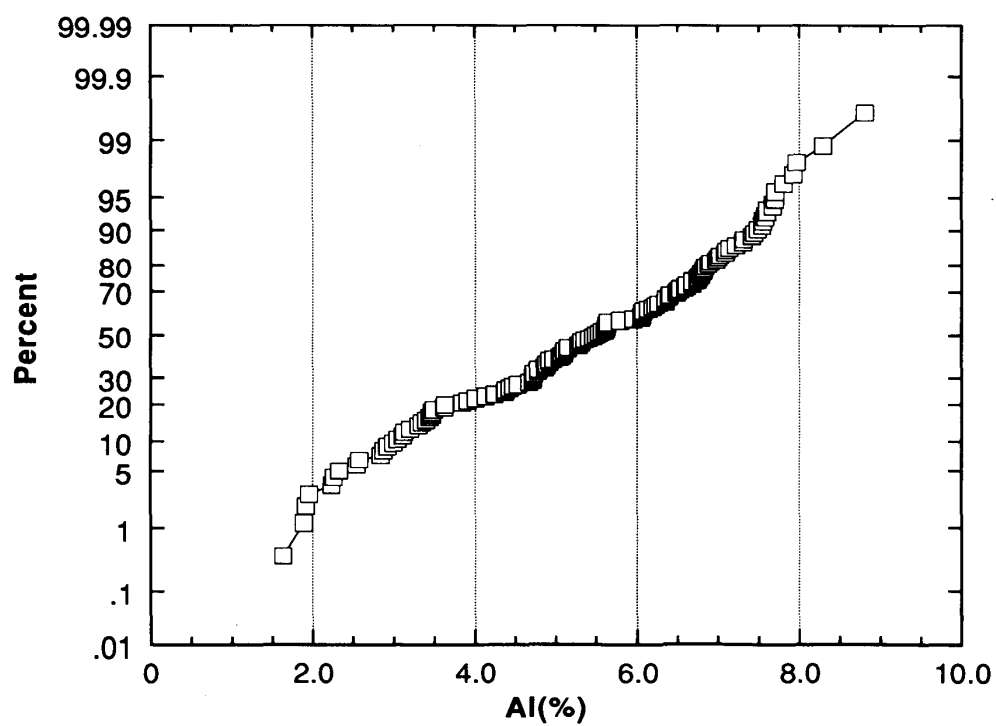
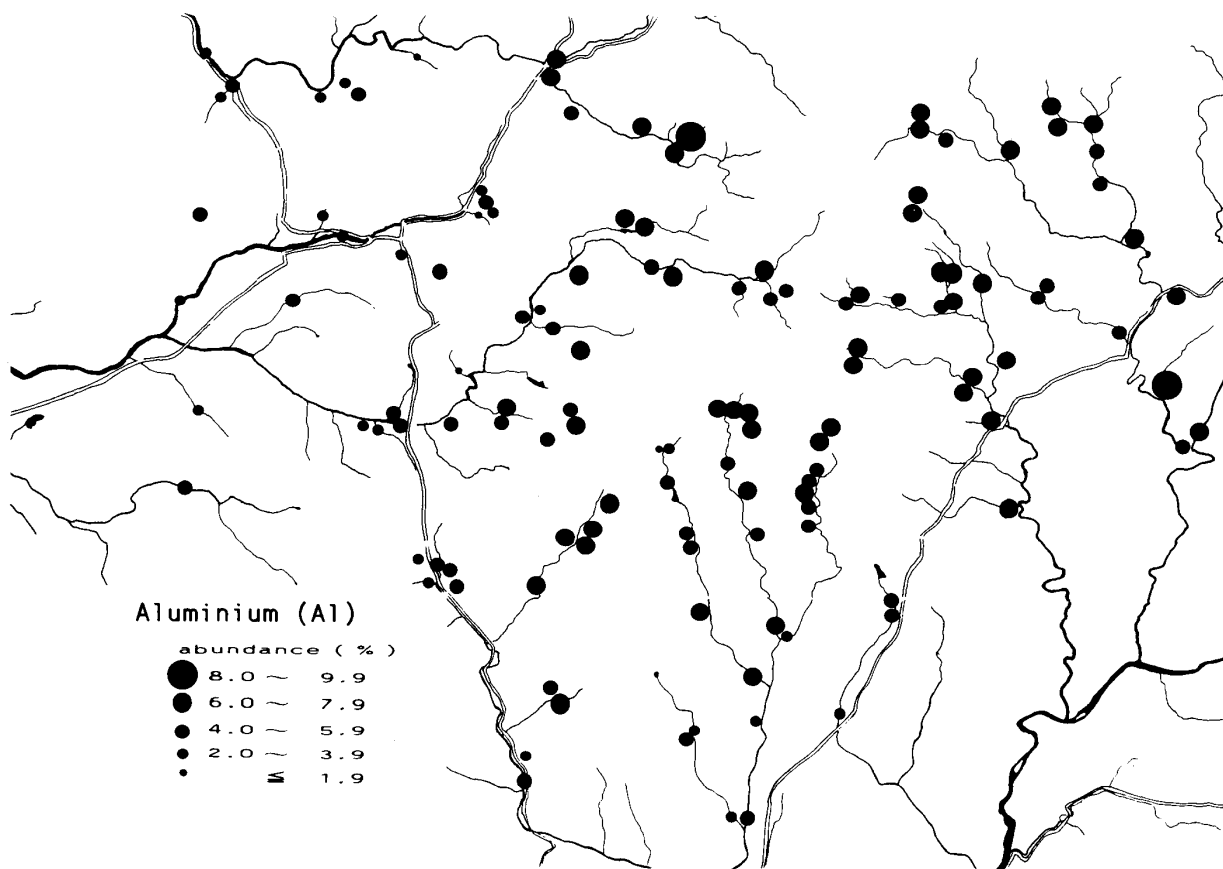
Sample	Weight (g)	Na (%)	K (%)	Mg (%)	Ca (%)	Al (%)	Fe (%)	Mn (%)	Ti (%)	P (%)	Ce(ppm)	Co(ppm)	Cr(ppm)	Cu(ppm)	Ni(ppm)	Sr(ppm)	V(ppm)
07C01	0.5042	1.16	1.80	0.20	0.79	4.92	1.35	0.034	0.200	0.047	29.8	3.3	12.8	12.3	5.1	86	19.5
07C02	0.5162	0.94	1.89	0.19	0.57	4.37	1.32	0.039	0.245	0.071	32.8	5.5	35.8	32.7	10.2	73	25.7
07C03	0.5172	0.15	1.16	0.14	0.07	3.34	2.44	0.097	1.357	0.020	93.9	10.4	69.2	14.0	10.6	29	58.9
07C04	0.5056	1.72	1.91	0.16	0.90	6.07	1.12	0.049	0.190	0.013	38.5	2.5	6.5	3.4	2.3	76	16.8
07C05	0.5098	1.49	1.46	0.35	1.12	5.11	2.84	0.154	1.395	0.015	73.5	4.8	32.8	5.2	3.1	77	53.8
07C06	0.5067	0.85	1.68	0.22	0.56	4.13	1.82	0.040	0.387	0.099	41.3	6.4	33.9	59.4	12.5	61	30.8
07C07	0.5021	0.99	2.25	0.29	0.51	3.20	1.13	0.040	0.174	0.022	25.9	4.6	35.3	28.8	12.8	66	26.3
07D01	0.4815	2.28	2.04	0.10	0.91	5.08	0.78	0.031	0.219	0.013	32.3	1.8	4.1	3.0	1.6	72	12.1
07D02	0.5031	0.35	1.50	0.10	0.16	2.57	1.73	0.059	1.098	0.013	126.5	6.1	27.3	20.9	13.1	43	38.8
07D03	0.5463	2.00	2.10	0.25	1.40	5.63	1.77	0.062	0.490	0.016	46.4	3.2	7.3	4.4	3.5	104	28.6
07D04	0.5399	1.61	2.31	0.18	0.63	4.93	1.19	0.022	0.144	0.027	20.5	4.3	24.2	12.3	11.2	65	19.9
07D05	0.4697	0.54	1.33	0.09	0.10	1.96	0.56	0.022	0.180	0.011	19.6	2.0	23.2	8.3	5.5	32	17.2
07D06	0.5402	0.71	1.80	0.34	0.44	2.99	0.95	0.034	0.256	0.037	29.6	4.0	38.5	19.2	13.1	46	26.3
07D07	0.5605	0.89	1.75	0.16	0.26	3.05	0.78	0.013	0.163	0.029	18.8	9.4	24.1	33.2	12.6	43	31.1
07D08	0.5321		1.96	0.08	1.01	5.05	0.49	0.017	0.031	0.007	14.8	7.2	1.5	1.1	0.4	57	4.9
07G01	0.4963	0.40	1.80	0.09	0.20	1.88	0.42	0.022	0.484	0.020	34.5	1.6	20.7	16.0	17.9	30	32.0
07G02	0.5242	0.38	1.40	0.11	0.14	2.23	1.13	0.051	0.103	0.011	15.8	1.1	12.4	17.5	5.4	33	13.9
07G03	0.5007	1.14	2.09	0.16	0.17	3.47	1.18	0.039	0.251	0.045	29.7	1.8	25.6	47.1	16.9	36	36.0
07G04	0.5220	0.63	1.61	0.24	0.47	2.33	0.88	0.030	0.200	0.018	30.0	6.4	25.4	28.2	10.0	58	21.2
07G05	0.5686	0.74	1.77	0.13	0.26	3.11	0.78	0.033	0.200	0.027	24.6	9.7	15.5	15.5	7.7	36	22.4
07G06	0.5234	0.82	1.81	0.37	0.63	4.89	1.61	0.053	0.238	0.086	46.8	11.4	40.3	61.3	19.0	69	38.4
07G07	0.5145	0.21	3.50	0.03	0.04	5.32	0.25	0.013	0.099	0.009	20.1	5.8	7.5	5.6	3.4	32	11.5
07G08	0.5183	0.32	1.62	0.10	0.21	1.63	0.47	0.024	0.190	0.010	13.3	3.2	24.6	9.7	5.3	21	10.9
07G09	0.5016	1.12	2.07	0.10	0.40	3.84	1.59	0.047	0.433	0.062	48.6	10.5	32.6	90.6	14.4	75	25.6
07G10	0.5098	0.74	2.67	0.07	0.32	3.40	0.33	0.018	0.133	0.011	30.3	6.8	23.3	8.3	2.7	57	7.6
07G11	0.4892	0.88	1.89	0.18	0.52	4.24	3.09	0.139	1.524	0.031	181.8	5.2	20.2	56.9	6.7	66	59.3
07G12	0.4992	0.99	1.61	0.26	0.70	3.47	1.18	0.030	0.195	0.034	33.7	10.2	41.3	128.0	13.3	91	22.8
07G13	0.5019	0.53	2.46	0.03	0.07	2.26	0.16	0.010	0.071	0.007	14.5	6.2	9.5	3.6	2.0	34	4.8
07G14	0.4952	0.31	2.14	0.16	0.19	3.44	0.32	0.015	0.103	0.015	16.4	3.5	16.3	9.7	5.9	35	14.8
07G15	0.4954	0.91	1.72	0.29	0.88	3.91	1.49	0.056	0.170	0.045	39.0	8.8	36.8	39.7	12.7	74	28.8
07G16	0.5007	0.77	2.27	0.25	0.58	5.29	1.42	0.070	0.214	0.129	43.3	1.2	33.1	42.9	15.9	80	33.2
07G17	0.4954	0.60	2.47	0.09	0.17	3.30	0.74	0.024	0.332	0.028	60.2	8.9	18.9	23.9	7.0	44	19.6
07G18	0.4988	0.58	1.74	0.50	0.55	5.32	1.46	0.031	0.216	0.198	35.5	5.1	57.0	125.8	147.8	64	33.4
08A01	0.5428	2.70	2.38	0.14	0.92	4.88	0.66	0.033	0.042	0.009	16.1	1.0	1.7	2.3	0.6	72	6.7
08A02	0.5489	1.93	1.63	0.04	0.63	3.63	0.51	0.022	0.052	0.009	19.2	0.7	3.5	1.9	0.6	63	5.6
08A03	0.5364	1.07	0.87	0.03	0.49	1.92	0.28	0.014	0.113	0.011	24.8	1.1	2.2	2.7	0.6	78	8.8
08A04	0.5383	3.35	1.58	0.18	1.61	5.61	1.06	0.033	0.071	0.012	18.7	1.6	2.3	3.3	1.2	108	14.6
08A05	0.5377	4.07	2.55	0.14	1.22	4.73	0.78	0.031	0.058	0.009	15.5	1.4	1.7	1.6	0.6	77	11.3
08A06	0.5324	3.06	1.36	0.28	2.12	6.20	1.40	0.063	0.103	0.016	27.4	2.3	5.2	1.7	0.6	135	22.8
08A07	0.5309	2.90	1.40	0.32	1.99	6.06	1.64	0.069	0.107	0.019	24.0	2.9	3.7	2.0	1.1	127	25.4
08A08	0.5487	2.91	1.98	0.11	1.04	4.98	0.78	0.036	0.051	0.014	37.1	1.3	1.9	3.6	1.4	77	8.1
08A09	0.5230	2.88	2.15	0.24	1.13	5.47	1.35	0.052	0.186	0.013	53.6	2.4	2.6	40.3	0.7	100	19.9
08A10	0.5276	2.69	2.04	0.24	1.41	5.79	1.30	0.043	0.092	0.011	17.6	2.3	2.5	1.9	0.6	103	19.3
08B01	0.5004	2.95	2.13	0.30	1.78	7.21	1.47	0.076	0.095	0.019	23.7	2.4	3.9	3.5	1.0	118	21.7
08B02	0.5018	2.66	1.85	0.37	1.85	6.76	1.97	0.077	0.161	0.048	26.0	3.9	34.2	39.8	19.1	114	26.2
08B03	0.5018	2.94	1.85	0.34	1.93	6.68	1.58	0.071	0.108	0.014	20.0	2.8	3.8	2.7	1.7	116	23.8
08B04	0.5029	3.09	2.17	0.24	1.57	7.32	1.29	0.056	0.100	0.014	25.8	2.0	2.7	2.2	0.9	107	16.5
08B05	0.5011	3.21	1.91	0.23	1.78	7.58	1.21	0.058	0.080	0.017	24.5	2.1	2.9	2.3	2.1	123	15.9
08B06	0.5013	3.27	1.95	0.17	1.64	7.93	0.98	0.045	0.062	0.012	17.6	1.7	2.1	1.7	2.0	104	12.3
08B07	0.5013	3.32	1.79	0.08	1.25	7.00	0.59	0.040	0.032	0.010	20.6	0.9	1.7	1.7	6.8	78	5.5
08B08	0.5000	3.04	1.80	0.26	1.83	7.14	1.33	0.071	0.113	0.017	27.7	2.5	3.3	1.9	1.3	119	19.3
08B09	0.5005	3.59	3.02	0.25	1.90	7.97	1.25	0.067	0.081	0.017	30.3	2.4	3.5	1.7	1.0	136	17.7
08B10	0.5008	2.84	2.01	0.23	1.50	7.49	1.36	0.092	0.081	0.024	45.1	2.6	3.2	3.5	1.3	110	17.5
08B11	0.5012	2.96	1.77	0.14	1.32	5.53	0.96	0.030	0.064	0.013	17.8	1.8	5.7	2.1	1.0	86	11.6
08B12	0.5012	3.05	1.57	0.26	1.96	5.50	1.32	0.036	0.089	0.015	20.3	2.6	3.3	1.9	0.7	121	19.9
08B13	0.5008	2.82	2.00	0.19	1.24	4.71	1.32	0.042	0.086	0.015	20.1	2.7	1.9	3.3	1.1	89	16.0
08C01	0.5104	2.67	1.73	0.08	0.91	5.63	0.54	0.041	0.034	0.012	23.2	1.3	5.1	4.7	2.1	50	5.9
08C02	0.5062	2.52	2.29	0.21	1.17	6.08	1.07	0.048	0.075	0.012	28.8	2.0	2.7	1.9	0.9	72	13.5
08C03	0.5112	3.23	2.40	0.07	0.92	7.68	0.67	0.041	0.038	0.012	21.7	0.9	1.4	2.3	1.1	43	4.1
08C04	0.5051	2.92	2.75	0.17	1.14	7.60	1.61	0.041	0.109	0.017	28.1	2.6	2.5	1.9	1.8	79	12.8
08C05	0.5076	2.26	2.06	0.08	0.87	6.06	0.95	0.036	0.285	0.014	45.1	1.3	1.9	1.7	0.6	68	11.2
08C06	0.5070	1.26	2.32	0.22	0.57	7.10	1.79	0.041	0.213	0.030	51.6	5.2	16.8	13.4	6.5	71	31.1
08C07	0.5049	2.20	2.83	0.20	1.06	6.68	1.04	0.035	0.067	0.014	23.3	2.1	2.9	3.3	1.2	98	13.8
08C08	0.5064	1.67	2.05	0.10	0.70	4.78	0.87	0.038	0.353	0.018	44.0	2.6	11.6	7.4	2.2	60	14.4
08C09	0.5012	0.57	1.68	0.12	0.16	2.87	6.25	0.275	4.491	0.024	363.7	13.7	19.2	9.6	4.4	29	122.5
08D01	0.5575	3.04	1.95	0.10	1.04	5.12	0.69	0.029	0.049	0.012	21.4	1.3	1.9	1.9	1.1	72	5.8
08D02	0.5289	2.56	2.06	0.10	0.88	4.67	0.63	0.029	0.055	0.009	25.9	1.1	3.6	1.7	0.7	53	7.4
08D03	0.5290	2.64	2.12	0.11	1.03	5.64	0.69	0.032	0.056	0.010	37.5	1.1	2.1	1.7	0.7	59	7.5
08D04	0.5516	3.71	2.88	0.07	1.25	7.02	0.73	0.031	0.055	0.010	21.1	1.1	1.2	1.2	0.5	69	4.5
08D05	0.5174	1.94	2.79	0.09	0.57	5.41	1.31	0.100	0.131	0.018	20.6	1.7	10.4	3.9	1.8	53	11.6
08D06	0.5441	1.50	2.44	0.16	0.61	4.37	0.88	0.045	0.077	0.015	18.5	2.5	5.5	11.0	3.1	62	16.9
08D07	0.5463	1.84	2.85	0.17	0.94	5.28	0.88	0.035	0.088	0.010	15.7	1.8	2.3	1.8			

## Appendix A. continued.

Sample	Weight (g)	Na (%)	K (%)	Mg (%)	Ca (%)	Al (%)	Fe (%)	Mn (%)	Ti (%)	P (%)	Ce(ppm)	Co(ppm)	Cr(ppm)	Cu(ppm)	Ni(ppm)	Sr(ppm)	V(ppm)
08E01	0.4965	1.82	1.78	0.15	0.91	4.43	0.83	0.021	0.078	0.014	31.2	1.8	8.0	6.4	2.7	75	11.0
08E02	0.5001	3.01	1.54	0.15	1.43	7.09	1.10	0.037	0.068	0.017	31.4	2.2	2.5	10.1	1.5	85	8.7
08E03	0.5050	2.57	1.08	0.15	1.38	5.64	1.12	0.036	0.069	0.022	33.9	1.8	2.0	2.2	0.9	87	9.6
08E04	0.4922	3.04	2.14	0.16	1.32	6.98	1.06	0.038	0.071	0.019	36.7	3.4	4.2	7.2	2.5	89	11.1
08E05	0.5177	2.02	1.68	0.64	3.36	6.05	1.24	0.066	0.093	0.044	44.4	1.8	20.0	13.0	6.9	73	13.8
08E06	0.5042	2.75	1.55	0.21	1.67	6.59	1.12	0.043	0.063	0.017	34.0	4.4	2.7	8.1	1.4	101	13.7
08E07	0.5051	2.75	1.46	0.26	1.77	6.35	1.27	0.059	0.080	0.019	51.9	2.1	3.1	1.6	0.7	106	19.2
08E08	0.4977	2.35	1.78	0.33	1.32	6.81	2.35	0.085	0.187	0.047	36.7	5.8	8.8	12.7	8.1	90	27.9
08E09	0.5094	2.53	1.78	0.40	1.64	6.40	2.26	0.077	0.166	0.050	37.5	5.3	10.2	9.6	4.1	96	33.8
08E10	0.4926	3.06	1.50	0.44	2.69	7.81	2.08	0.068	0.144	0.030	31.3	3.8	4.3	2.5	1.3	55	26.9
08E11	0.5058	1.83	2.25	0.48	1.40	7.54	3.05	0.135	0.193	0.075	35.5	6.7	14.2	30.0	5.7	111	40.0
08E12	0.5331	2.00	2.52	0.25	0.91	6.91	1.73	0.085	0.114	0.033	20.0	3.9	7.0	18.1	3.6	87	19.3
08E13	0.5533	2.05	2.98	0.16	0.70	6.74	1.05	0.032	0.073	0.026	29.8	4.8	7.7	15.2	3.0	62	11.5
08E14	0.4789	1.68	2.84	0.12	0.58	7.70	1.46	0.064	0.094	0.034	26.6	6.2	6.5	26.1	7.2	43	14.8
08E15	0.5109	2.61	2.26	0.17	0.64	6.84	2.20	0.104	0.064	0.020	37.6	2.6	12.4	9.4	5.3	32	12.5
08E16	0.4825	1.71	1.81	0.15	0.75	8.29	6.74	0.344	0.104	0.037	83.4	4.6	9.0	12.4	4.7	63	17.1
08E17	0.4891	0.93	3.25	0.20	0.49	6.35	1.32	0.071	0.121	0.040	33.4	3.4	8.5	9.1	3.5	50	17.8
08F01	0.4999	3.59	2.10	0.40	2.09	6.27	2.18	0.078	0.168	0.023	48.3	4.9	14.6	7.7	2.6	111	32.9
08F02	0.5023	3.77	2.23	0.14	1.37	6.39	0.99	0.032	0.078	0.029	47.9	2.0	3.6	9.5	1.9	88	11.0
08F03	0.4948	2.89	1.47	0.15	1.33	5.96	0.93	0.026	0.067	0.018	36.3	1.9	2.8	6.2	1.5	84	9.7
08F04	0.5235	1.56	2.03	0.51	0.63	6.53	6.06	0.328	0.233	0.080	64.1	77.9	30.7	48.3	17.3	60	48.2
08F05	0.4925	2.64	1.49	0.24	1.71	6.35	1.21	0.048	0.103	0.034	42.3	3.9	8.4	11.5	4.5	74	18.8
08F06	0.4939	2.45	1.51	0.22	1.23	6.23	2.03	0.130	0.080	0.017	30.9	2.4	3.0	1.9	0.7	116	18.4
08F07	0.4913	1.26	1.56	0.37	0.94	6.61	2.98	0.119	0.174	0.314	65.2	9.8	25.0	50.9	12.2	82	36.1
08F08	0.5002	3.08	1.73	0.26	1.63	6.88	1.44	0.040	0.104	0.017	37.1	2.7	5.5	2.6	1.8	105	15.5
08F09	0.4930	3.93	1.44	0.12	1.65	7.71	0.93	0.033	0.071	0.015	49.4	1.4	1.0	3.4	0.5	103	7.5
08F10	0.5097	2.12	4.35	0.09	0.45	6.79	0.70	0.027	0.053	0.011	15.1	1.1	2.3	16.1	1.4	35	7.1
08F11	0.4903	2.56	2.31	0.50	2.11	5.57	2.25	0.066	0.164	0.022	18.2	5.2	13.3	3.3	4.3	110	36.6
08F12	0.4885	1.76	2.35	0.48	1.66	4.01	2.13	0.078	0.138	0.029	16.4	5.0	9.5	8.7	2.4	78	36.0
08F13	0.4928	2.26	3.23	0.27	1.00	4.53	1.37	0.042	0.105	0.016	16.8	2.7	4.1	10.4	1.2	62	20.5
08F14	0.5039	2.66	2.70	0.05	0.82	5.36	0.74	0.040	0.138	0.010	24.3	1.0	2.4	3.3	0.9	33	6.2
08F15	0.4931	2.32	2.07	0.10	0.64	4.72	0.86	0.031	0.062	0.012	22.5	1.7	3.3	2.9	1.2	39	8.7
08F16	0.4962	2.59	2.33	0.12	0.59	4.72	1.45	0.073	0.083	0.024	24.5	2.4	4.8	6.5	2.1	37	11.9
08F17	0.4905	2.69	2.50	0.18	0.90	5.11	1.59	0.074	0.101	0.033	27.7	3.1	7.7	9.9	2.6	63	15.8
08G01	0.5032	3.24	1.95	0.11	1.15	7.42	1.14	0.098	0.089	0.015	37.2	1.5	13.4	6.9	1.9	63	9.0
08G02	0.3948	3.65	2.76	0.15	1.42	8.80	1.22	0.053	0.125	0.015	39.9	8.4	2.7	1.5	0.6	107	7.6
08G03	0.4996	2.97	2.14	0.10	0.95	7.44	1.28	0.083	0.074	0.023	20.5	6.5	5.2	12.1	2.5	61	8.8
08G04	0.5030	1.31	2.00	0.64	0.95	4.78	1.69	0.051	0.152	0.033	39.0	11.7	128.8	35.2	48.4	80	22.1
08G05	0.4993	1.72	2.04	0.27	0.16	6.49	1.97	0.065	0.257	0.055	36.4	5.4	16.2	22.4	9.6	105	35.8
08G06	0.4977	1.57	1.53	0.33	0.78	6.82	2.03	0.070	0.178	0.145	52.5	20.8	57.2	54.5	21.1	78	28.8
14A01	0.5482	2.77	1.87	0.29	1.78	6.79	1.37	0.063	0.112	0.016	19.0	2.4	4.5	3.4	2.0	118	21.7
14A02	0.5390	1.51	1.79	0.23	0.98	5.15	1.39	0.026	0.165	0.173	27.5	4.6	19.5	43.9	7.8	76	24.4
14A03	0.5222	2.87	1.76	0.15	1.34	6.51	0.94	0.034	0.073	0.018	25.5	1.6	2.6	3.8	1.1	96	11.0
14A04	0.5174	2.38	1.56	0.24	1.29	7.55	2.05	0.103	0.137	0.026	34.5	3.4	7.8	55.6	4.0	100	20.4
14A05	0.5107	2.58	2.16	0.13	1.12	6.14	0.87	0.020	0.086	0.025	29.3	1.5	5.6	7.4	2.1	96	10.5
14A06	0.5109	2.07	1.79	0.14	0.91	5.16	1.03	0.052	0.358	0.022	44.8	2.3	8.6	4.7	2.0	77	17.3
14A07	0.5383	1.25	1.98	0.16	0.72	4.47	1.46	0.064	0.539	0.043	40.6	3.4	25.7	9.1	6.8	90	28.6
14A08	0.5368	1.31	1.79	0.16	0.68	4.86	1.87	0.071	0.812	0.034	56.4	20.7	14.5	9.3	6.1	68	35.4
14A09	0.5186	2.00	1.86	0.11	0.82	5.62	3.02	0.305	1.961	0.044	266.8	8.3	11.6	6.8	4.2	76	57.4
14A10	0.5423	3.11	2.16	0.14	1.33	7.30	1.41	0.209	0.103	0.034	33.6	2.1	3.0	4.7	1.4	112	10.2
14B01	0.5002	0.73	1.58	0.38	0.95	4.72	2.20	0.035	0.241	0.285	31.7	8.3	1.9	80.0	18.2	48	46.5
14B02	0.5012	1.91	1.68	0.17	0.86	2.92	1.22	0.042	0.139	0.078	19.1	4.0	14.1	19.5	5.7	57	20.9
14B03	0.5008	0.97	2.11	0.11	0.41	3.12	1.10	0.052	0.429	0.031	22.8	5.0	14.8	15.8	5.8	48	23.3
14B04	0.5021	1.14	1.89	0.14	0.43	3.49	1.60	0.144	0.354	0.060	25.5	19.0	25.4	12.3	16.6	50	28.1
14B05	0.4962	2.31	1.91	0.13	0.80	3.62	1.43	0.071	0.103	0.081	16.5	3.8	9.9	8.2	4.6	54	14.1
14B06	0.5036	1.23	1.77	0.19	0.83	2.54	1.05	0.031	0.132	0.016	20.5	3.8	26.3	32.7	10.6	64	19.0
14B07	0.5020	1.27	2.19	0.16	0.66	2.84	0.99	0.029	0.133	0.053	18.4	5.4	18.0	22.5	8.2	52	21.8
JG-1a (1)	0.5025	2.59	3.25	0.38	1.46	6.36	1.30	0.042	0.130	0.036	36.0	4.7	15.1	1.5	5.9	138	19.6
JG-1a (2)	0.4962	2.37	3.10	0.39	1.40	6.49	1.30	0.000	0.129	0.035	33.0	4.7	14.0	1.5	5.1	158	19.7
reference *		2.53	3.35	0.42	1.52	7.53	1.43	0.046	0.150	0.035	47.1	5.7	18.6	1.3	6.4	185	32.0

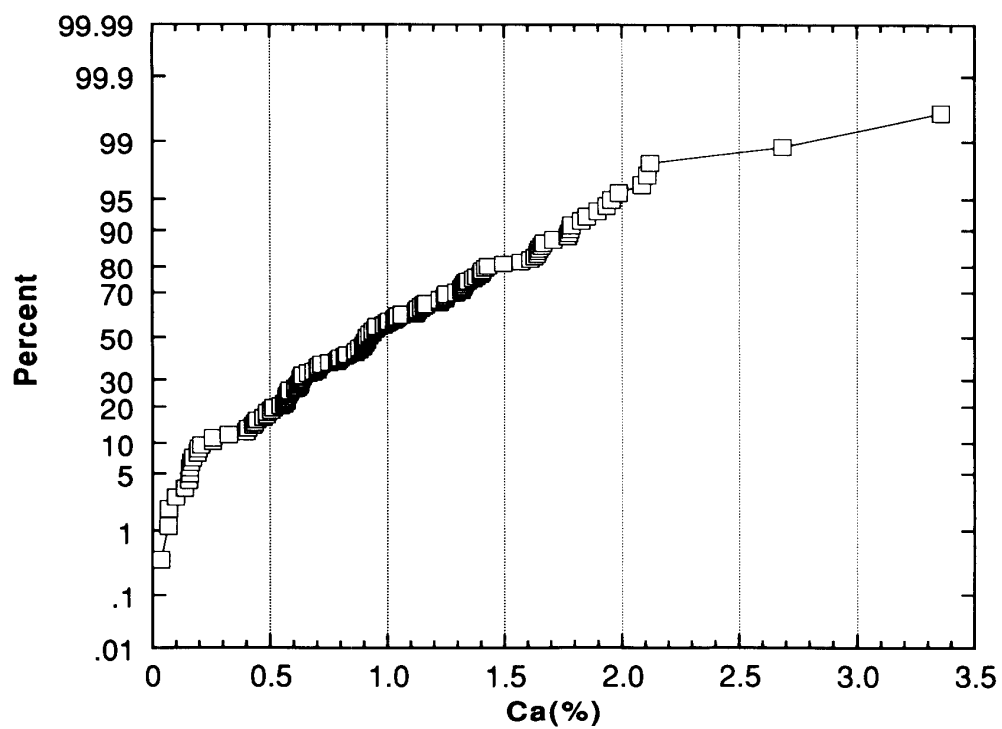
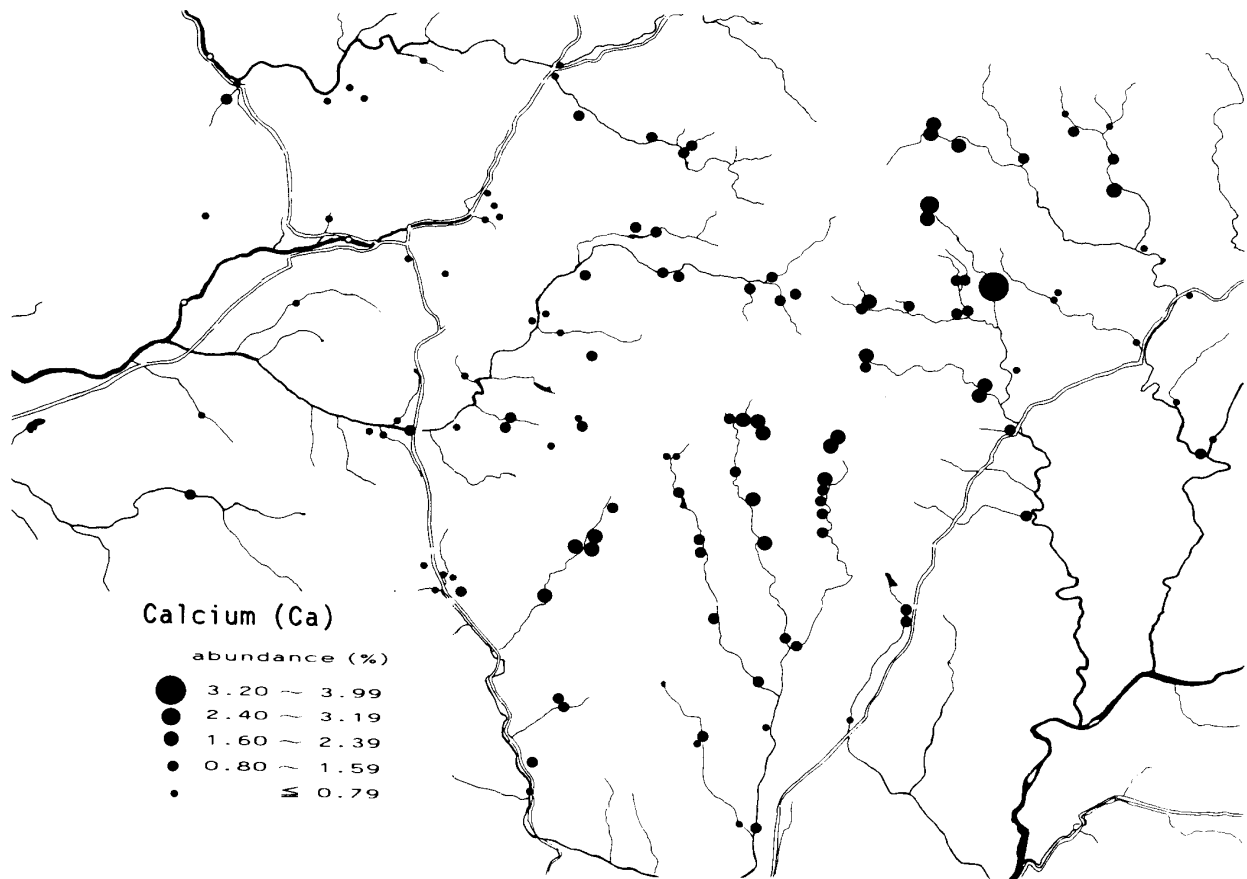
\*Recommended value by Ando et al. (1989)

Appendix B. Areal distribution pattern and the cumulative frequency distribution of Al abundance.

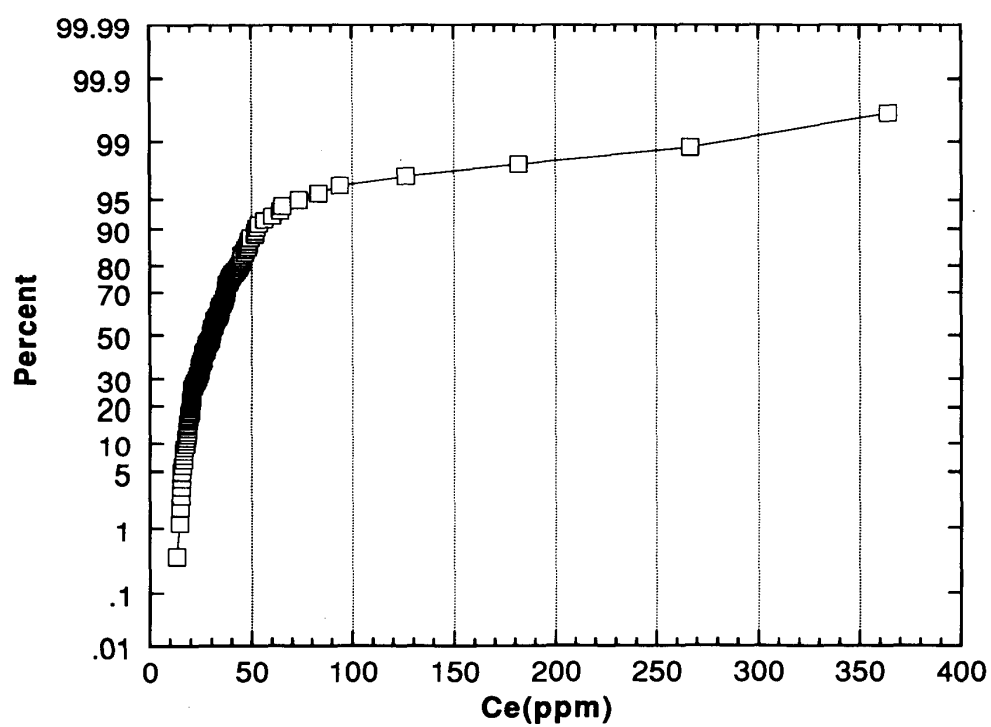
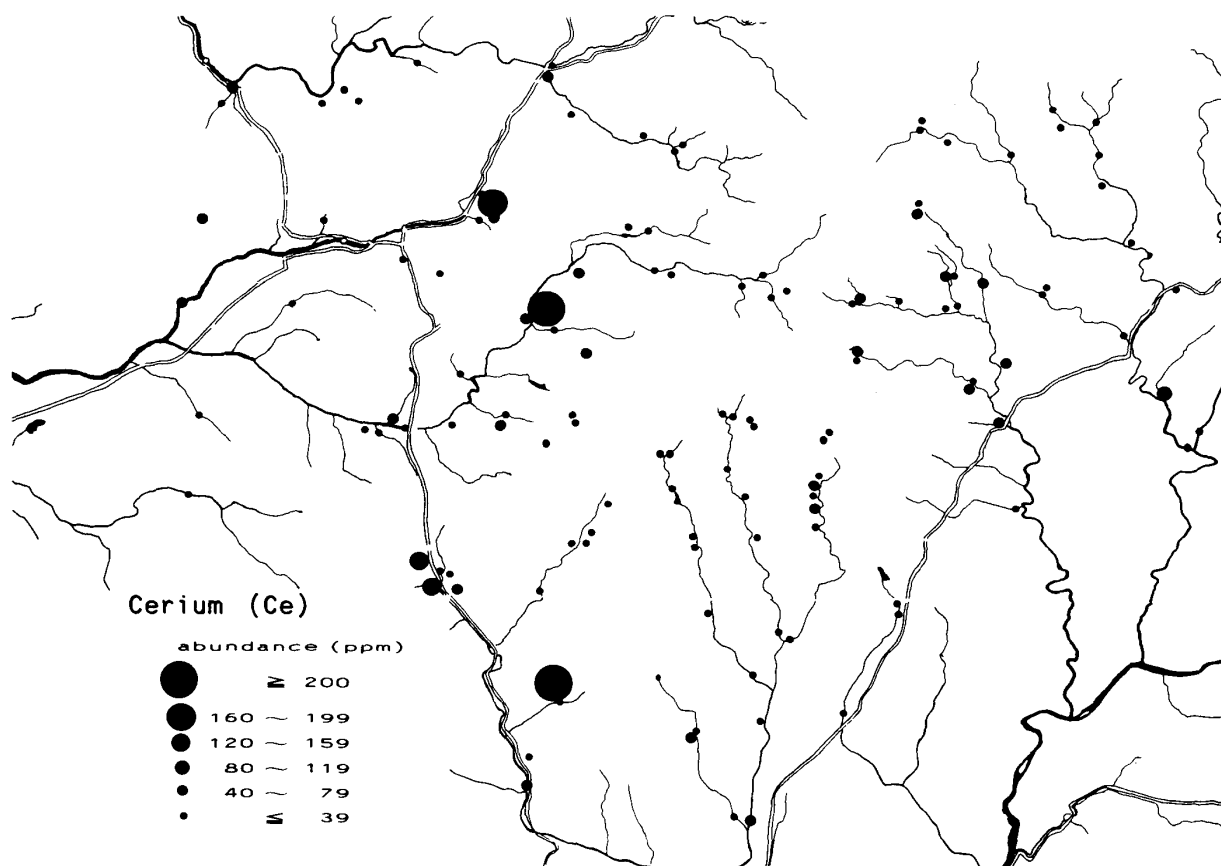




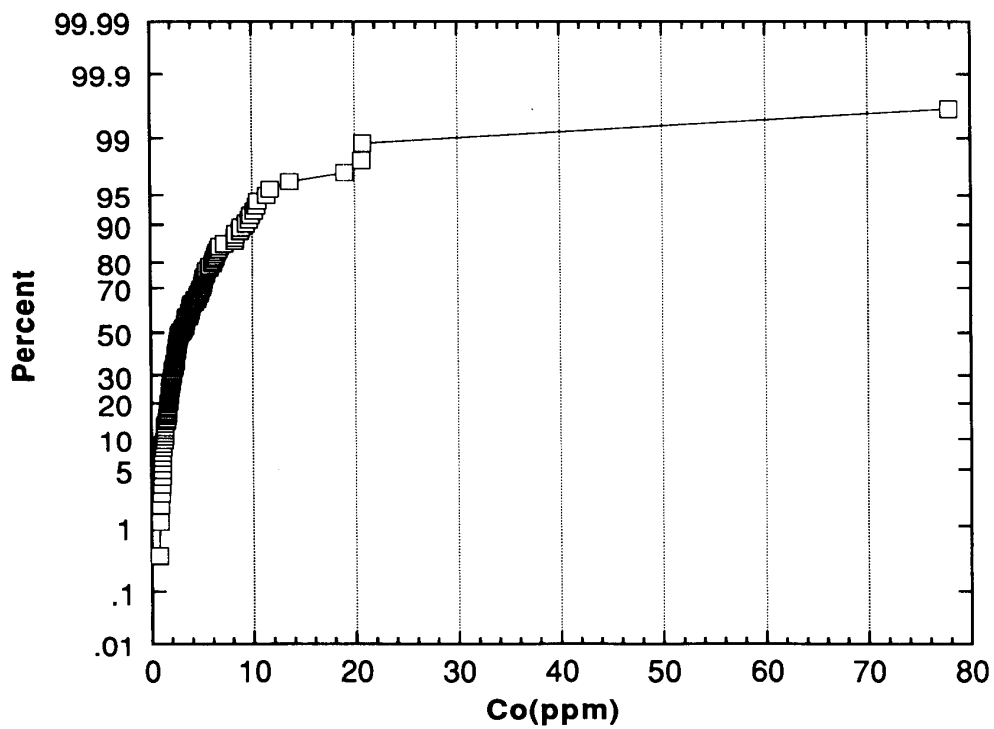
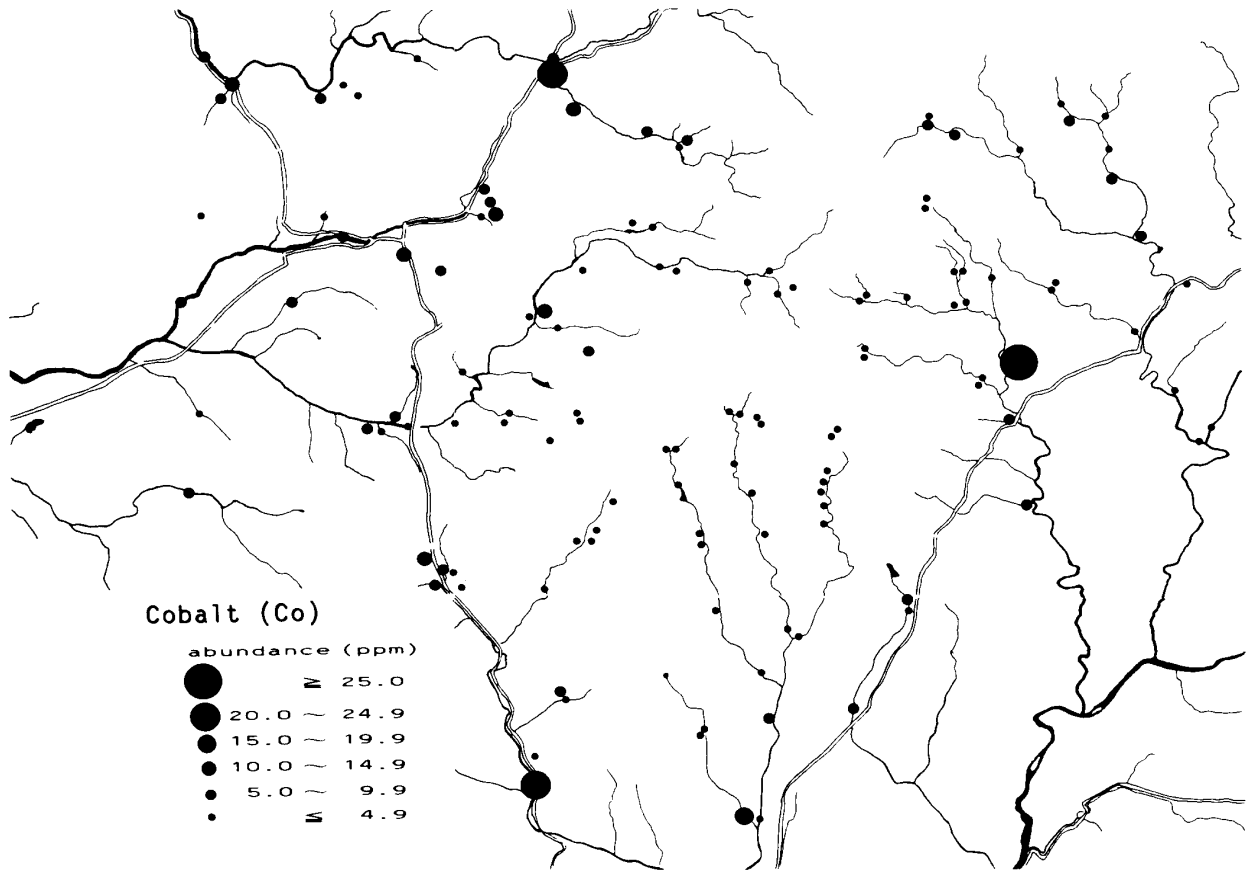
Appendix C. Areal distribution pattern and the cumulative frequency distribution of Ca abundance.



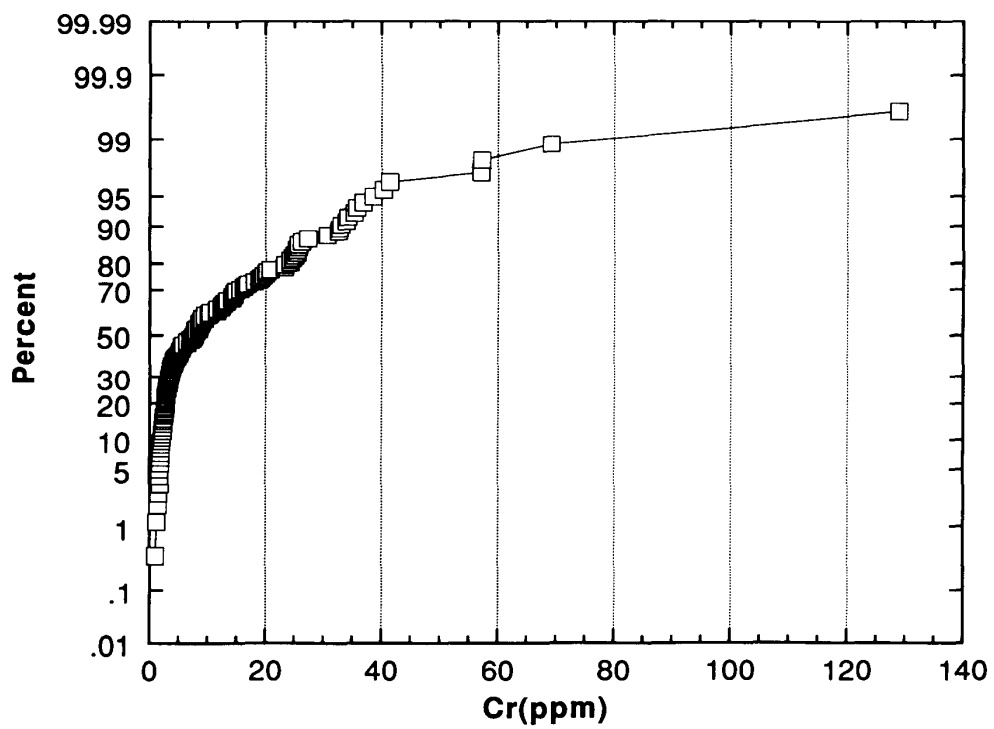
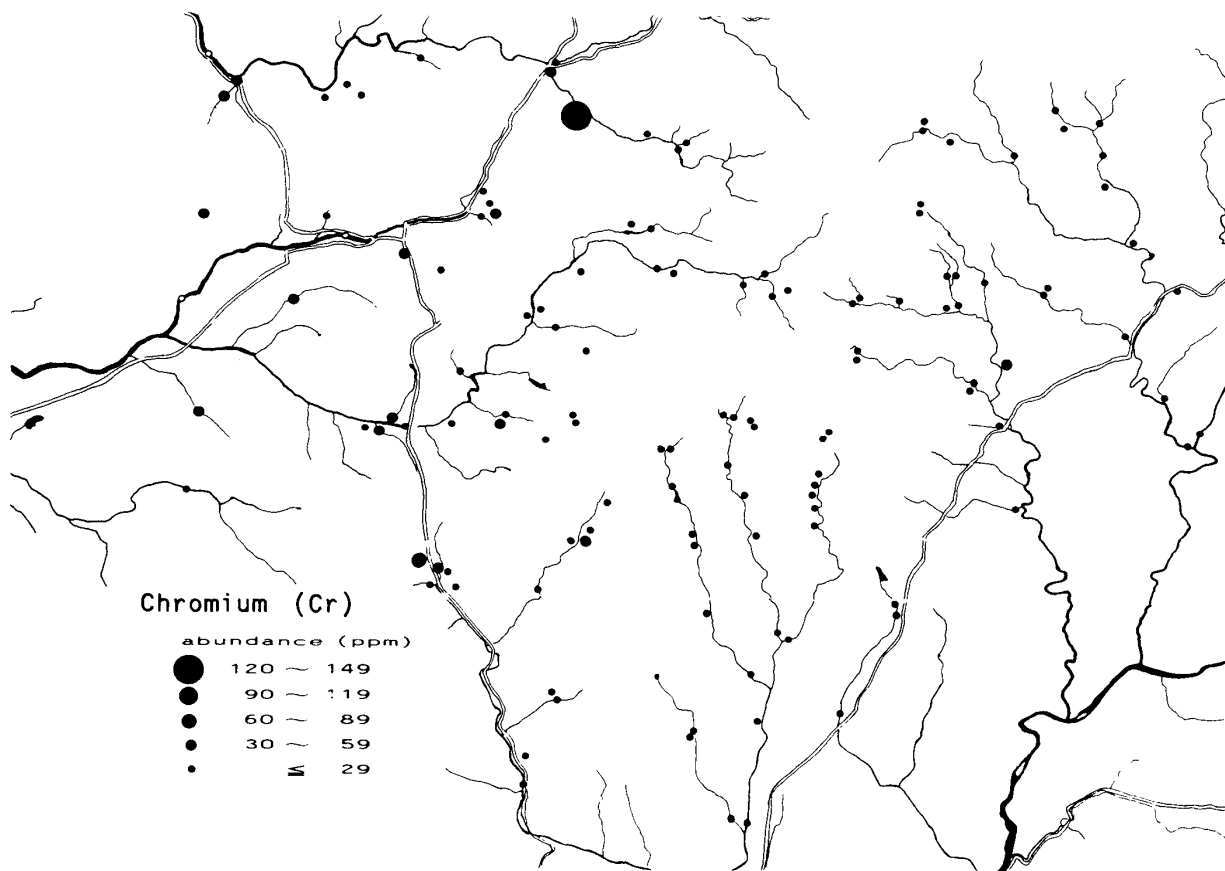
Appendix D. Areal distribution pattern and the cumulative frequency distribution of Ce abundance.



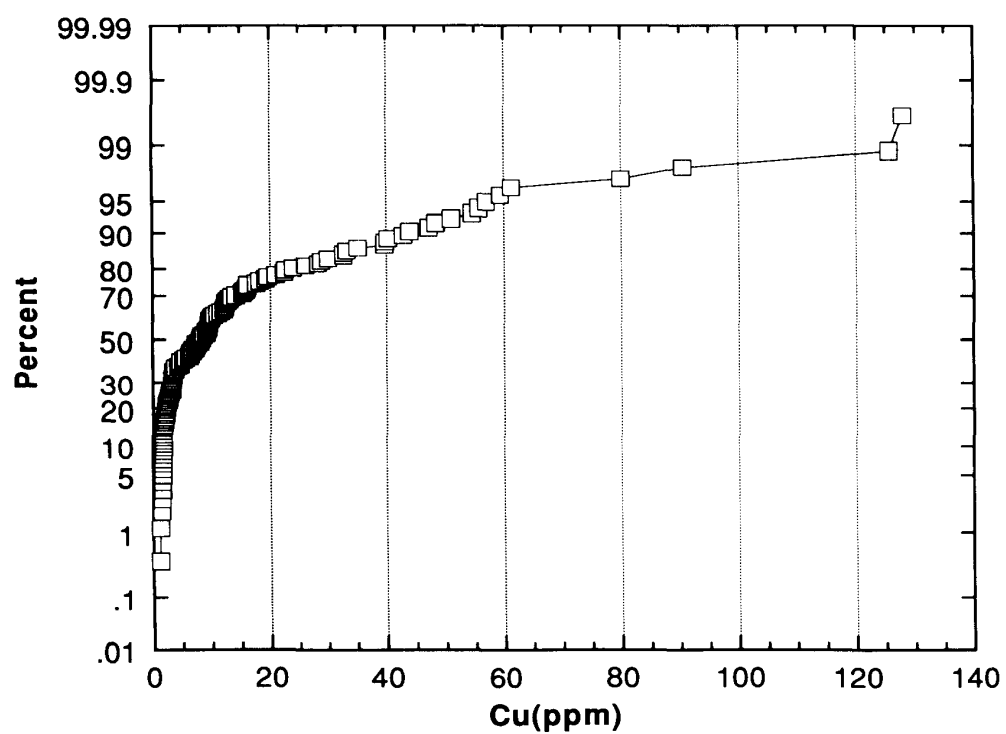
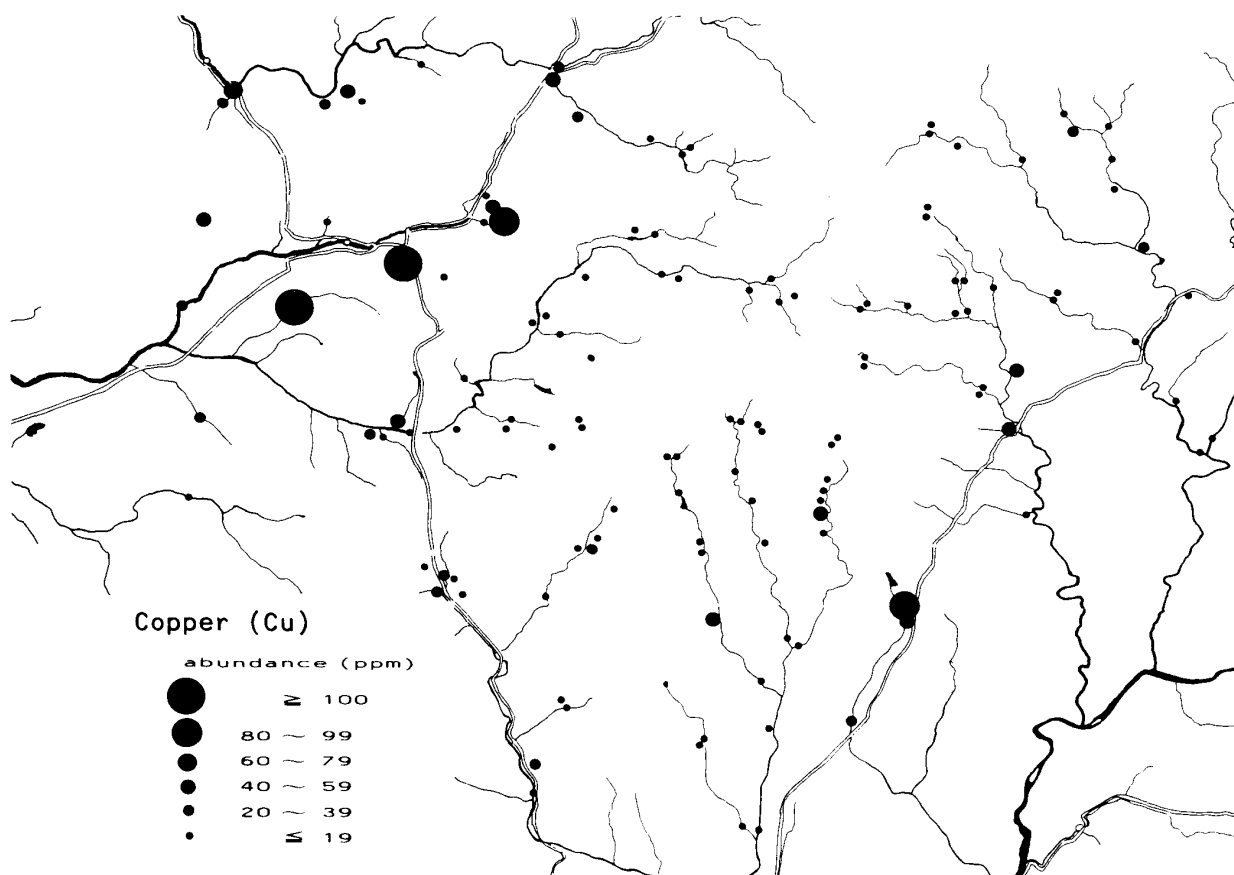
Appendix E. Areal distribution pattern and the cumulative frequency distribution of Co abundance.



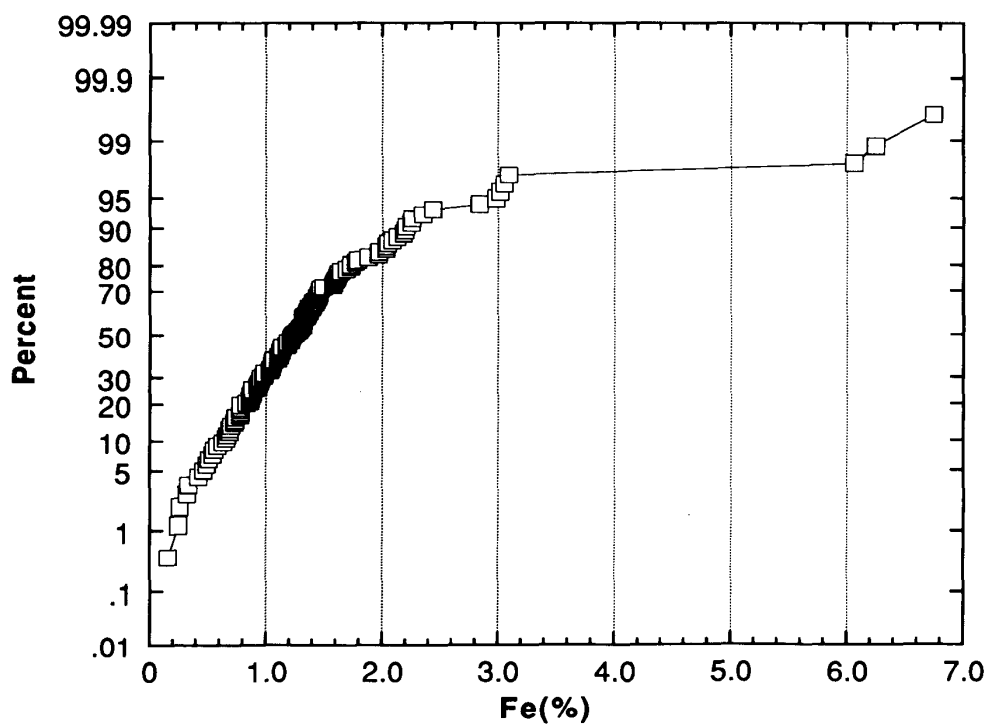
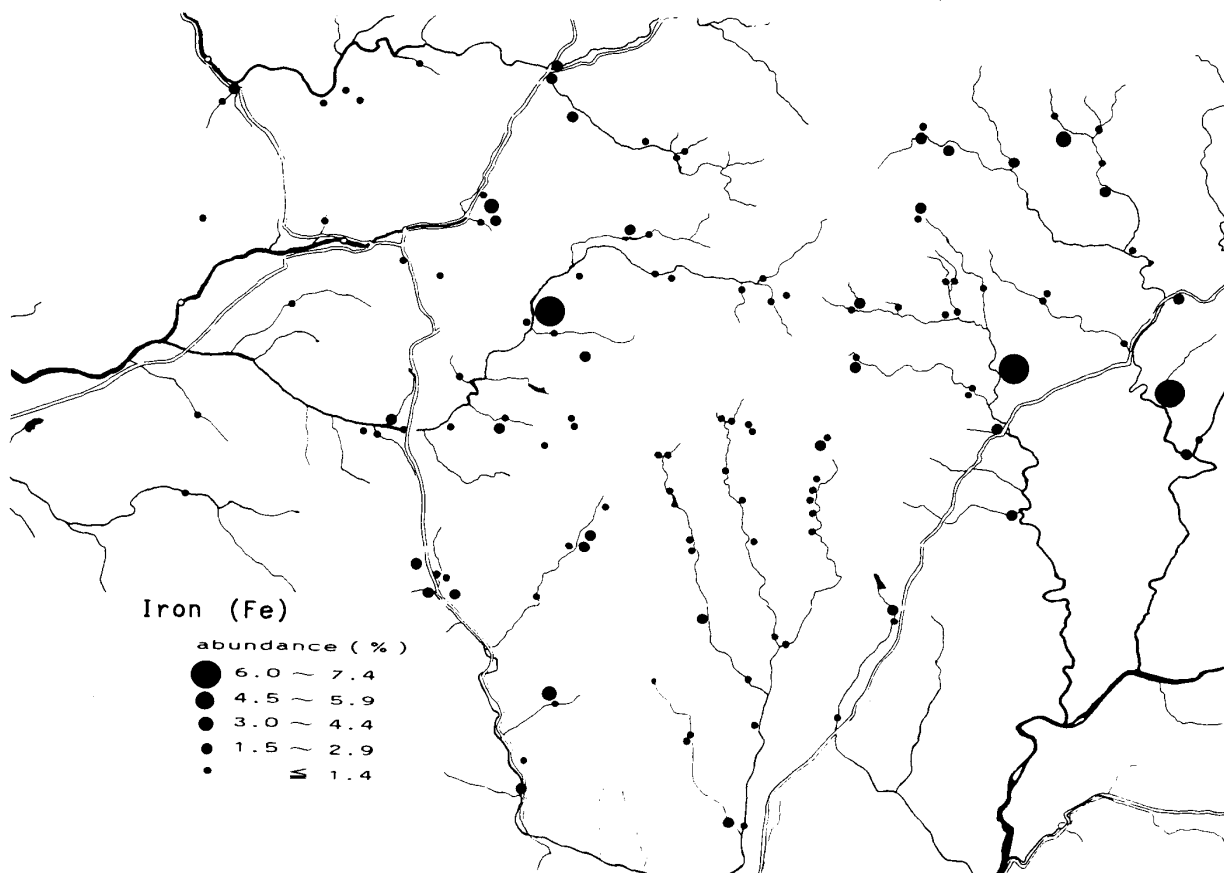
Appendix F. Areal distribution pattern and the cumulative frequency distribution of Cr abundance.



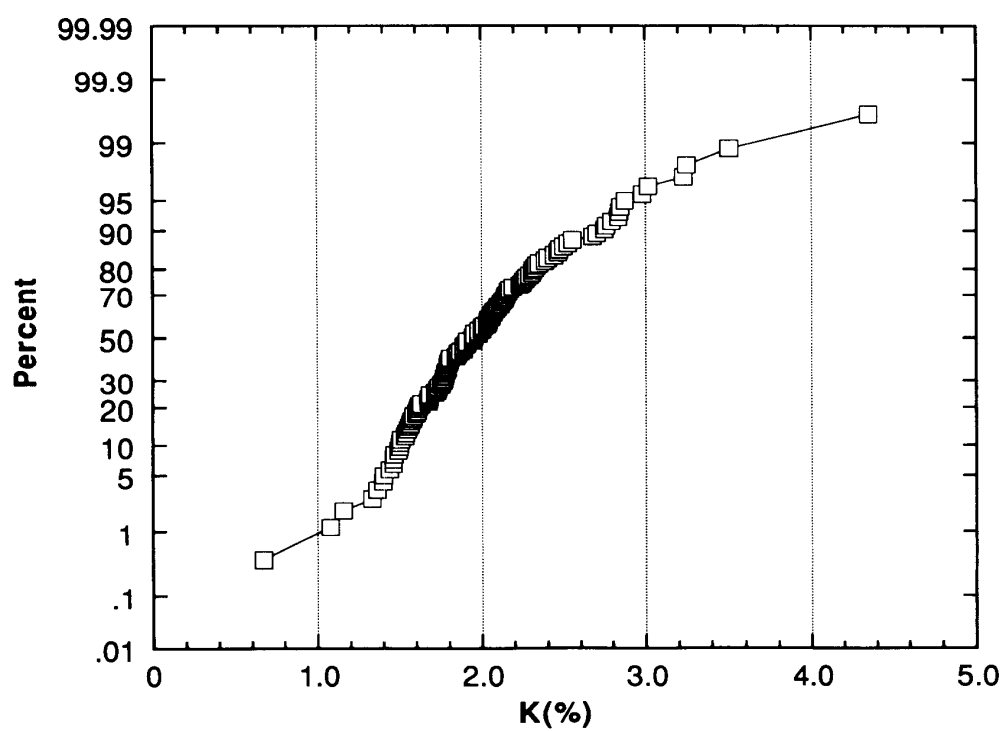
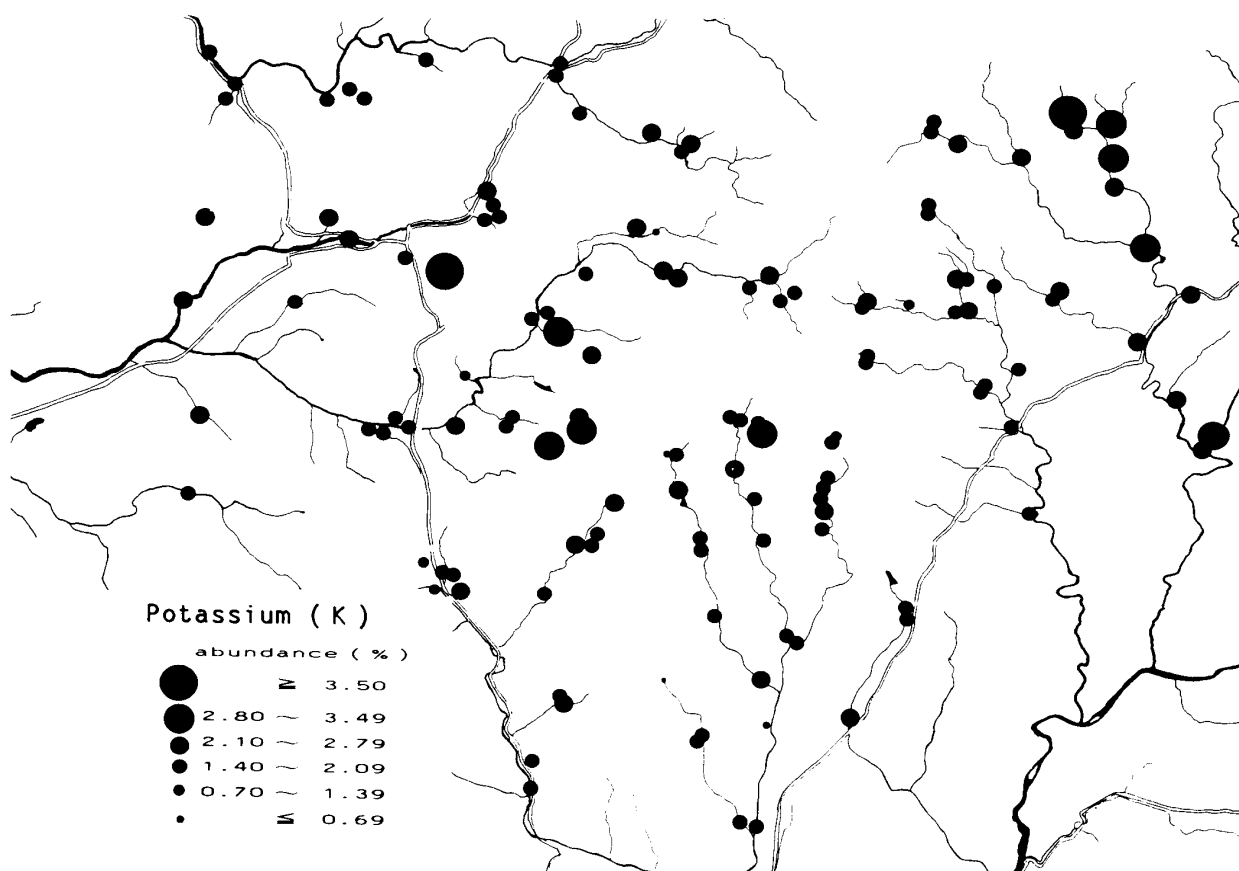
Appendix G. Areal distribution pattern and the cumulative frequency distribution of Cu abundance.



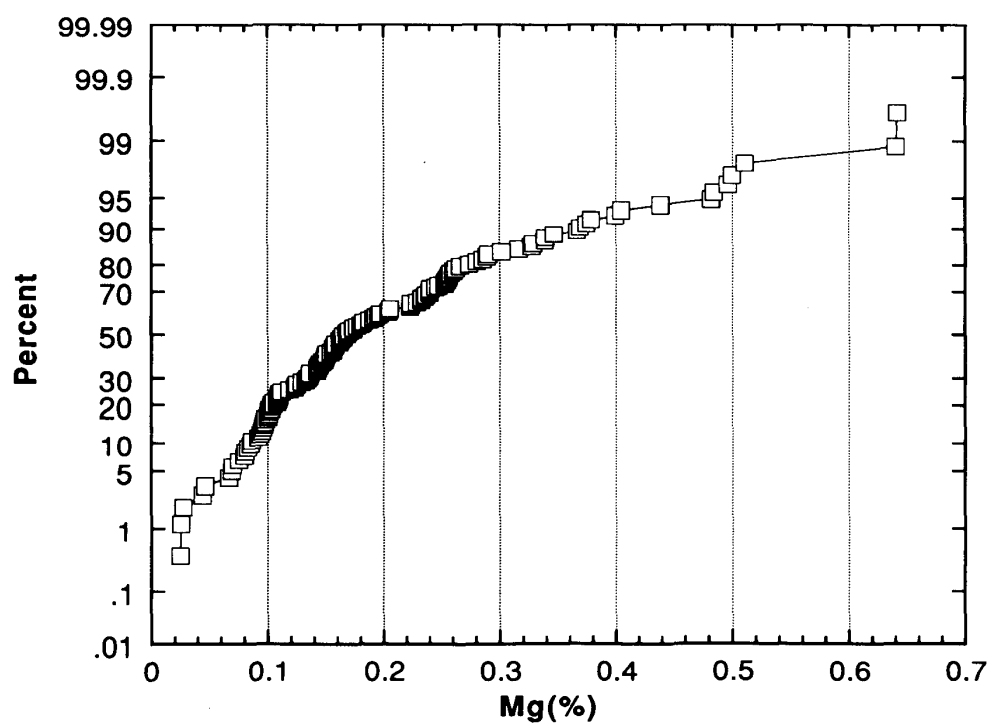
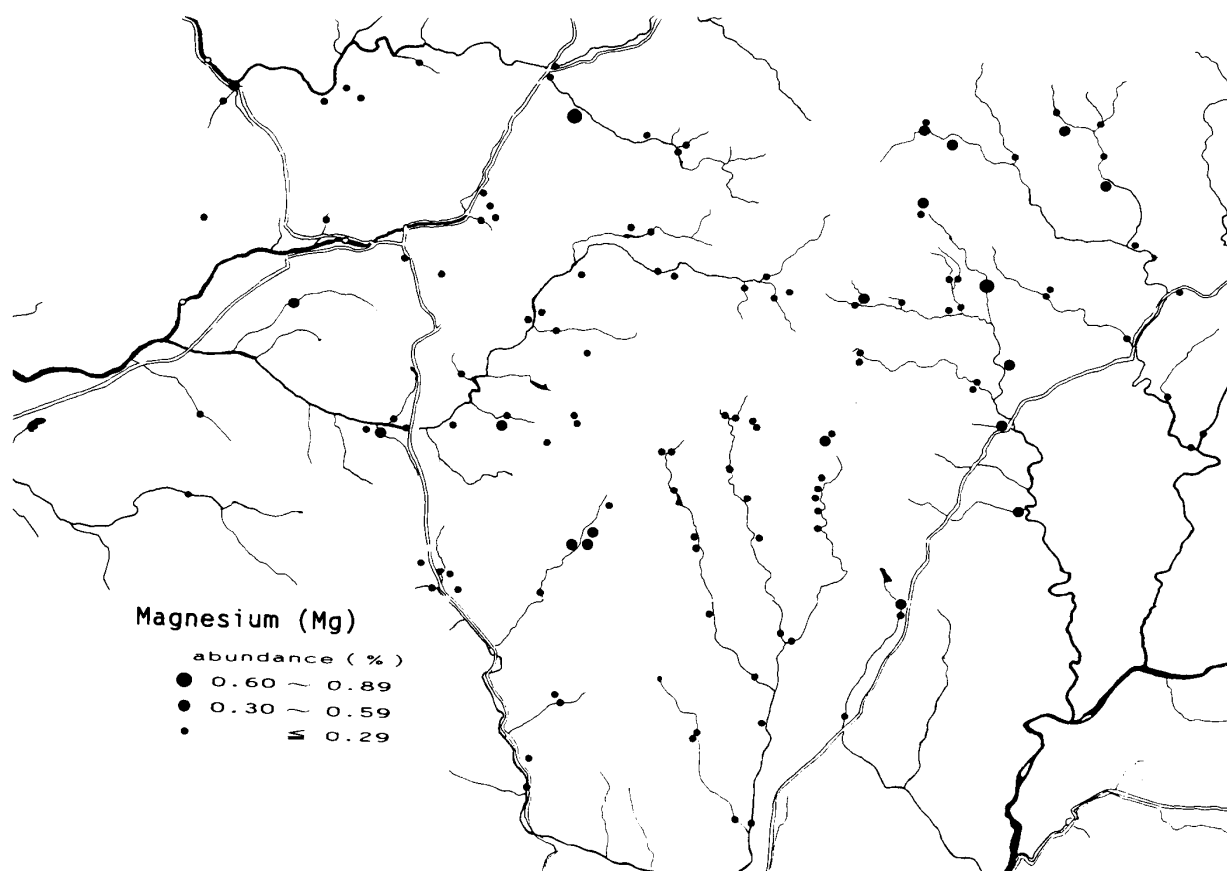
Appendix H. Areal distribution pattern and the cumulative frequency distribution of Fe abundance.



Appendix I. Areal distribution pattern and the cumulative frequency distribution of K abundance.

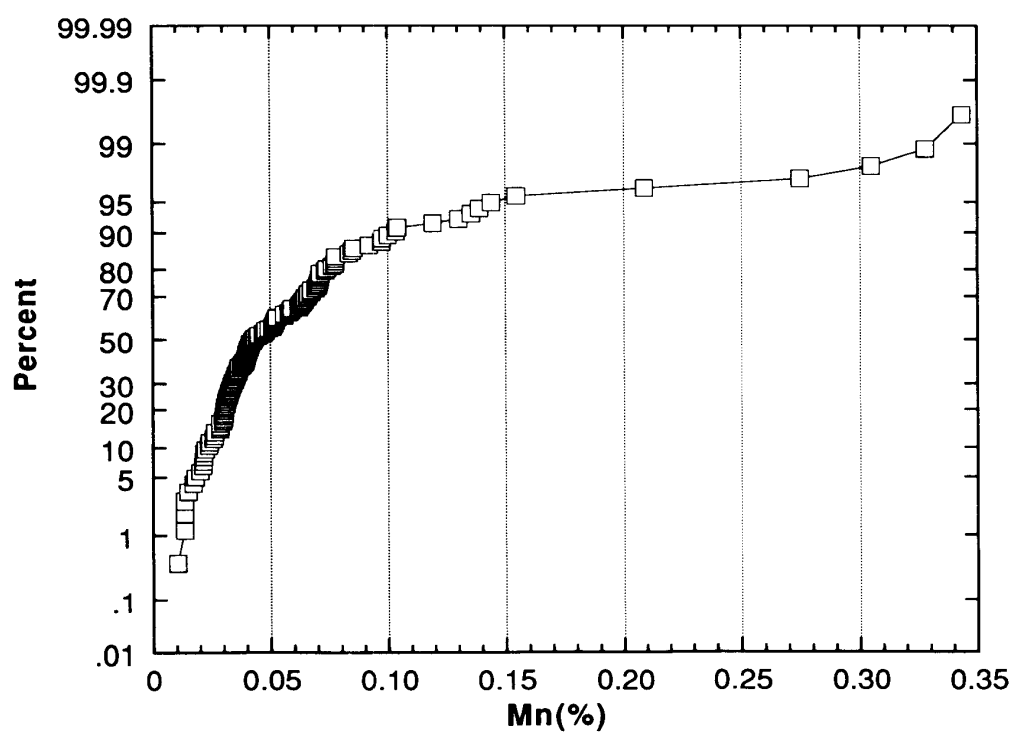
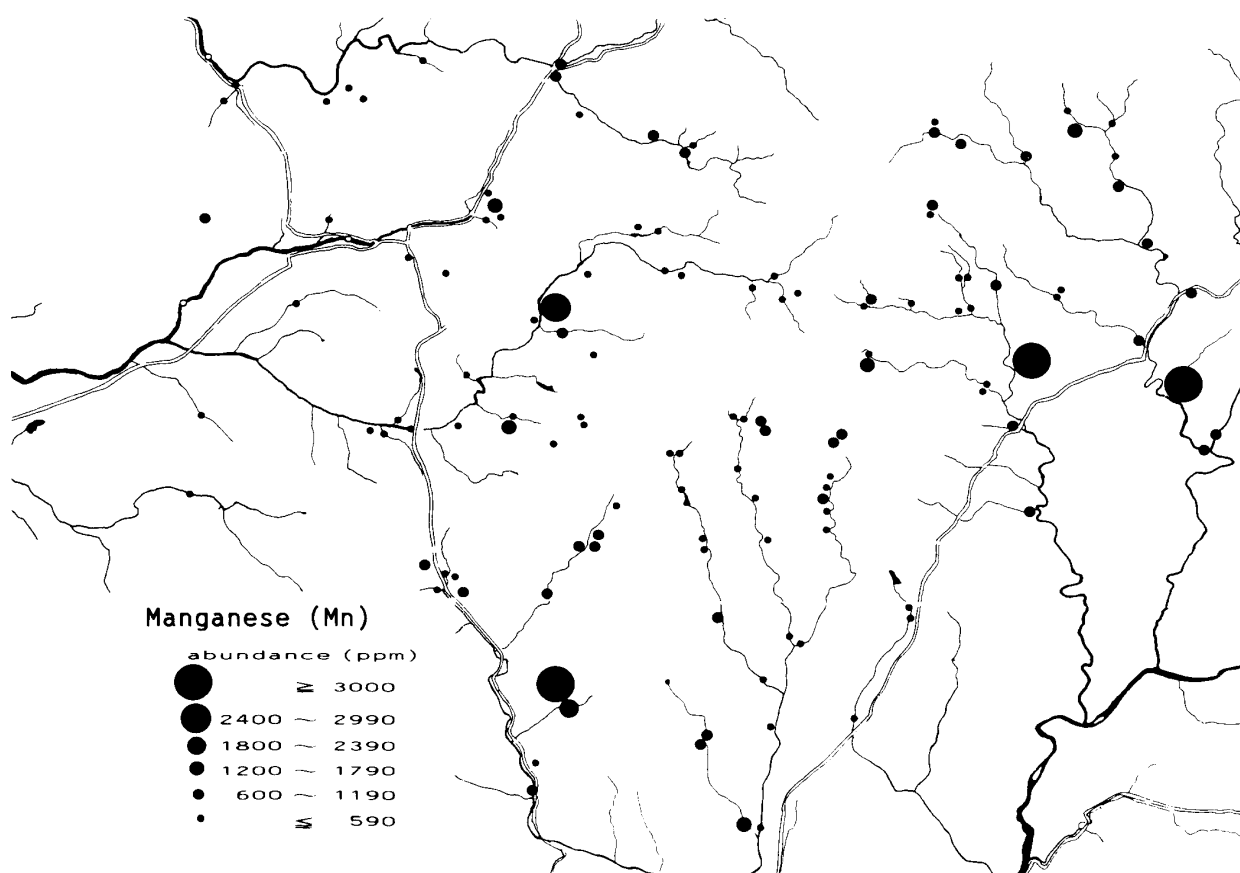


Appendix J. Areal distribution pattern and the cumulative frequency distribution of Mg abundance.

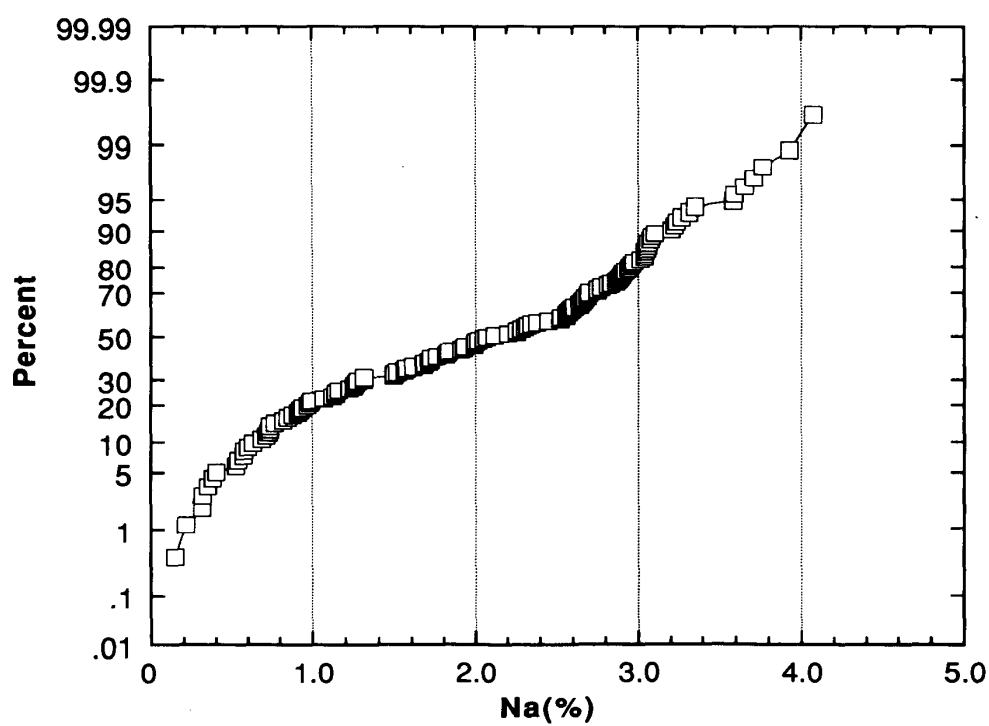
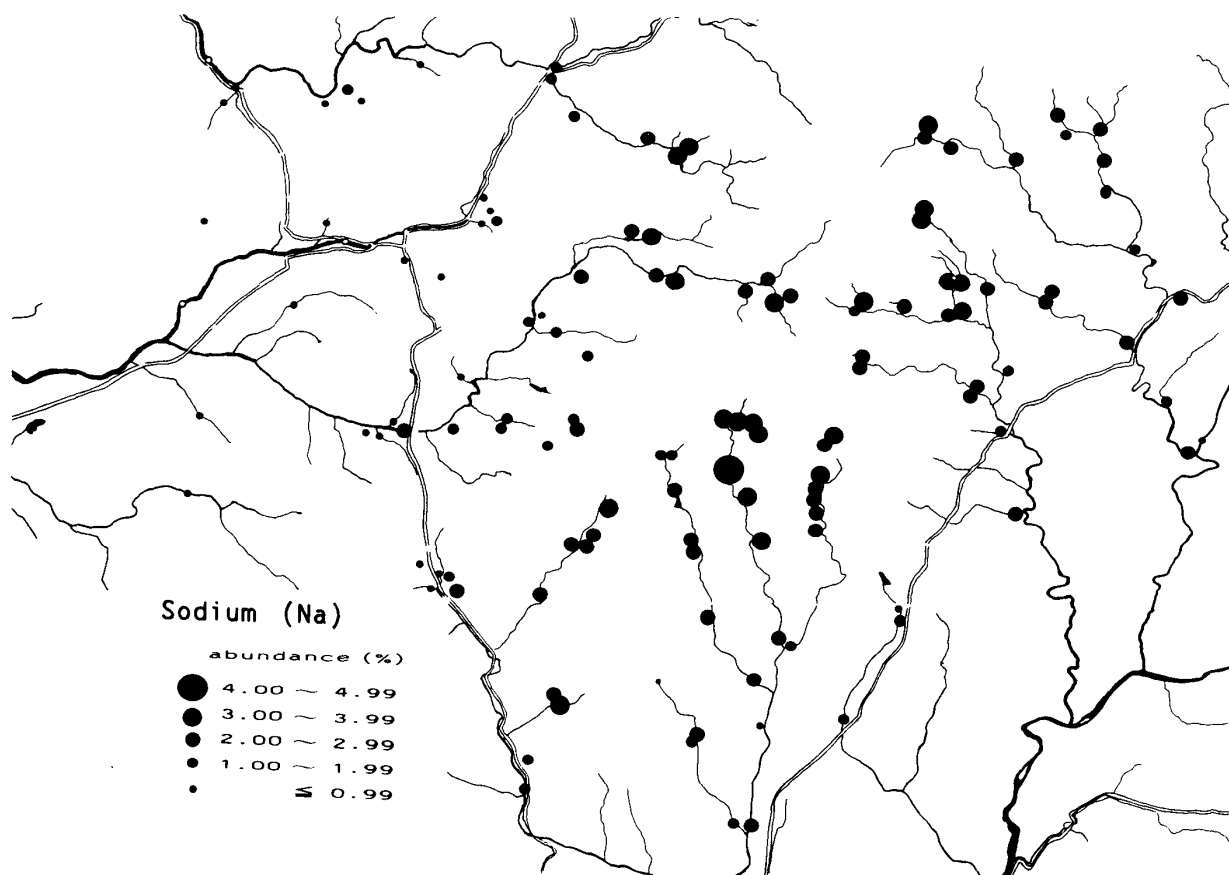




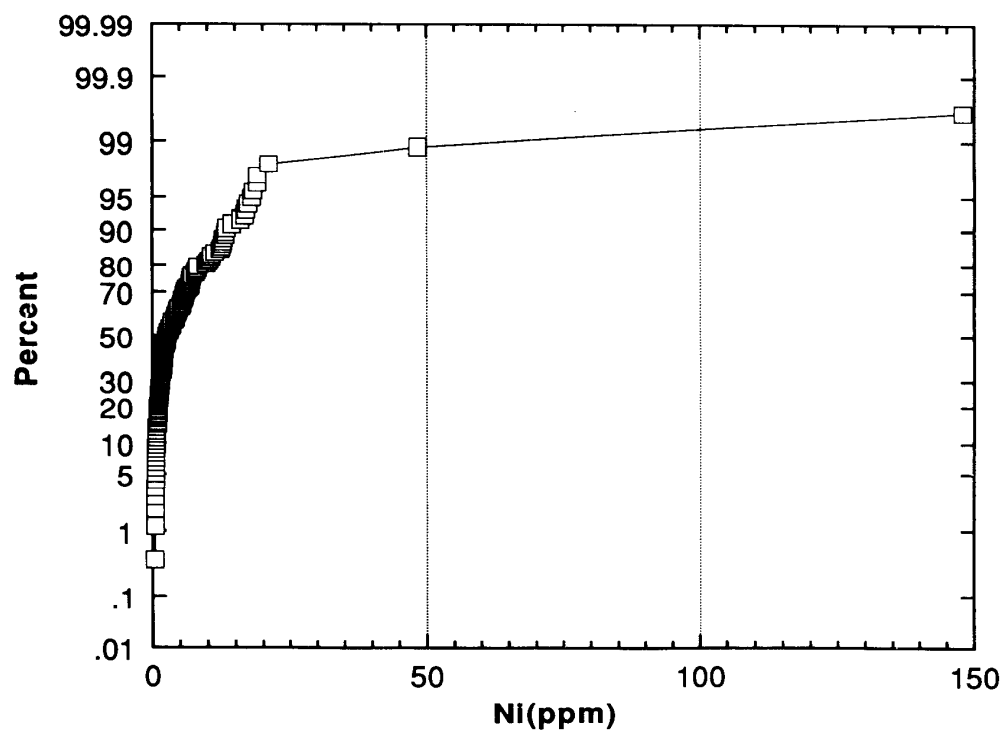
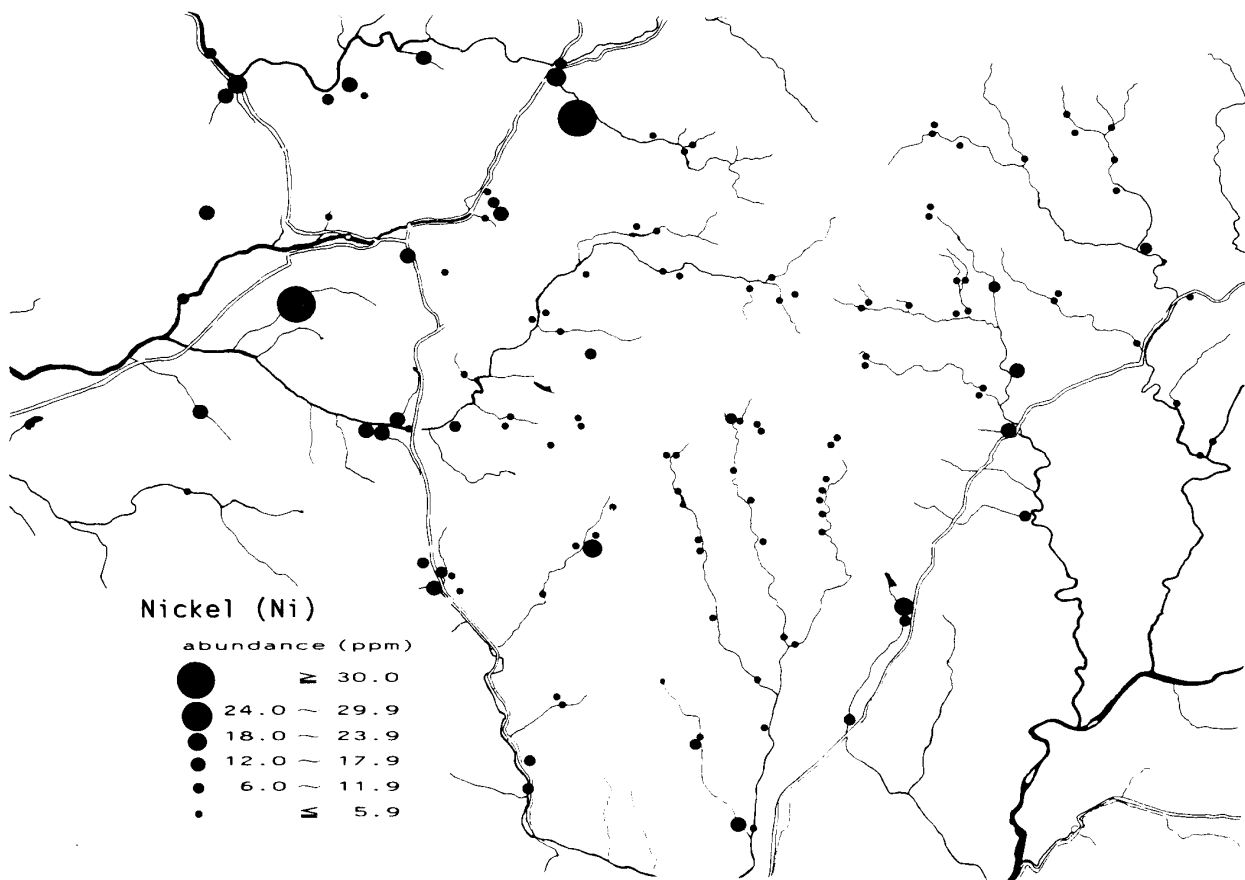
Appendix K. Areal distribution pattern and the cumulative frequency distribution of Mn abundance.



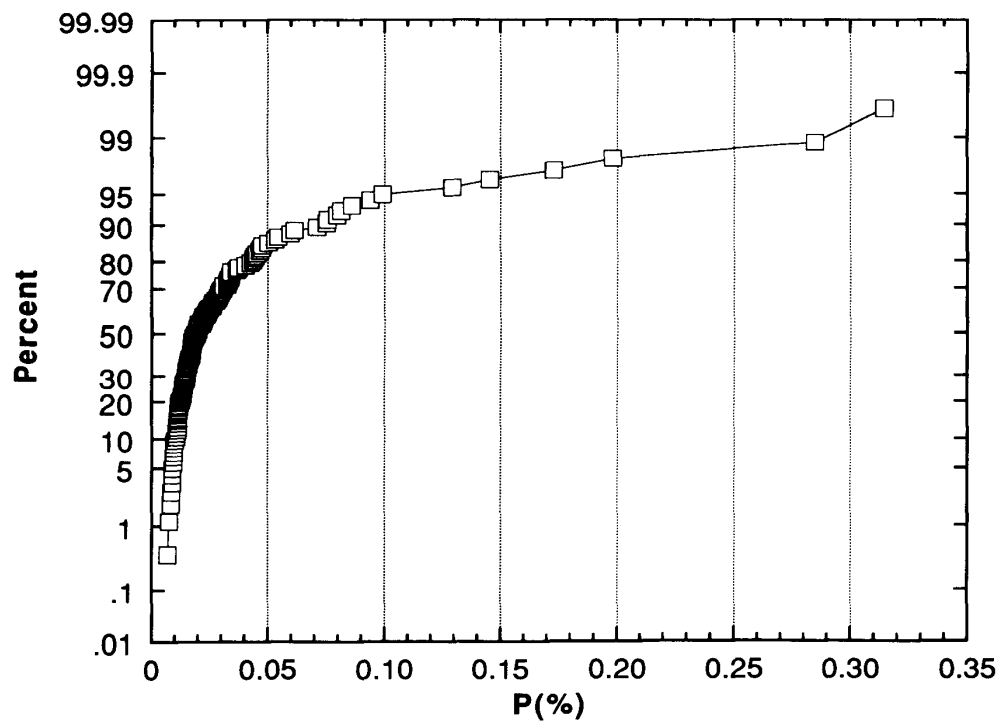
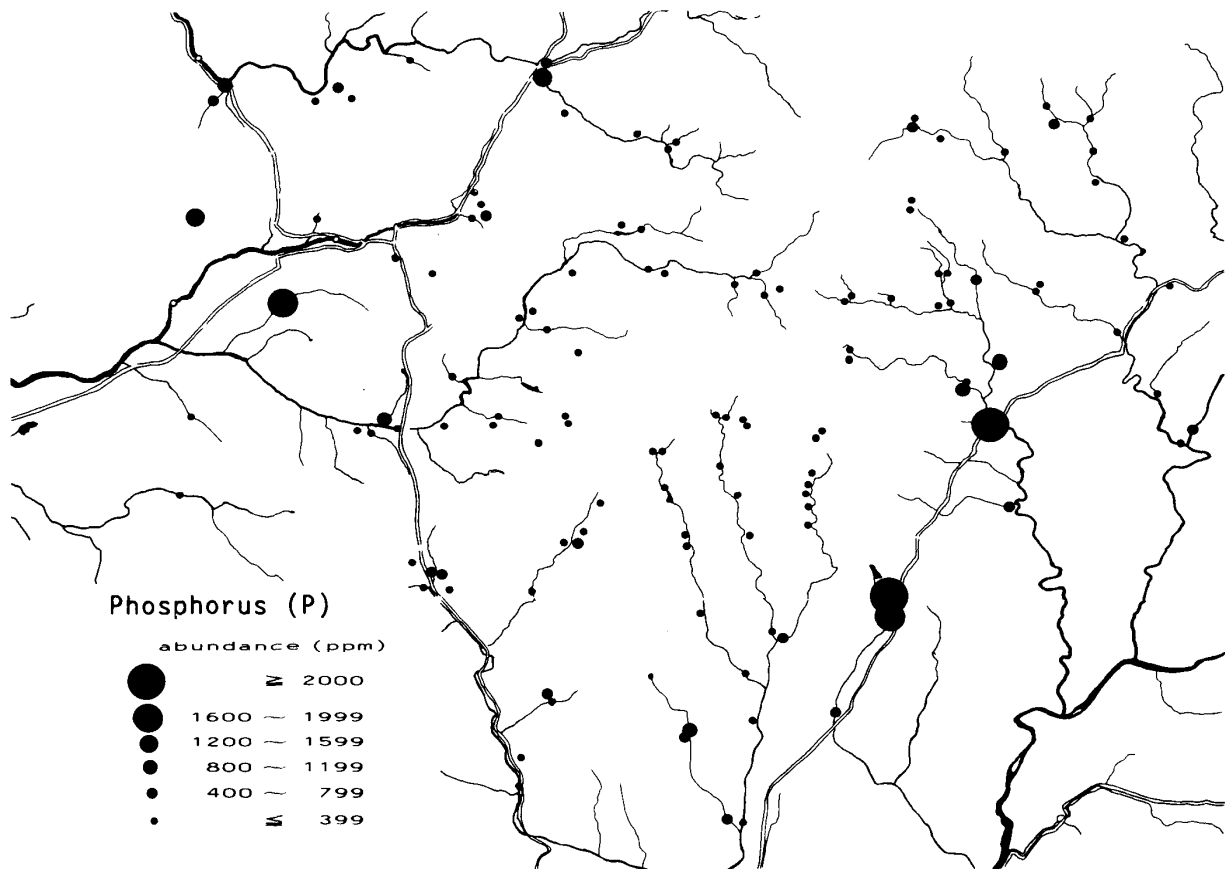
Appendix L. Areal distribution pattern and the cumulative frequency distribution of Na abundance.



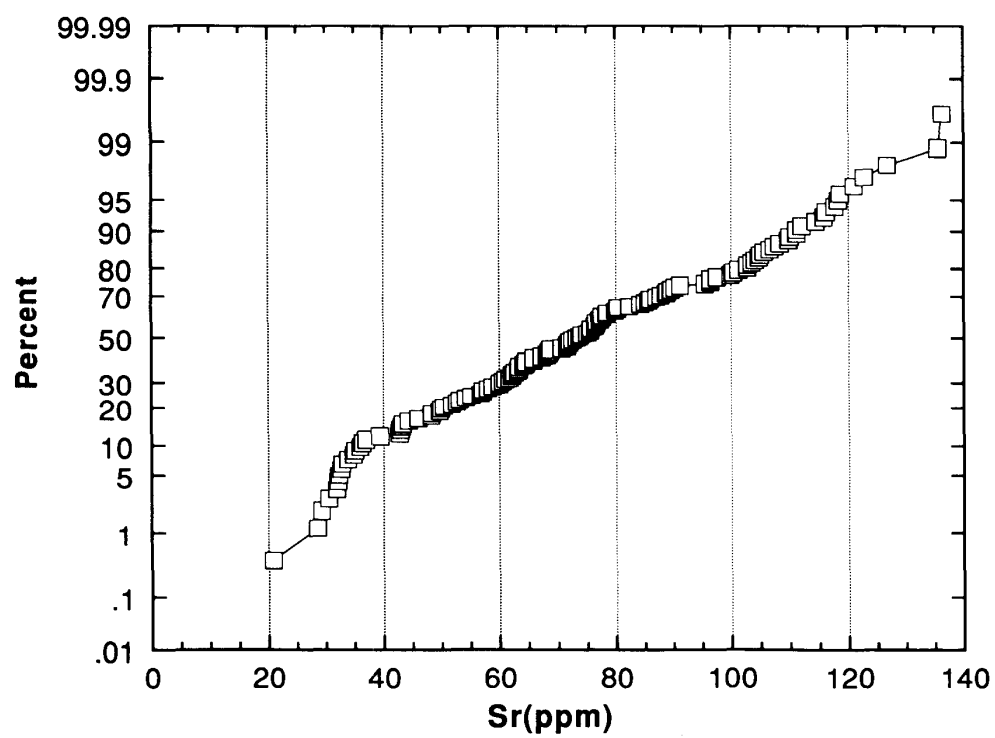
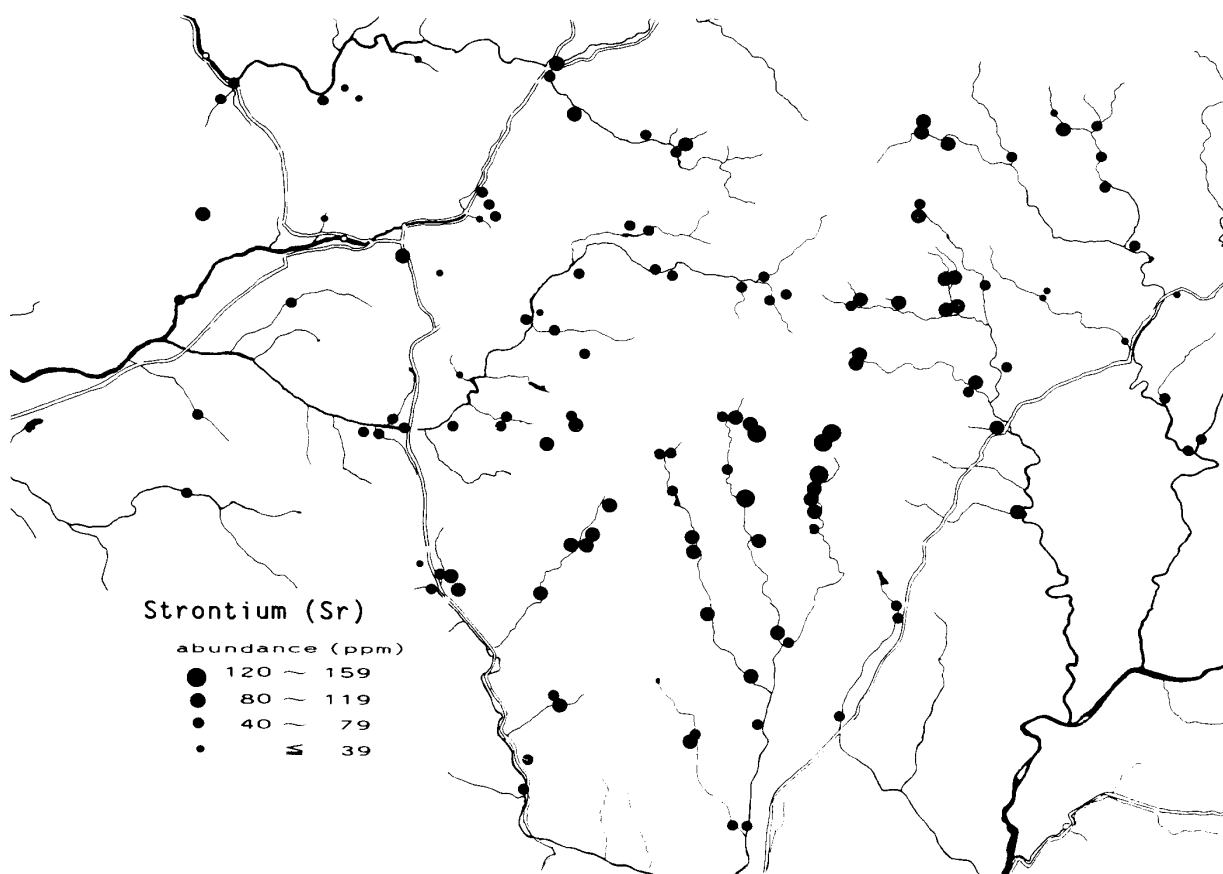
Appendix M. Areal distribution pattern and the cumulative frequency distribution of Ni abundance.



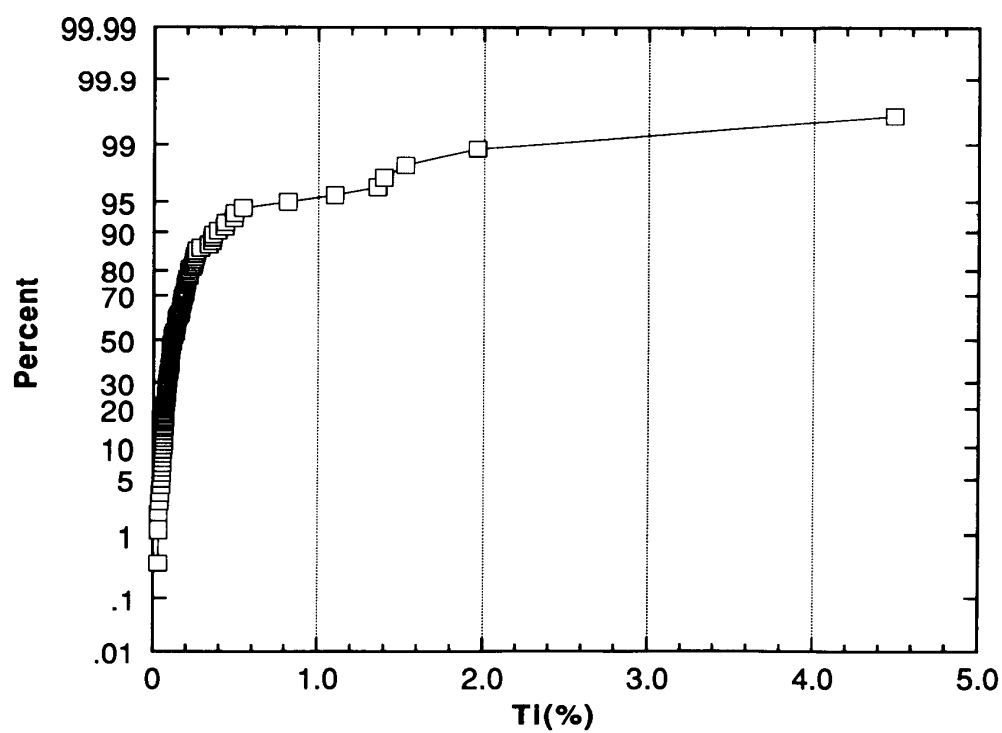
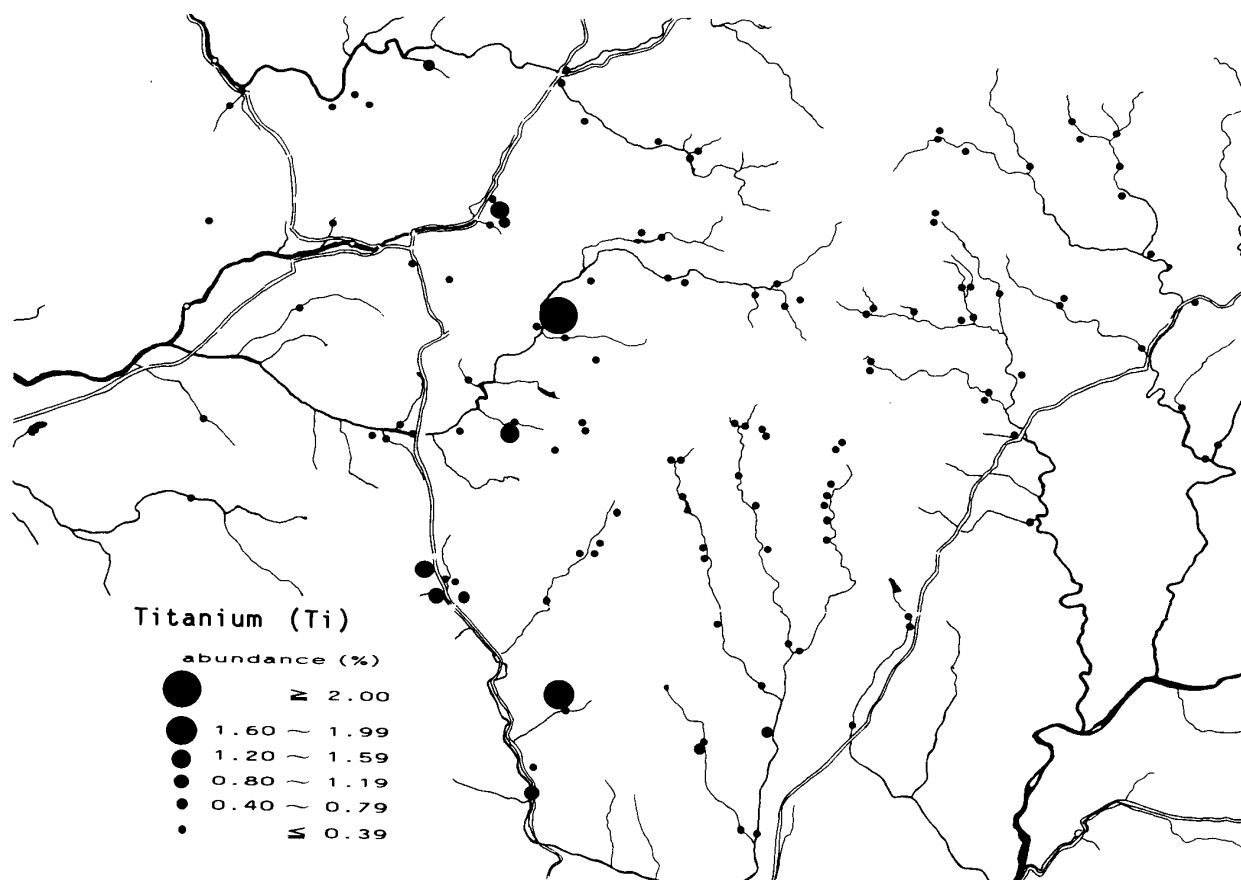
Appendix N. Areal distribution pattern and the cumulative frequency distribution of P abundance.



Appendix O. Areal distribution pattern and the cumulative frequency distribution of Sr abundance.



Appendix P. Areal distribution pattern and the cumulative frequency distribution of Ti abundance.



Appendix Q. Areal distribution pattern and the cumulative frequency distribution of V abundance.

