ultramafic and basic rocks with limestone bands would be correlated with the upper Vumba mixed formation and lower Vumba felsic formation.

The Mosetse River gneiss group which consists of granitic gneiss is similar in lithofacies to the G_{2t}-dominant Tutume meta-arkose group, so that the two groups is correlated.

However, since the Mosetse River gneiss group has intercalated limestone, there is a possibility that the group is correlated with the Vumba volcanic group.

1-4 Mineralized Zones

The surveyed area contains three mineralized zones: They are the Vumba zone, where gold deposits and nickel-bearing copper sulfide deposits are expected to be found: the Timbale zone, where rare element-bearing copper molybdenum ore deposits related to pegmatite intrusion are expected: and the North Matsitama zone, where copper deposits of syngenetic origin are likely to exist. Some parts of the three zones were explored during the years from late 1960's to early 1970's by the Anglo-American Group. The extent of exploration is shown in Table 6 and Fig. 11, 12.

1-4-1 Ore Deposits and Mineralization in Vumba Zone

In the Vumba volcanic group in this zone, there are many points where gold mineralization is recognised. In fact there are abandoned gold prospects previously explored and mined by the ancients, European prospectors, and modern mining organisations. Table 7 and Fig. 13 summarise the previous gold mining activities.

Mineralization is found in a sheared zone which has a north-northwest trend in amphibolite. In the sheared zone, gold is found in the gold-bearing sulfides disseminated in or around quartz bands in amphibolite or elsewhere in the amphibolite. The sulfides occur in masses in the quartz and in fine grains disseminated in amphibolite. They include pyrite, pyrrhotite, arsenopyrite, Loellingite, and chalcopyrite, but it is not known yet in what form gold occurs.

Near the mineralized zone, there are small stock-like quartz-diorite rock bodies.

Fig.11 Areal map showing the relationship of GS-17 project and previous surveies.

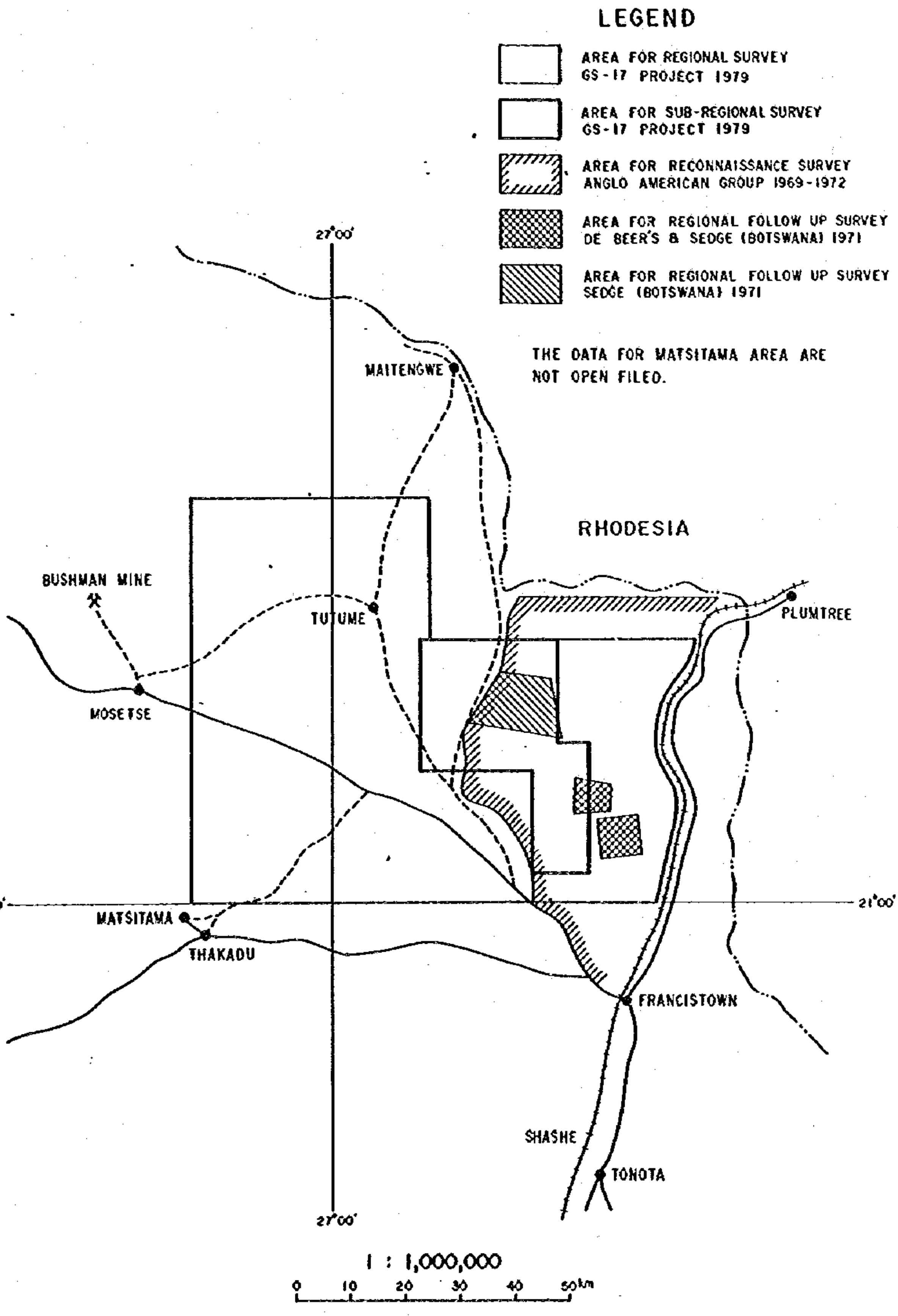


Fig. 12 Previous exploration localities, Vumba mineralized zone
(Anglo-American group open file report 1971, 1972)

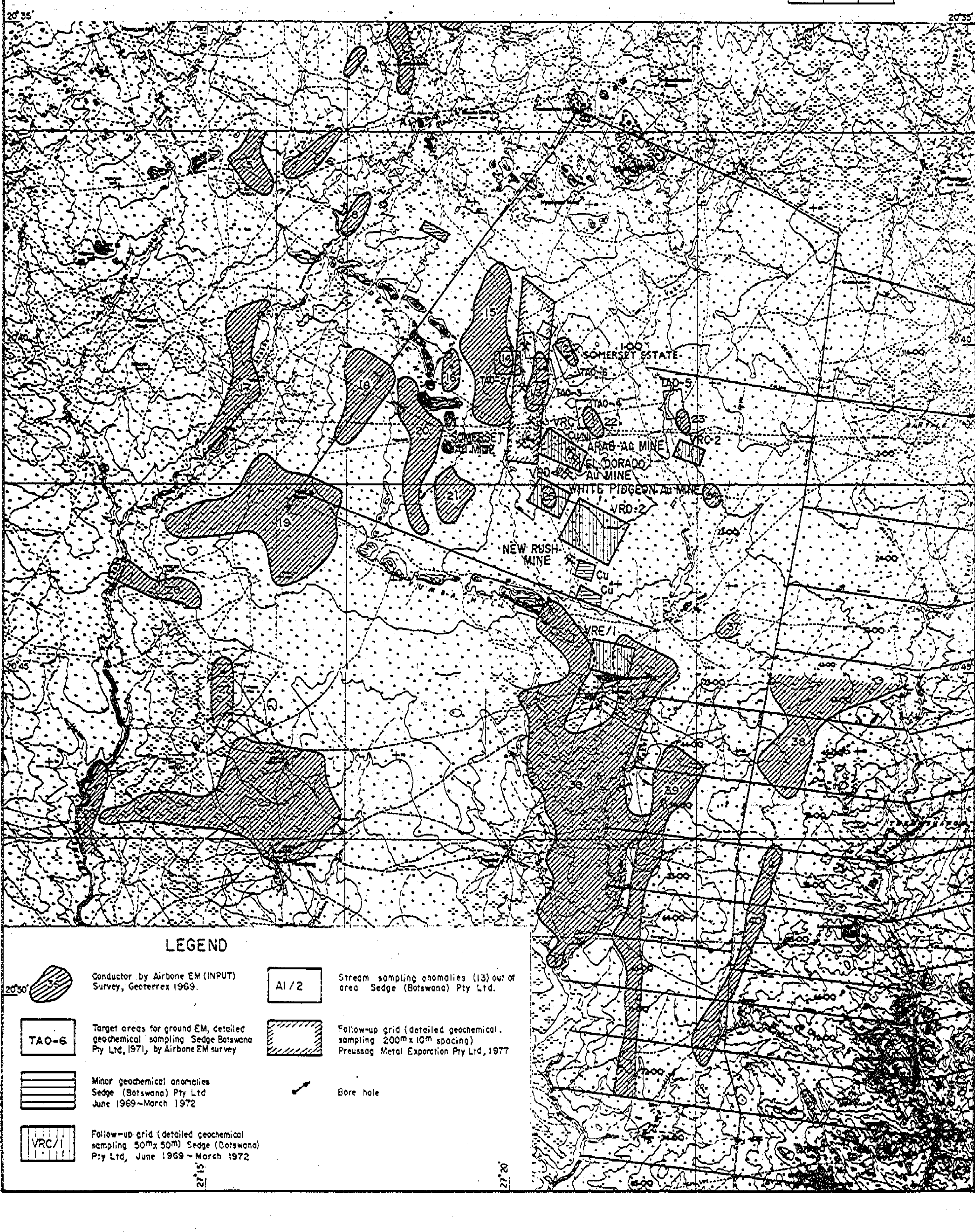


Fig. 13

Old gold workings in the Vumba mimeral province
(SEDGE Botswana Pty. Ltd. 1972. open-file report)

1 : 50,000

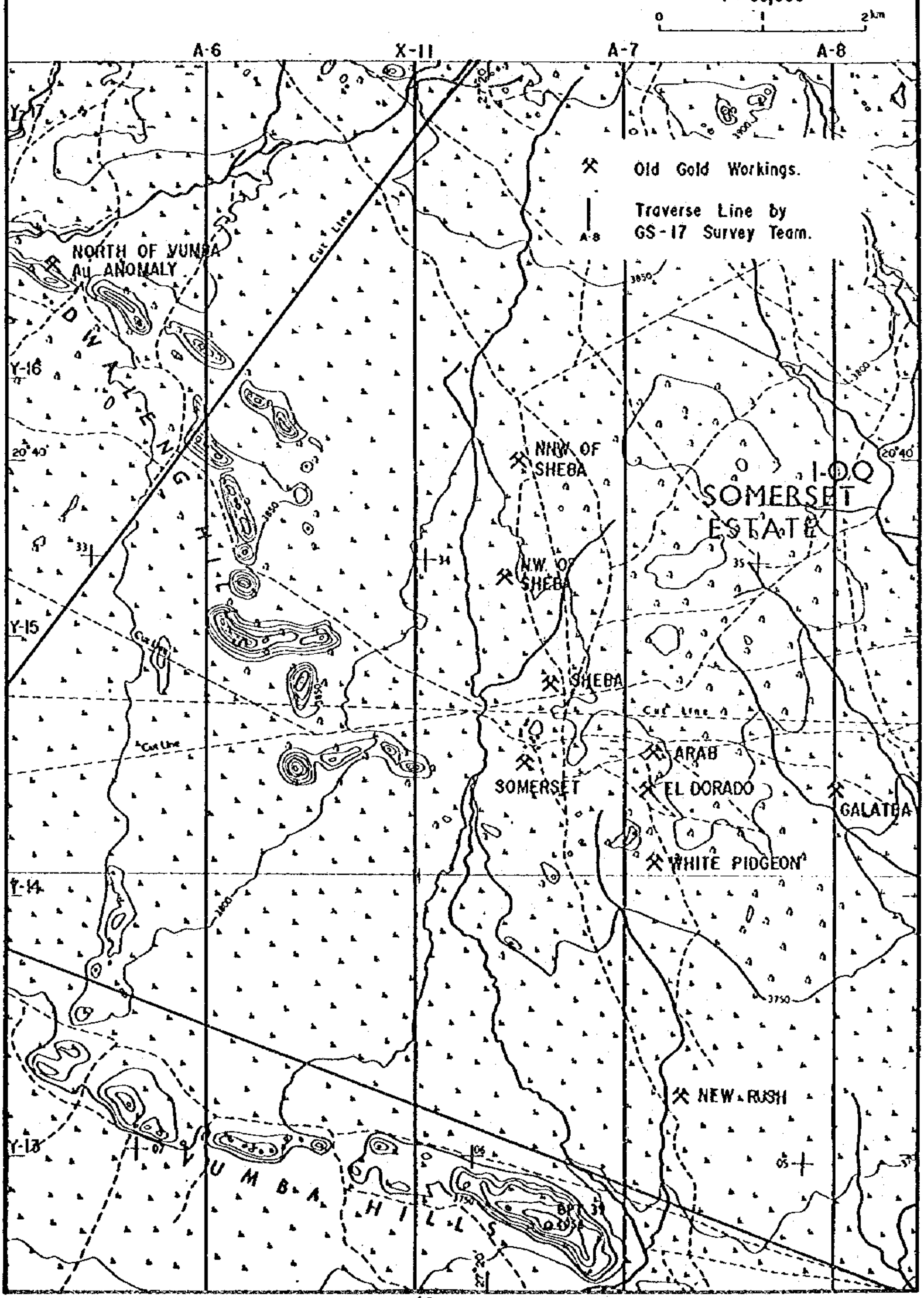
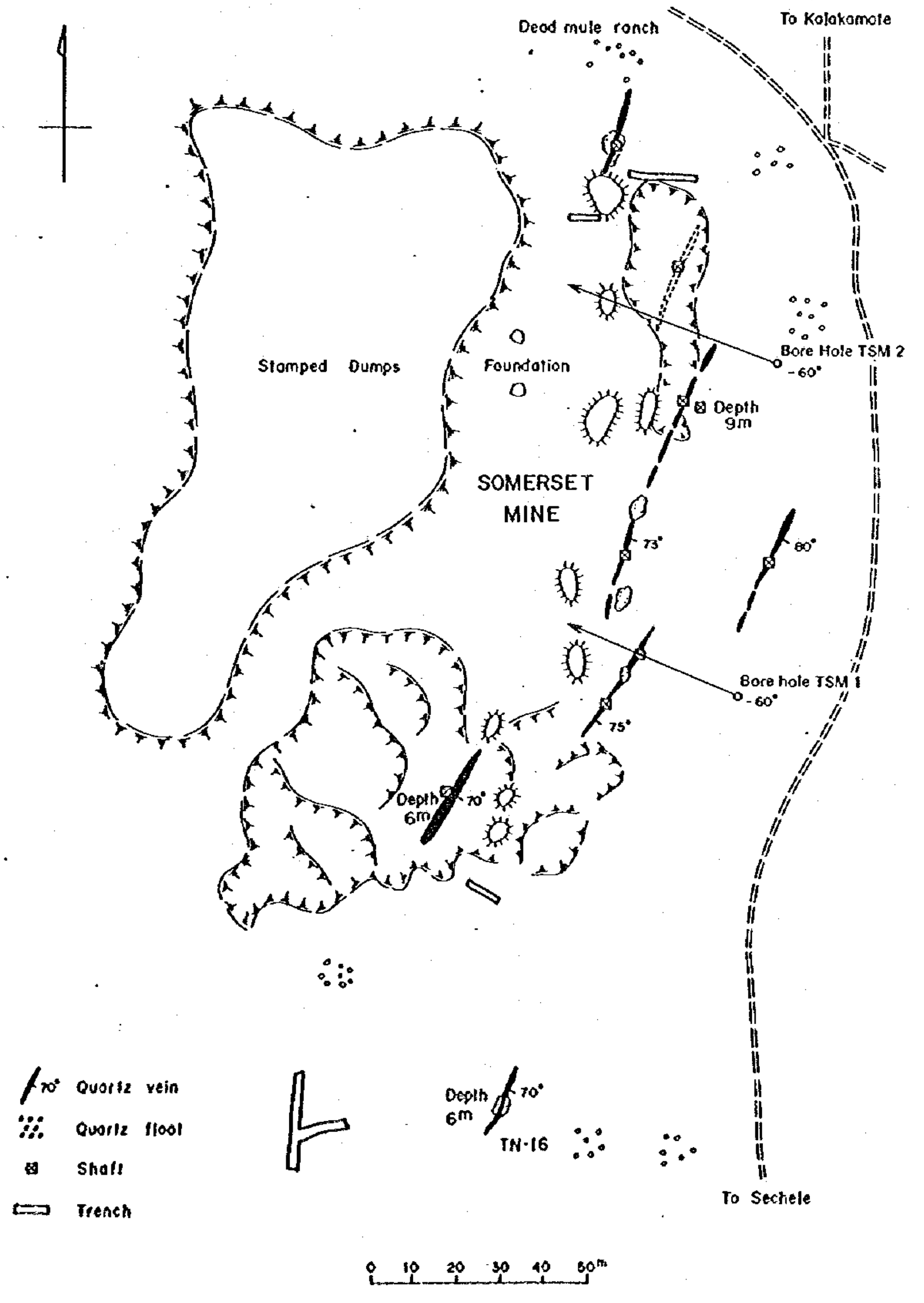


Fig. 14 Workings of Somerset mine.



Of the mineral showings listed in Table 7, Somerset is the largest and the only that has been mined. Judging from the previous mining records and the mine site condition tehre, gold-bearing quartz vein exists in a sheared zone which has a NNE - SSW trend, the vein having an extension of 200 meters and a width of 1 meter, and the grade of gold is estimated at 5 g/t. At the mine site, there are about 2,500 tons of stocked ore and some heaps of waste dump. (Fig. 14).

In this zone, the Anglo-American Group conducted explorations for nickel-bearing copper sulfide in the period of from the late 1960's to the early 1970's. As part of the explorations, the group drilled two holes (TSM-1, TSM-2) underneath the Somerset outcrop for exploration of gold. Neither of the holes intersected mineable ore deposits in depth. It was, therefore, thought that mineable ore existed only in the secondary enrichment zone near the surface. Thus, exploration was given up.

In our recent survey, we were unable to carry out detailed investigation of all the showings listed in Table 7, but took samples from the three showings of Somerset, Sheba and El Dorado, to check the potentiality of the zone. Assay results are shown in Table 8.

None of the showing are typical hydrothermal gold-bearing quartz veins associated with intruded granitic stock. Rather, they are so-called saddle reef type ore deposits in which quartz is concentrated at the top or bottom of minor foldings or in the sheared zone by metamorphic differentiation which took place when the Vumba volcanic group under went regional metamorphism. Generally, the ore deposits seem to be irregular and small, with gentle dipping. The results of sample analysis are shown in Table 8. Gold is associated with sulfides. Primarily it is of low grade, but is enriched in the weathered residual zone near the surface. Particularly in the area between the Somerset showing and Sheba showing to its north, unrecorded sulfide-rich outcrops and pits are found scattered. Since the Anglo-American Group has conducted detailed surveys for copper-bearing nickel ore deposits in the zone, we felt no need to make similar surveys there.

The Anglo-American survey consisted of a series of investigation starting with airborne geophysical surveys, followed by a geological survey, geochemical survey and heavy mineral sampling. Anomalies found in the airborne geophysical surveys (magnetic and electromagnetic) were subjected to systematic follow-up on the ground. With regard to two anomalies (TA03, TA06) which were determined to be due to bed rock, three holes were drilled but they failed to intersect any mineralized zone. Only slight sulfide dissemination was found. Surveys in the zone were discontinued as a large copper-bearing nickel ore deposit was discovered in the Phikwe-Selebi area and exploration efforts were diverted there for the most part. A summary of the Anglo-American surveys is shown in Table 6 and Fig. 12. According to open file records of the Geological Survey Department, the explorations described below were conducted for the two anomalies.

TA03 Anomaly, located in the central part of the Vumba zone, was given fourth grade priority in the airborne E.M. survey of the Vumba-Tati area. It is located in amphibolite, green schist, and quartz-amphibole schist in the Vumba volcanic group. Concerning this anomaly, ground follow-up was conducted and revealed that limonite occurs on a boundary of the rocks and shows a nickel content of 300 - 350 ppm. Also, E.M. anomaly overlapping the limonite position was detected. Two holes 100 meters apart were drilled under the limonite outcrop. Dissemination of pyrite and pyrrhotite in amphibolite was confirmed at 61.3 - 63.9 m and 69.4 - 78 m depths in one of the holes, and at 92.4 - 94.6 m depth in the other hole.

TA06 Anomaly, located 800 meters northeast of TA03 Anomaly, is found in amphibolite. Analytical value of geochemical survey was 145 ppm nickel and 80 ppm copper. Nevertheless, drilling was conducted because E.M. anomaly and magnetic anomaly overlapped the geochemical anomaly. However, the drilling hole did not intersect any mineralized zone.

1-4-2 Ore Deposits and Mineralization in Timbale Zone

In 1969, geochemical exploration for heavy mineral concentration was done by De Beer's in the Timbale igneous complex and copper and molybdenum anomalies accompanied by vanadium and yttrium anomalies were found in the complex and its aureole, related to pegmatite intrusion (Litherland, 1975). Although not investigated in detail, the environment showed certain similarities with the copper-porphyry type of mineralization.

The geochemical exploration was followed by regional geochemical exploration by soil sampling. For the anomalies found, an I.P. method geophysical survey was conducted and two most promising points were selected. Two holes were drilled in one of the two points and gave maximum values of 1,500 ppm copper and 50 ppm molybdenum, so that exploration was suspended. The extent and results of the De Beer's survey are shown in Fig. 15.

Table 6. Previous Exploration Records (Airbone Geophysical Survey and Follow-up Exploration) from Open-File Report, Geological Survey Botswana

Anomalies by airbone EM (INPUT) 1969	Recommendations by Geoterrex 1971	Priority	Follow up by Sedge (Botswana) Pty Ltd. from June 1969 to March 1972
Zone 2 conductor	Surficial conductor (Brakish water)		
3	Surficial conductor (Brakish water)		
4			
5			
7	Bedrock conductor (Halo around Zone 6. Would be examined for disseminated mineralization after Zone 6 shown good results.)		
8	Surficial conductor (Brakish water)		
12	Bedrock conductor (Ground magnetic, EM surveies were recommended.)	3	TAO-6, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Magnetometry), Diamond drilling (1 Hole, TAO6-1)
13	Bedrock conductor (may be combination of bedrock & surficial sources)	4	TAO-3, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Megnetometry), Diamond drilling (2 Hole, TAO-3-1, TAO3-2)
14	Bedrock conductor (Follow up on this one may be considered contingent on the result obtained (Zones 12 & 13)	4	TAO-2, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop EM, Magnetometry)
15	Surficial conductor (Weathering product)		
17	Surficial conductor (Brakish water)		
18			
19	Surficial conductor (Weathering product)		
20	Surficial conductor (Weathering product)		
21	Surficial conductor (Brakish water)		
22	Bedrock conductor (Very weak conductor)	4	TAO-4, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop GM, Magnetometry)
23	Bedrock conductor (Good possibility for a thin bedrock source)	3	TAO-5, 50m x 50m spacing, geochemical sampling, ground geophysical survey (Loop GM, Magnetometry)
24	Surficial conductor (Brakish water)		
25	Surficial conductor (Weathering product)		VRD-1, 50m x 50m spacing, geochemical sampling
26	Surficial conductor (Weathering product)		
27	Surficial conductor (Weathering product)		
28	Surficial conductor (Brakish water)		
29	Surficial conductor (Agricultural higher soil moisture)		
37	Surficial conductor (Weathering product) (Brakish water)		VRE-1, 50m x 50m spacing, geochemical sampling
38	Surficial conductor (Weathering product) (Brakish water)		
39	Surficial conductor (Weathering product) (Brakish water)		
40	Surficial conductor (Weathering product) (Brakish water)		

TAD-3 Detailed 200m x 10m spacing, geochemical sampling does by Preusage Metal Exploration 1977
VRD-2 50m x 50m spacing, geochemical sampling
VRC-2 50m x 50m spacing, geochemical sampling

Table 7. Description of Old Gold Workings in The Vumba Mineral Province
(Open Filed Sedge (Botswana) Pty. Ltd. 1972, Report from Geological Survey Department)

Name	Location	Geological Setting	Scale		Grade g/t (T.P.M.)	Operation Records
			Strike (m)	Width (m)		
New Rush	Southern most in the area	Steeply inclined quartz vein in highly metamorphosed amphibolite. NNE direction	400	±1	Max. 2.23	Prospecting by 3 shafts sinking, trench
Arab	Near Dead Mule ranch to Tsessebe road	The vein consists of quartz containing some pyrrhotite in NW shear plane. N45°W direction	220	±1	Max. 2.91	Working area not extensive, random shafts sunk, prospecting stage.
Sheba	NW extention of Arab workings	The identifiable quartz veins in NW zone have a NE trend and do not look promising.	Zone strike 300	-1	Max. 9.00	Do not seem to have yielded much ore. Prospecting stage.
El Dorado	About 1 km SE of the Arab mine shear	Quartz vein in shear plane which is on the same trend as Arab shear	+30	±0.5	Max. 1.05	Propsecting stage. It consists of a shaft and pits
Galatea	Near the eastern margin of Vumba schist belt	Situated on the contact of a small granodiorite plug and green schist. Quartz vein with some pyrrhotite. Assay results were poor except one sample	30	±0.5	Max. 10.2	Prospecting and mining by a shaft & a glory hole
White Pidgeon	Near El Dorado mine	East of the main granodiorite. Quartz veins in NW trend shear zone in green schist	110	±0.5	9.95	Workings extend below a depth of 30 m which is water level in the shafts. There is a honeycomb of interconnected small underground workings from which some 5,000 - 10,000 tons of ore was probably obtained.
Workings north of Sheba mine	2 km north of Somerset mine and are in vicinity of input 12, 13 Anomalies	Quartz veins in shear zone in green schist	-		5.50	Development does not seem to have passed the prospecting stage.
Workings mine of Sheba mine	1.2 km north of Somerset mine	Two sets of quartz veins in coarse grained green schist. Some 200 m SE of the main workings, there is an opaline gossan which to be of no economic value.		±0.3		A few hundred tonnes of ore was probably extracted. There small shafts have opened up.
North Vumba gold anomaly	North western side of serpentinite	Obtained when panning. The rocks consist of basic rock and serpentinite intruded by acidic rock.			None	Trench sampling results proved to be negative.
Somerset mine	In the vicinity of Dead Mule ranch	Set of quartz veins extend over 200 m on a NNE trending. The sidewalls of the veins are virtually unmineralized. Veins were payable only in the zone of supergene enrichment.	+200	±1	5.0	The largest old working in the north Tati schist belt, working extend over 150 - 200 m. Total 2,500 tonnes ore expect. Neither of two bore holes intersected any mineralization beneath the old workings.

Table 8. Analytical Data on Ore

(1) Chemical Analysis

	Location	Analysis (%) Au (g/t)						
		Au	Cu	Pb	Zn	Ni	Co	Mo
S - 1	Matsitama	-	0.02	0.00	0.01	0.01	0.00	0.000
S - 55	Kalakamate	-	0.00	0.00	0.00	0.00	0.00	0.160
S - 554	Somerset Mine	0.4	0.04	0.00	0.01	0.01	0.01	0.000
S - 556	El Dorado Mine	0.0	0.00	0.00	0.01	0.00	0.00	0.000
S - 557	El Dorado Mine	0.0	0.01	0.00	0.01	0.02	0.00	0.000
S - 558	Sheba Mine	2.3	0.03	0.00	0.02	0.01	0.00	0.000
S - 559	Sheba Mine	7.8	0.06	0.00	0.01	0.01	0.00	0.000
S - 560	Matsitama Mine	0.3	3.61	1.00	5.97	0.00	0.01	0.000

(2) Natures of Ore

	Sample	Ore Microscopy
S - 1	Fine amphibolite schist	
S - 55	Micro mus. - bio. granite with M_oS_2 dissemination	M_oS_2: 30 x 60 μ ~ 0.2 x 1.0 m/m
S - 554	Quartz patch in banded amphibolite	
S - 556	Banded amphibolite with thin layer of quartz	
S - 557	Porous quartz vein	
S - 558	Quartz patch in banded amphibolite	Cp (4 ~ 20 μ). Py (10 ~ 60 μ)
S - 559	Limonitized amphibolite	Py (20 μ ~ 0.8 mm), Cp (16 ~ 80 μ), Po (20 μ ~ 0.1 mm) Lo (50 μ ~ 1 mm)
S - 560	Banded copper ore in carbonaceous layer of amphibolite	Cp (5 μ ~ 1.2 mm), Sp (0.1 ~ 0.8 mm), Gn in Cp, Sp
S - 98	Dombashaba G_4 biot. granite	Cp (4 ~ 20 μ)

Cp: Chalcopyrite, Gn: Galena, M_oS_2: Molybdenite, Po: Pyrrhotite, Py: Pyrite, Sp: Sphalerite
Lo: Loellingite

Some of other anomalies, including vanadium, ytrium, nickel, copper, niobium, molybdenum, tin, tungsten, gold, and lead, were thought to be related to rare metal mineralization, but since no outcrop was found, there was no field evidence. It is likely that these anomalies were not caused by a single type of mineralization, but involved many factors, for example: some copper, molybdenum, and ytrium anomalies are associated with pegmatite veins which intruded in the later stage of Timbale granitic activity: some anomalies are related with dolerite intrusion; vanadium anomalies are associated with pegmatite veins which intruded in the later stage of Timbale granitic Timbale igneous complex.

In our survey, heavy mineral sampling by panning was perfomred in the Timblale zone and, for comparison, in northern Sebina at two points each. Each sample was subjected to X-ray diffraction analysis and X-ray fluorescence analysis (Table 9, PL. 5, Apex. 4).

Geologically, granitic rocks (G_4) and dolerite occur in the Timbale zone, and Vumba schist relic, granitoid (G_1, G_2) and dolerite occur in the Sebina zone. Sandy samples concentrated to $\frac{1}{(n \times 1{,}000)}$ by panning were used in the X-ray analysis. The samples consisted, for the most part, of magnetite and ilmenite.

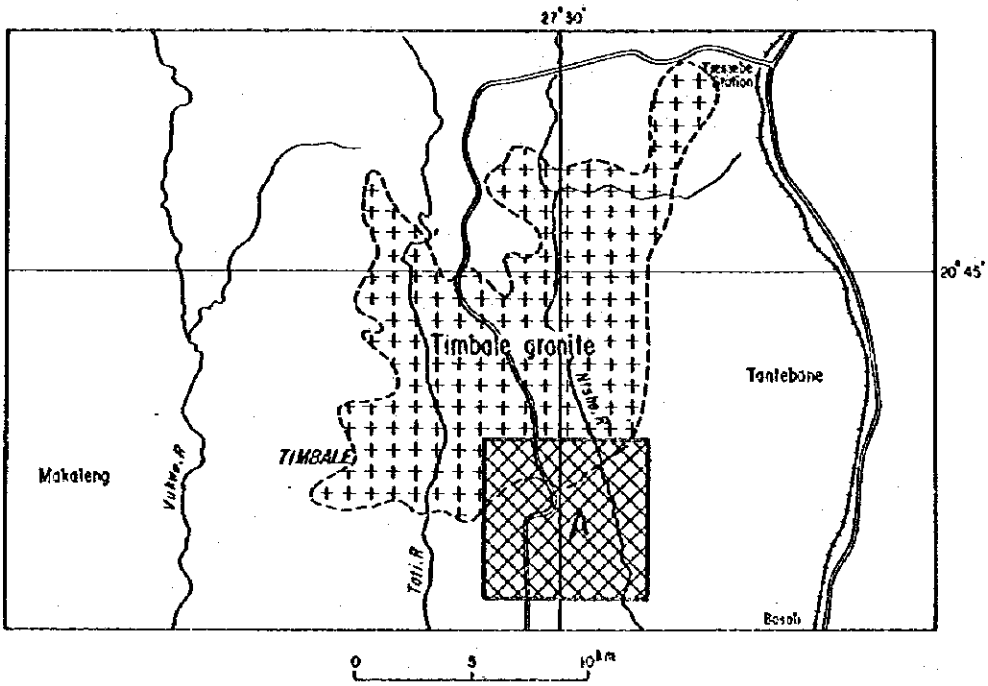
Ilmenite, magnetite and monazite were confirmed by X-ray diffraction analysis as heavy minerals in samples from the Timbale zone (S-542, S-549). The X-ray fluorescence analysis revealed a very large amount of Ti, Fe, Mn, a rather large amount of Y, Zr, Nb, Th and traces of Cr, Ni, Cu, Zn, Pb, Rb, Sr, Ta, La, Ce, Pr, Nd, V.

In the Sebina zone, monazite was absent but other heavy minerals were found in a similar combination to that in the Timbale zone, as similar minerals occur in the two zones. In S-546, no La or Ce was detected. This presumably because the sampling point was near ultramafic rocks. (S-546, S-547)

Although our investigation did not cover the entire area in detail, the results of geological and geochemical surveys indicate little possibility of porphyry type copper-molybdenum ore deposits in the Timbale zone.

Fig. 15 Geochemical distribution of molybdenum, timbale block.

(De beer's-sedge Botswana open-file report 1972)



Detail of Area A

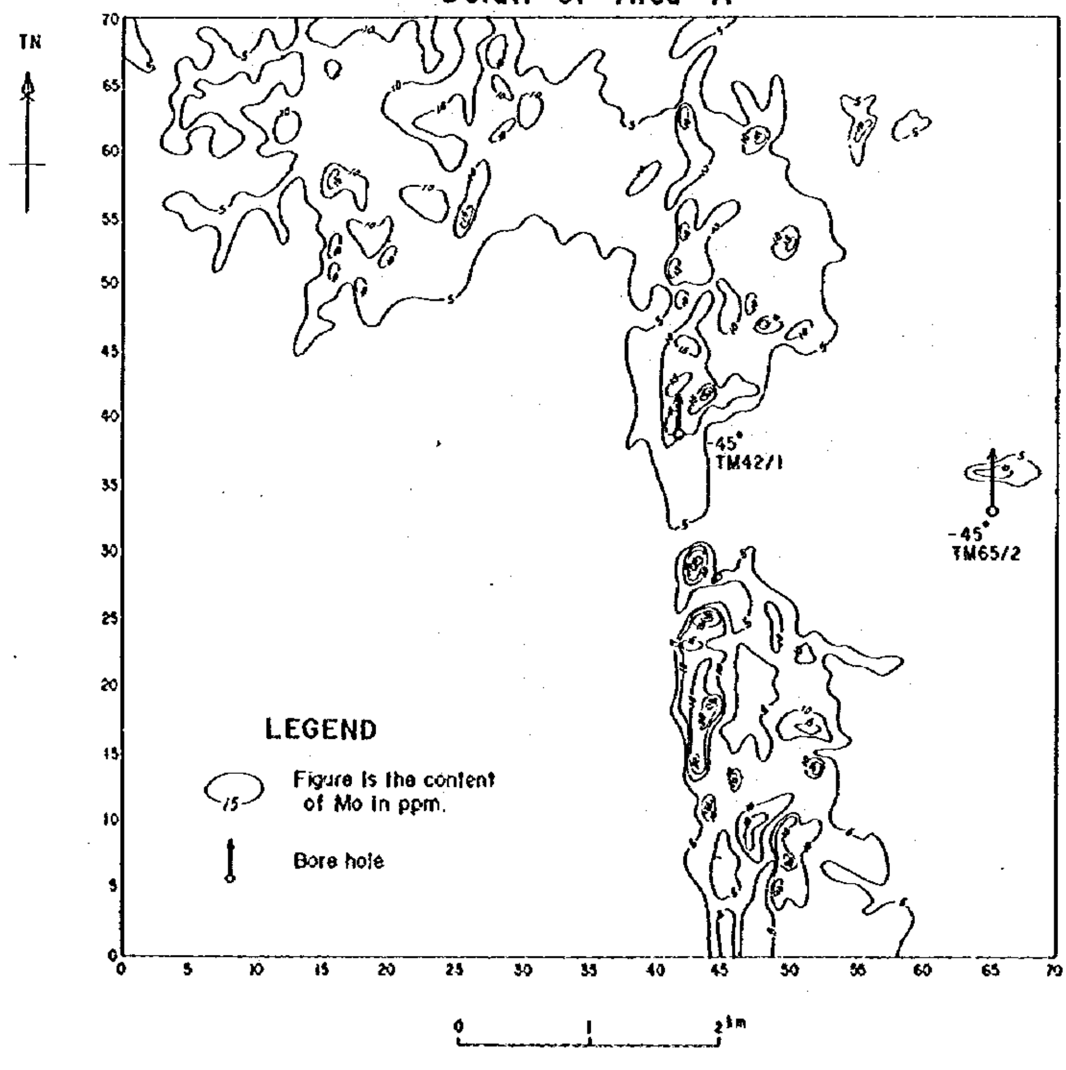


Table 9. Data on X-Ray Diffraction and Fluorescence Analysis

(1) X-Ray Diffraction Analysis

Sample No.	Location	Geology of Surroundings	Quartz	Feldspar	Ilmenite	Magnetite	Amphibole	Monazite
S - 542	Timbale Hill	G_4 Granite, Dolerite ~ Gabbro	+++	+++	++	+	+	
S - 549	Timbale Hill	G_4 Granite, Dolerite ~ Gabbro	+++	+++	+			−
S - 545	7 km N W of Sebina	Ultramafic, Amphibolite, Tonalite - Granite	+++	+++	+++	+	+	
S - 546	9 km N W of Sebina	Gneiss (G_{2g}, G_{2ht}, G_1), Meta-arkose.	+++	++	+++		++	

(2) X-Ray Fluorescence Analysis

Sample No.	Ti	Cr	Mn	Fe	Ni	Cu	Zn	Pb	Rb	Sr	Y	Zr	Nb	Ta	La	Ce	Pr	Nd	Th	V
S - 542	+++	−	++	+++	−	−	+	−	−	+	+	++	+		−	−	−	−	+	
S - 549	+++	+	++	+++	−	+	+	+	+	+	+++	+++	+++	−	+	+	+	+	+++	−
S - 545	+++	+	++	+++	−	−	+	−	−	−	+	++	+		−	+	−	−	+	
S - 546	+++	+	++	+++	−	+	+			+	+	+++	+						−	

+++: Abundant, ++: Common, +: A little, −: Rare

Concerning rare elements, there is no large rare element ore deposit, at least in the very limited area that 2 panning samples cover.

Since our survey failed to discover any new outcrops, there is no reason to give priority to the Timbale zone in next year's exploration.

1-4-3 Ore Deposits and Mineralization in North Matsitama Zone

In the southern end of the survey area, there is the Matsitama sedimentary basin, which is thought to constitute a part of the Rhodesian croton. Distributed irregularly in the basin area, is the Matsitama schist and metasedimentary group which has undergone amphibolite facies regional metamorphism, and consists of basic schists, amphibolite, quartzite, limestone, and banded iron stone. Sulfides, mainly copper sulfide, occur in the limestone (ranging from siliceous limestone to calcareous quartzite) and the schists. The sulfides do not contain nickel but are accompanied by gold, silver, and lead and zinc minerals. Judging from occurrence, the sulfides are presumably of syngenetic origin. This ore deposit is rather similar to the sedimentary copper ore deposit in the Damaran Mobil zone of western Botswana but differs from the Selebi Phikwe copper nickel ore deposit and the copper nickel ore deposit in the Tati schist belt.

The Mtssitama sedimentary basin has many workings for copper, which were discovered in 1962 by the Anglo-American Group and the group conducted much exploration of the zone. Up to the present, a total of 14 showings have been confirmed at Thakadu, Makala, Logolo, Peolane-Noko, Nakalakwana Hill, Dihudi, Sebotha-Samsonga-Esoka, Mutsuku, Kamela, Lengau, Nare, Nakalakwana Prospect, Kukama, Lepashe, Agente, Palamela. The most promising of them is Thakadu and Makala, where reserves of 8 million tons of 2.2% Cu (including copper oxide ore) have been confirmed (J.W. Baldock, 1977). Exploration of this zone was discontinued in 1966, when a large ore deposit was found at Selebi-Phikwe, which is now in production. The main scene of exploration now has moved to Bushman Lineament, a cataclastic deformation zone to the west of the survey area.

The survey area is located in the northwestern edge of the Matsitama sedimentary basin. The line connecting the showings at Lengau, Nare, Nakalakwana Prospect, and Nakalakwane Hill forms the southern limit of the survey area. The Matsitama schist and metasedimentary group has a strike with a NW-SE trend and dips to the south. Consequently, it may be thought that this group does not extend into our survey area because a lower member group, miz., the Mosetse River gneiss group, outcrops there. However, as the Mosetse River gneiss group has intercalated limestone lenses, which make it similar to the Matsitama group, there is a possibility that a part of the Mosetse River gneiss group is included in the Matsitama group. This is suggested by the results of our geochemical survey.

In an attempt to find Matsitama type ore deposits in the survey area, we conducted geochemical check sampling and ore sampling along two traverse lines in the center of the Matsitama mineralized zone. The analytical results of ore are presented in Table 8.

The ore samples contained visible amounts of sphalerite and galena; and the nickel content was extremely low in proportion to copper. This is in sharp contrast to the nature of ore in the Vumba zone, where nickel content is high as well as copper content.

2. Geochemical Survey

2-1 Introduction

2-1-1 Outline of Geochemical Survey

The purpose of the present geochemical survey is to detect geochemical anomaly areas due to mineralization and to obtain the basic data for further surveys and studies by analyzing element contents in soil within the survey area and statistically analyzing their behavior by means of an electronic computer.

For the indicative elements, Cu, Ni and Mo were chosen at the beginning, but Mo content was found to be of values below 3 ppm as the result of chemical analysis and was judged inadequate as an indicative element. Consequently Pb and Zn were added as indicative elements.

In the analytical process, first the characters of the soil samples and the various environmental aspects of the sampling sites were studied and then the relations between these and the indicative elements were investigated. As the result, it was found that extraction of mineralization anomalies by the interpretation for each indicative element is difficult; so that an analytical technique was conducted by the principal component analysis method which is a technique of the multivariate analysis method.

2-1-2 Number of Samples

The total number of samples subjected to analysis is 539, the breakdown of which is shown Table 10.

Table 10. Breakdown of Samples

Contents	No. of Sample	Remarks
Regional survey area	383	* Out of this, 74 samples are identical with the ones in regional survey area.
Sub-regional survey area	188*	
Samples for comparing sampling horizon	7	
Mo indicating sites	4	
Matsitama mineralized horizon (reference samples)	27	
Outside of survey area	2	

The sampling density is 14 km^2 per sample in the regional survey area and 4 km^2 per sample in the sub-regional area.

2-1-3 Soil Profile and Sampling Method

The soil in these areas consists of red lateritic soil (accounting for 22%), brown soil (66%), and dark-gray moist soil called "black turf" (11%). Lateritic soil has a thickness of 30 to 50 cm at the top and is a red oxidization zone containing iron oxide cores. Underlying it, there is a transitional zone, 50 cm to 1 m thick and reddish-brown to brown in color, accompanied by the veinlets of iron oxide; this reaches weathered country rock at bottom. Dark-gray moist soil, which is rich in plant roots, has a thickness of 1 m to over 3 m; the thickness to its country rock has not yet been confirmed. The profile of brown soil is unknown.

As for sampling, in the regional survey area the intervals of survey lines were set at 6 km and the spacing of sampling points at 2.5 km. In the sub-regional survey area, the former were set at 2 km and the latter at 2.5 km. All of their positions were determined by means of a compass and a measuring chain and then plotted on the topographical maps.

The sampling depth was made to be 30 cm making reference to the open filed report of Sedge (1972). For comparison purpose, samples from different depths in the same spot were taken at nine places (the combination of the sample Nos. 63-496, 65-497, 71-499, 85-500, 131-501, 151-502, 191-503, 213-504, 219-505, and analysed, but no significant difference was recognized.

When sampling was made, the color tones of soil, its grain size and dry or moist condition, quantities of plant roots, the kinds, quantities and shape of pebbles in soil, vegetation, topography, and kinds of exposed rock and boulders were recorded. (Apex. 5).

2-1-4 Method of Analysis

With regard to the samples taken, the undersize from a 80 mesh sieve was colleted, and, after having been air-dried, subjected to analysis in Japan. Since import of soil into Japan is not allowed, in bringing them into Japan, they had to be disinfected by hot (about 120°C) steam at Narita Quarantine Station immediately after import, in accordance with the arrangement with the quarantine authorities.

For the analysis, the atomic absorption spectroscopy method was applied to the samples for all the contents of Cu, Pb, Zn, Ni and Mo, and in addition Co for part of the samples.

The outline of the analysis procedure is as follows:

An amount of 20 ml of hydrochloric acid and 5 ml of nitric acid was added to 5.00 grams of a sample; it was heated until it became dry and solid. After it has been let to cool, 10 ml of hydrochloric acid was added to it, and it was reheated and dissolved. This was diluted with water to make constant volume of 100 ml, and the filtrate was subjected to analysis by atomic absorption spectroscopy. Only Mo was atomized with nitrous oxide-acetylene flames, and the other elements with air-acetylene flames. The warelength was: 3,247 Å for Cu, 2,170 Å for Pb, 2,139 Å for Zn, 2,320 Å for Ni, 2,408 Å for Co, and 3,133 Å for Mo. As a result of a comparative test for five samples, the resolving power of the above process was about 70% of that when leached with fluoric acid.

2-2 Characters of Samples and Environment of Sampling Area

The exploration work had to be set about without any preliminary knowledge about the characters of the samples and the environment of the sampling sites, which are useful in the analysis of the results of geochemical exploration.

Therefore, the work was started, prior to the analysis of the results of chemical analysis, with the studies of various kinds of information recorded during the sampling, including the interrelationship between color tones, grain size, existence of organic matters and humidity of soil samples, the vegetation, topography, kinds of pebbles, kinds of exposed rock, and others.

2-2-1 Frequencies of Items

Table 11-1 ~ 8 collectively sets forth the frequencies of various items about the natures of the soil samples and the enviornment of the sampling sites.

The color tones of the soil have been classified into eight kinds, unsubdivided red, red-brick, reddish brown, unsubdivided brown, light-brown, grayish brown, light-gray,

Table 11. Frequencies of Natures of Soil Samples and of Other Characteristics Around Sampling Sites

(1) Soil Color

Code	Color	Frequency	Percentage	Frequency	Percentage
10	Red unsubdivided	12	2.4	112	22.6
11	Brick red	50	10.1		
12	Reddish brown	50	10.1		
20	Brown unsubdivided	33	6.6	264	53.1
21	Light brown	70	14.1		
22	Grayish brown	161	32.4		
31	Light gray	66	13.3	121	24.4
32	Dark gray - Black	55	11.1		

(N=497)

(2) Plant Roots in Sampling Horizon

Code	Amount	Frequency	Percentage
0	None	13	2.6
1	a little	248	49.9
2	Medium	171	34.4
3	Abundant	65	13.1

(N=447)

(3) Vegitation Around Sampling Sites

Code	Type	Frequency	Percentage
1	Tree Savanna	215	43.3
2	Shrub Savanna	237	47.7
3	Cultivation, Grassland	45	9.0

(N=497)

(4) Topography

Code	Type	Frequency	Percentage
1	Mountain, Hill	11	2.2
2	Flatland	431	86.7
3	River, Riverbank	38	7.6
4	Lowland, Marshland	17	3.4

(N=497)

(5) Dry/Wet (Humidity)

Code	Type	Frequency	Percentage
0	Dry	427	85.9
1	Wet (Moist)	70	14.1

(N=497)

(6) Soil Nature - 1

Code	Type		Frequency		Percentage		Percentage	
10	Clayey	Not characteristic	10	62	2.0	12.5	16.1	100.1
11		Lateritic	4		0.8		6.5	
12		Organiferous	43		8.7		69.4	
13		Stream Sediment	5		1.0		8.1	
20	Sandy	Not Characteristic	323	435	65.0	87.5	74.3	100.1
21		Lateritic	91		18.3		20.9	
22		Organiferous	2		0.4		0.5	
23		Stream Sediment	19		3.8		4.4	

(N=497)

(7) Soil Nature - 2

Code	Type	Frequency	Percentage
0	Not Characteristic	333	67.0
1	Lateritic	95	19.1
2	Organiferous	45	9.1
3	Stream Sediment	24	4.8

(N=497)

(8) Surface Condition

<table>
<tr><th colspan="3">Outcrop</th><th colspan="4">Floats Except Quartz</th><th colspan="5">Quartz Float</th></tr>
<tr><th></th><th>Freq.</th><th>%</th><th></th><th>Freq.</th><th>%</th><th>%</th><th></th><th>Freq.</th><th>%</th><th>%</th><th></th></tr>
<tr><td rowspan="4">No</td><td rowspan="4">411</td><td rowspan="4">82.7</td><td rowspan="2">No</td><td rowspan="2">355</td><td rowspan="2">86.4</td><td rowspan="4">No
79.2</td><td>No</td><td>270</td><td>76.1</td><td rowspan="4">No
73.0
Yes
27.0</td><td rowspan="4">No
73.3</td></tr>
<tr><td>Yes</td><td>85</td><td>23.9</td></tr>
<tr><td rowspan="2">Yes</td><td rowspan="2">56</td><td rowspan="2">13.6</td><td>No</td><td>30</td><td>53.6</td></tr>
<tr><td>Yes</td><td>26</td><td>46.4</td></tr>
<tr><td rowspan="4">Yes</td><td rowspan="4">86</td><td rowspan="4">17.3</td><td rowspan="2">No</td><td rowspan="2">39</td><td rowspan="2">45.3</td><td rowspan="4">Yes
20.8</td><td>No</td><td>36</td><td>92.3</td><td rowspan="4">No
74.4
Yes
25.6</td><td rowspan="4">Yes
26.7</td></tr>
<tr><td>Yes</td><td>3</td><td>7.7</td></tr>
<tr><td rowspan="2">Yes</td><td rowspan="2">47</td><td rowspan="2">54.7</td><td>No</td><td>28</td><td>59.6</td></tr>
<tr><td>Yes</td><td>19</td><td>40.4</td></tr>
</table>

(N=497)

Yes or No : Existence of outcrop, etc.

and dark-gray to black, which have been put into the broad classification of red group (accounting for 23%), brown group (53%), and gray group (24%). This gray group includes the soil which is dark-gray to black in color and is called "black turf" in southern Africa, accounting for 11% of the total. (Table 11-1)

For the amount of the roots of the plants at the sampling horizon, classification has been made a little (accounting for 50%), medium (34%), abundant (13%), and none (3%). (Table 11-2)

The vegetation around the sampling sites has been classified into Shrub or bush savanna (accounting for 48%) where trees, 1 to 3 meters high, are mainly of *acacia* family, tree savanna (43%) where trees, 5 to 10 meters high, are broadleaf ones, mostly *mopani*, and cultivated land or grassland (9%). (Table 11-3)

The topography has been classified into hill, flatland, river, riverbank, lowland, and marshland, most of the topography (87%) being covered by flatland. (Table 11-4)

In spite of the sampling work having been carried out in the dry season, 14% of the soil was moist. (Table 11-5)

The difference in grain size of the soil samples, one of their characters, has been expressed as follows: sandy samples accounting for 87.5%, while clayey ones 12.5%. As one way of expressing the characters of the soil, classification has been made as follows: lateritic soil (accounting for 19%), organic one (9%), stream sediments (5%), and one without any distinguishing character (67%). From the combination of these two characters induced is the feature that lateritic soil is sandy while organic one is clayey. (Table 11-6, 11-7)

The rate of distribution of exposed rock around the sampling sites is only 17% of the total sites. The rate of distribution of quartz pebbles or boulders in the soil is 27%, while the rate of boulders other than those of quartz being distributed there is 21%. The rate of boulders other than those of quartz being distributed when exposed rock exists in the vicinities comes up to 55%; the being compared with the rate of 14% when there is no exposed rock in the vicinities, a clear difference is recognized. On the other hand, the rate of quartz pebbles or boulders being distributed hardly varies regardless of whether exposed rock exists in the vicinities of the sampling sites or not; the rate was found 26 or

27%. This makes one infer that the distribution of quartz pebbles or boulders in the soil has been brought about by some regional mechanism more wide-ranging than the local distribution of exposed rock. In addition to the above, frequency of the quantities and shape of pebbles at the sampling horizon and frequency of kinds of rock in boulders and exposed rock were studied, but any particular relations were not observed. (Table 11-8)

2-2-2 Relations between Color Tones of Soil and Other Items

It is generally viewed that the item that reflects the chemical composition of the country rock the most among the items mentioned in the above seciton is the color tones of the soil. Therefore, studies have been made of the relations between the color tones of the soil and the other items by making Tables 12-1 ~ 9.

The quantities of plant roots in the soil are small to medium in red soil and brown one, and it is the average character of the whole area. With dark-gray to black soil, or black turf, it exhibits the tendency of being characteristically rich in plant roots. Light-gray soil with Code No. 31 presents a character entirely different from that of dark-gray soil with Code No. 32, rather similar to that of brown soil. Since this is a phenomenon recognized in common with the other items mentioned below, light-gray soil is regarded as belonging in brown soil in the broad classification of color tones. (Table 12-1)

As for vegetation, it is characteristic that the rate of being occupied by shrub savanna in dark-gray soil, or black turf, is as high as 69%. In the red soil category, the soil of Code No. 10 (unsubdivided) shows a high rate of being occupied by shurb savanna, but the ones of Code Nos. 11 and 12 in the same category are not indicative of this tendency. This could be accounted for by inconsistency of the definition of vegetation kinds by the surveying members, such as how to treat mixed vegetation. (Table 12-2)

As for the topography, flatland is predominant, its covering rate ranging from 64 to 92%, as indicated in the frequency over the whole area; but, characteristically, 27% of dark-gray soil is in lowland and marshland. (Table 12-3)

With regard to humidity of the samples, more than 90% of red soil and brown soil was found dry, while 73% of dark-gray soil moist conversely. (Table 12-4)

The character of the soil corresponds well to the broad classification of color tones: red soil is either sandy or lateritic, brown soil is sandy with no distinguishing character, and dark-gray soil is clayey and organic. (Table 12-5)

The rates of distribution of exposed rock, quartz pebbles or boulders, and other boulders in the vicinities of the sampling sites are 15%, 20%, and 23% respectively in the case of red soil, while in the case of brown soil they are 20%, 24%, and 20% respectively. No significant difference is recognized in them. In the case of dark-gray soil, however, they are 9%, 56%, and 18% respectively, indicating the tendency that exposed rock is less distributed than in the other kinds of soil and that quartz pebbles or boulders are more distributed. (Table 12-6, 12-7)

It has been indicated that the quantities and shape of pebbles at the sampling horizon are not related with the color tones of soil. (Table 12-8)

As for the classification of the exposed rock and boulders in the vicinities of the sampling sites according to their rock kinds, their relations with the color tones of soil have not be able to be clarified because of the small number of applicable samples. Therefore, the relation between the geological units in the eastern area of which the distribution of lithofacies has been revealed by Litherland (1975) (with 343 samples) and the color tones of soil has been described. In red soil, Am (amphibolite) and D (dolerite and gabbro), both being basic rock, accounted for 36% respectively. In brown soil, G_{2t} (tonalite gneiss), G_{2g} (granite gneiss), A_k (meta arkose), G_t (monzonite), G_{2ht} (hornblende tonalite gneiss), PG_{2g} (porphyroblastic granite gneiss), and G_{3t} (tonalite), which are all acidic rock, accounted for 6 to 22%. In dark-gray soil, A_m (amphibolite) accounted for 48%, while G_{2t} (tonalite gneiss) 16%. (Table 12-9)

As the result of studies of the above-mentioned, the relations between the color tones of soil and the other items are concluded as follows:

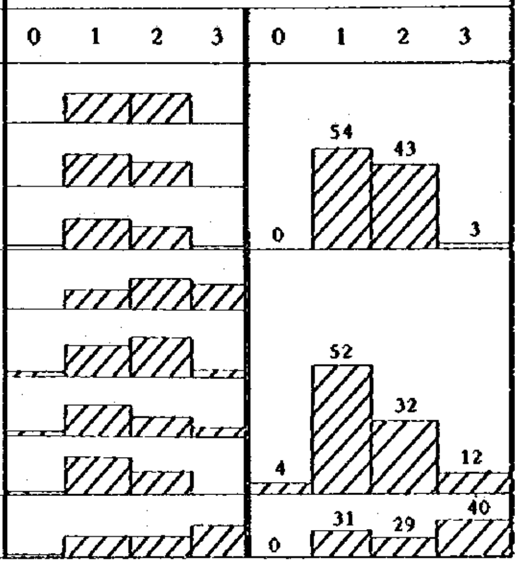
The rate of 72% of red soil, stemming from amphibolite and dolerite (or gabbro) as the country rock, is sandy and lateritic, and also permeable. As for the vegetation there, being the reflection of such properties, shrub savanna and tree savanna have been developed to the same degree, and the quantities of plant roots in the soil are small or medium. The rate of 82% of brown soil stems from acidic gneiss and the likes as the country rock, is sandy without any major characteristic, and also permeable. Regarding the vegetation there, tree savanna has been more developed than in red soil; the quantities of plant roots tend to be less. The rate of 48% of dark-gray soil,

Table 12. Relation between Soil Colors and Other Natures and Characters

(1) Soil Color – Plant Roots

Color		Frequency				Percentage %			
Code		0	1	2	3	0	1	2	3
Red	10	0	6	6	0	0	50	50	0
	11	0	30	20	0	0	60	40	0
	12	0	25	22	3	0	50	44	6
Brown	20	0	9	13	11	0	27	39	33
	21	1	29	32	8	1	41	46	11
	22	12	88	44	17	7	55	27	11
	31	0	44	18	0	0	71	29	0
D. Gray	32	0	17	16	22	0	31	29	40

Percentage Histogram

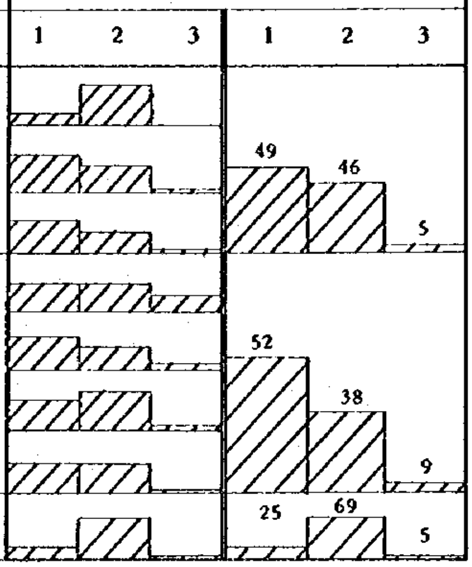


0: None, 1: A little, 2: Medium, 3: Abundant
Code number: Same as that of Table 11

(2) Soil Color – Vegetation

Soil Color		Frequency			Percentage %		
Code		1	2	3	1	2	3
Red	10	2	10	0	17	83	0
	11	26	20	4	52	40	8
	12	27	21	2	54	42	4
Brown	20	13	13	7	39	39	21
	21	38	24	8	54	34	11
	22	63	79	19	39	49	12
	31	32	32	2	48	48	3
D. Gray	32	14	38	3	25	69	5

Percentage Histogram

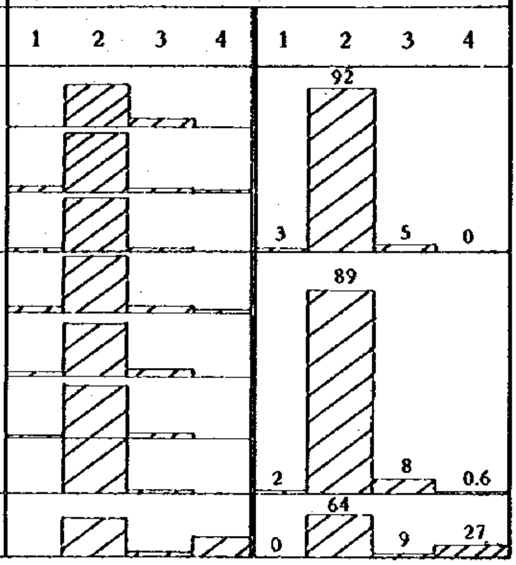


1: Tree Savanna, 2: Shrub Savanna, 3: Cultivation, Grassland

(3) Soil Color – Topography

Soil Color	Code	Frequency 1	2	3	4	Percentage % 1	2	3	4
Red	10	0	9	3	0	0	75	25	0
	11	1	48	1	0	2	96	2	0
	12	2	46	2	0	4	92	4	0
Brown	20	1	31	1	0	3	94	3	0
	21	2	61	7	0	3	87	10	0
	22	5	136	18	2	3	84	11	1
	31	0	65	1	0	0	98	2	0
D. Gray	32	0	35	5	15	0	64	9	27

Percentage Histogram

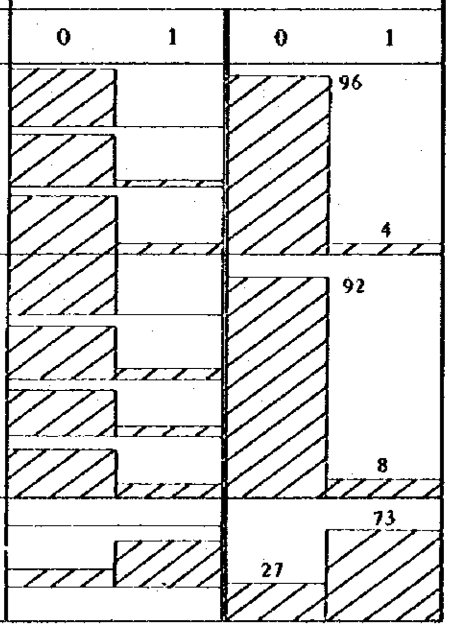


1: Mountain, Hill, 2: Flatland, 3: River, Riverbank, 4: Lowland, Marshland

(4) Soil Color – Dry/Wet

Soil Color	Code	Frequency 0	1	Percentage % 0	1
Red	10	12	0	100	0
	11	49	1	98	2
	12	46	4	92	8
Brown	20	33	0	100	0
	21	64	6	91	9
	22	148	13	92	8
	31	60	6	91	9
D. Gray	32	15	40	27	73

Percentage Histogram



0: Dry, 1: Wet

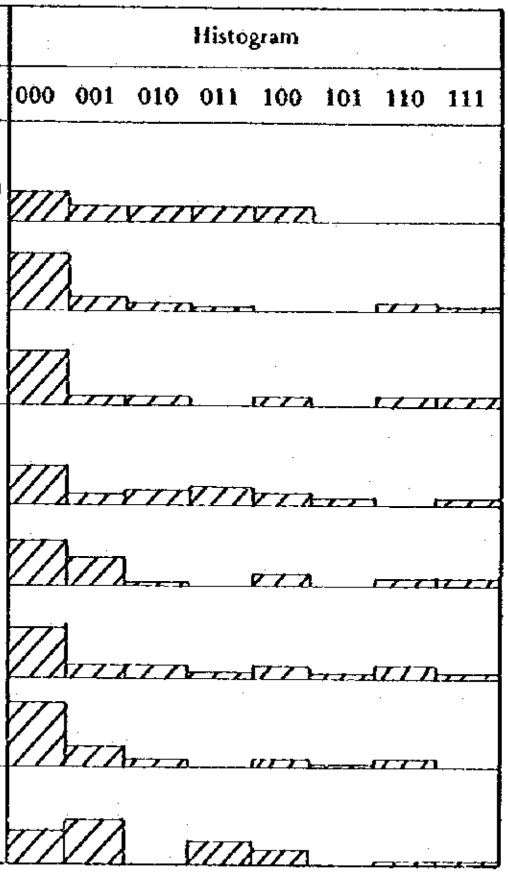
(5) Soil Color – Soil Natures

Soil Color		Frequency								Percentage %					
Code		10	11	12	13	20	21	22	23	1-	2-	-0	-1	-2	-3
Red	10	0	0	0	0	2	10	0	0	0 (0)	12 (100)	2 (17)	10 (83)	0 (0)	0 (0)
	11	0	4	0	0	4	42	0	0	4 (8)	46 (92)	4 (8)	46 (92)	0 (0)	0 (0)
	12	0	0	0	0	19	31	0	0	0 0	50 (100)	19 (38)	31 (62)	0 (0)	0 (0)
Brown	20	0	0	0	0	33	0	0	0	0 (0)	33 (100)	33 (100)	0 (0)	0 (0)	0 (0)
	21	1	0	3	0	60	5	1	0	4 (6)	66 (94)	61 (86)	6 (8)	4 (6)	0 (0)
	22	1	0	0	0	142	2	0	16	1 (0)	160 (100)	143 (89)	2 (1)	0 (0)	16 (10)
	31	4	0	0	1	61	0	0	0	5 (8)	61 (92)	65 (98)	0 0	0 0	1 2
D. Gray	32	4	0	40	4	2	1	1	3	48 (87)	7 (13)	6 (11)	1 (2)	41 (75)	7 (13)

1-: Clayey, 2-: Sandy, -0: Usual, -1: Lateritic, -2: Organiferous, -3: Stream sediment

(6) Soil Color – Surface Condition

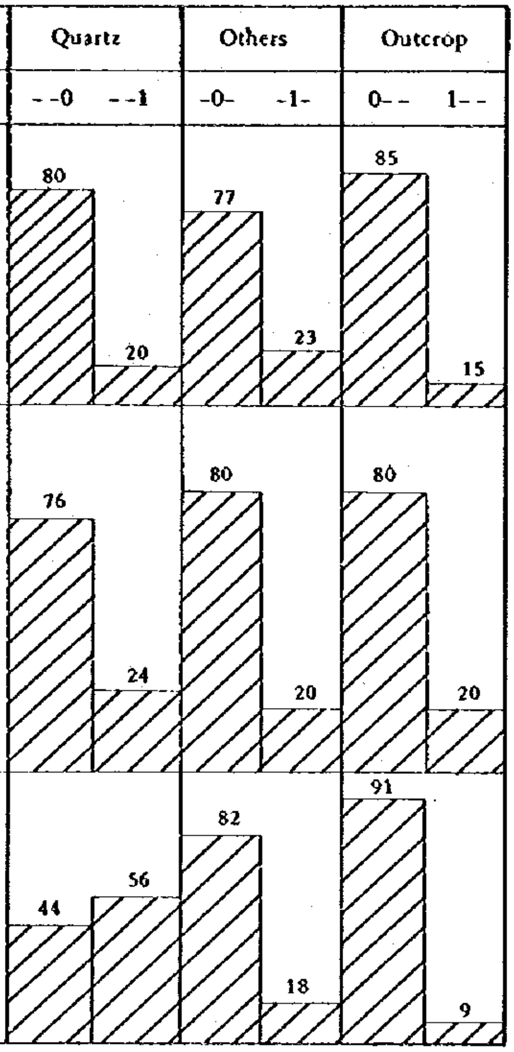
Soil Color		Frequency ( )%							
Code		000	001	010	011	100	101	110	111
Red	10	4 (33)	2 (17)	2 (17)	2 (17)	2 (17)	0 (0)	0 (0)	0 (0)
	11	36 (72)	6 (12)	3 (6)	2 (4)	0 (0)	0 (0)	2 (4)	1 (2)
	12	28 (56)	5 (10)	5 (10)	0 (0)	3 (6)	0 (0)	5 (10)	4 (8)
Brown	20	13 (39)	4 (12)	5 (15)	6 (18)	3 (9)	1 (3)	0 (0)	1 (3)
	21	37 (53)	18 (26)	2 (3)	1 (1)	7 (10)	0 (0)	3 (4)	2 (3)
	22	90 (56)	14 (9)	11 (7)	7 (4)	14 (7)	1 (1)	14 (9)	10 (4)
	31	42 (64)	14 (21)	2 (3)	0 (0)	4 (6)	1 (2)	3 (5)	0 (0)
D. Gray	32	20 (36)	22 (40)	0 (0)	8 (15)	3 (5)	0 (0)	1 (2)	1 (2)



1: Yes, 0: No, – –1: Quartz float, –1–: Other float, 1– –: Outcrop

(7) Soil Color -- Surface Condition

Soil Color		Quartz		Others		Outcrop	
Code		- -0	- -1	-0-	-1-	0- -	1- -
Red	10	8 (67)	4 (33)	8 (67)	4 (33)	10 (83)	2 (17)
	11	41 (82)	9 (18)	42 (84)	8 (16)	47 (94)	3 (6)
	12	41 (82)	9 (18)	36 (72)	14 (28)	38 (76)	12 (24)
Brown	20	21 (64)	12 (36)	21 (64)	12 (36)	28 (85)	5 (15)
	21	49 (70)	21 (30)	62 (89)	8 (11)	58 (83)	12 (17)
	22	129 (80)	32 (20)	119 (74)	42 (26)	122 (76)	39 (24)
	31	51 (77)	15 (23)	61 (92)	5 (8)	58 (88)	8 (12)
D. Gray	32	24 (44)	31 (56)	45 (82)	10 (18)	50 (91)	5 (9)



1: Yes, 0: No

(8) Soil

Soil Color		Frequency							Percentage %						
Code		00	11	12	13	21	22	23	0-	1-	2-	-0	-1	-2	-3
Red	10	6	1	1	0	2	1	1	6 (50)	2 (17)	4 (33)	6 (50)	3 (25)	2 (17)	1 (8)
	11	40	4	3	0	0	1	2	40 (80)	7 (14)	3 (6)	40 (80)	4 (8)	4 (8)	2 (4)
	12	38	2	7	0	0	1	2	38 (76)	9 (18)	3 (6)	38 (76)	2 (4)	8 (16)	2 (4)
Brown	20	20	5	5	0	1	0	2	20 (61)	10 (30)	3 (9)	20 (61)	6 (18)	5 (15)	2 (6)
	21	52	9	4	1	1	2	1	52 (74)	14 (20)	4 (6)	52 (74)	10 (14)	6 (9)	2 (3)
	22	121	9	18	2	2	7	2	121 (75)	29 (18)	11 (7)	121 (75)	11 (7)	25 (16)	4 (3)
	31	49	9	8	0	0	0	0	49 (74)	17 (26)	0 (0)	49 (74)	9 (14)	8 (12)	0 (0)
D. Gray	32	33	12	6	4	0	0	0	33 (60)	22 (40)	0 (0)	33 (60)	12 (22)	6 (11)	4 (7)

00: Soil only, 1-: Scattered pebble, 2-: Pebble bed, -1: Rounded, -2: Subangular, -3: Angular

(9) Soil Color – Geological Unit

Soil Color	Code	1 G_{1m} Monzonite	2 G_1 Tonalite	3 G_{2t} Tonalite gneiss	4 G_{2ht} Tonalite gneiss	5 G_{2g} Hornblende tonalite gneiss	6 PG_{2g} Porphyroblastic granite gneiss	7 PG_{2t} Porphyroblastic tonalite gneiss	8 G_{3t} Tonalite	9 G_{3g} Granite	10 G_4 Granite-Quartz monzonite	11 Ak Meta-arkose	12 Jan Jankee mixed gneiss	13 Um Ultramafic rock	14 Am Amphibolite	15 Ser Serpentinite	16 Px Pyroxenite	17 Fel Felsic metavolcanics	18 Al Aluminous schist	19 Ls Limestone	20 D Dolerite, Gabbro
Red	10	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	4
	11	0	1	1	1	1	0	0	0	0	0	1	0	0	19	2	0	1	1	0	12
	12	0	0	1	2	2	0	0	0	0	1	3	0	1	8	2	1	1	0	0	13
		0 (0)	1 (1)	2 (2)	3 (4)	3 (4)	0 (0)	0 (0)	0 (0)	0 (0)	1 (1)	4 (5)	0 (0)	1 (1)	29 (36)	4 (5)	1 (1)	2 (2)	1 (1)	0 (0)	29 (36)
Brown	20	0	4	6	3	6	2	0	0	0	0	1	1	0	1	0	0	0	1	0	0
	21	1	3	3	4	8	4	0	0	0	1	7	4	1	4	1	1	0	0	0	0
	22	3	11	27	6	23	8	0	9	3	6	15	3	0	0	0	1	0	0	0	2
	31	0	2	14	2	7	1	0	5	0	2	7	0	0	1	0	0	0	0	0	4
		4 (2)	20 (9)	50 (22)	15 (7)	44 (20)	15 (7)	0 (0)	14 (6)	3 (1)	9 (4)	30 (13)	8 (4)	1 (0)	5 (2)	1 (0)	2 (1)	0 (0)	1 (0)	0 (0)	6 (3)
D. Gray	32	0 (0)	1 (4)	4 (16)	1 (4)	1 (4)	1 (4)	0 (0)	0 (0)	1 (4)	0 (0)	0 (0)	0 (0)	2 (8)	12 (48)	2 (8)	0 (0)	0 (0)	0 (0)	0 (0)	1 (4)
Total No.	343	4 (1)	22 (6)	61 (18)	19 (6)	48 (14)	16 (5)	0 (6)	16 (5)	4 (1)	10 (3)	34 (10)	8 (2)	4 (1)	47 (14)	7 (2)	3 (1)	2 (1)	2 (1)	0 (0)	36 (10)

Brackted figures represent percentage.

which is called black turf, stemming from amphibolite as the country rock, is clayey and organic; mostly it is in a moist state, and is often accompanied by quartz pebbles or boulders. Also 15 samples out of 17 in total from lowland and marshland were this dark-gray soil. The vegetation there is expressed as shrub savanna for the most part; the quantities of plant roots tend to be more than those in the other kinds of soil.

2-3 Statistical Distribution of Indicative Elements

In order to extract geochemical anomalies related with mineralization, discrimination should be made between what is called background population which reflects the primary chemical components of the rocks forming the geology of the area and the anomaly population due to mineralization. If the former population is recognized as homogeneous, the mineralization population can easily be extracted statistically. However, as deduced from Table 12-9, 70% of the survey area is formed of acidic metamorphic rocks, and 30% of basic or ultramafic rocks.

It is expected that geochemical characters, that is, chemical components, of these two will greatly differ. Accordingly, a study is made hereunder of statistical distribution of indicative elements (Cu, Pb, Zn and Ni) for each geological unit; and then the distribution of the indicative elements of the soil that have been found to be broadly corresponding to the kinds of the rocks from which the soil stems is studied in the following.

2-3-1 Distribution of Elements for Each Geological Unit

Fig. 16 sets forth the plotting on a sheet on a logarithmic scale of the mean logarithmic values (M) and the standard deviation values (S) of Cu, Pb, Zn, and Ni contents for each of the 18 geological units with the use of 343 samples within the eastern area occupying the two thirds of which the distribution of lithofacies has been revealed by Litherland (1975).

On the top portion of this figure are entered the values for the total samples (497 samples but excluding duplicate ones with different depth in the same spots) for the sake of comparison. From this figure one can read first that the variance of Pb and Zn is small and that of Cu and Ni is large. Concerning the mean logarithmic values change, in the case of Cu, the mean logarithmic value of the acidic rock from Code Nos. 3 to 11 is lower than that of the total samples, while those of acidic rock of Code Nos. 1 and 2 and of basic to ultramafic rock from Code Nos. 12 to 20 are higher than the mean logarithmic value of the total samples. With regard to Ni, the comparison is distinctly bisected; the

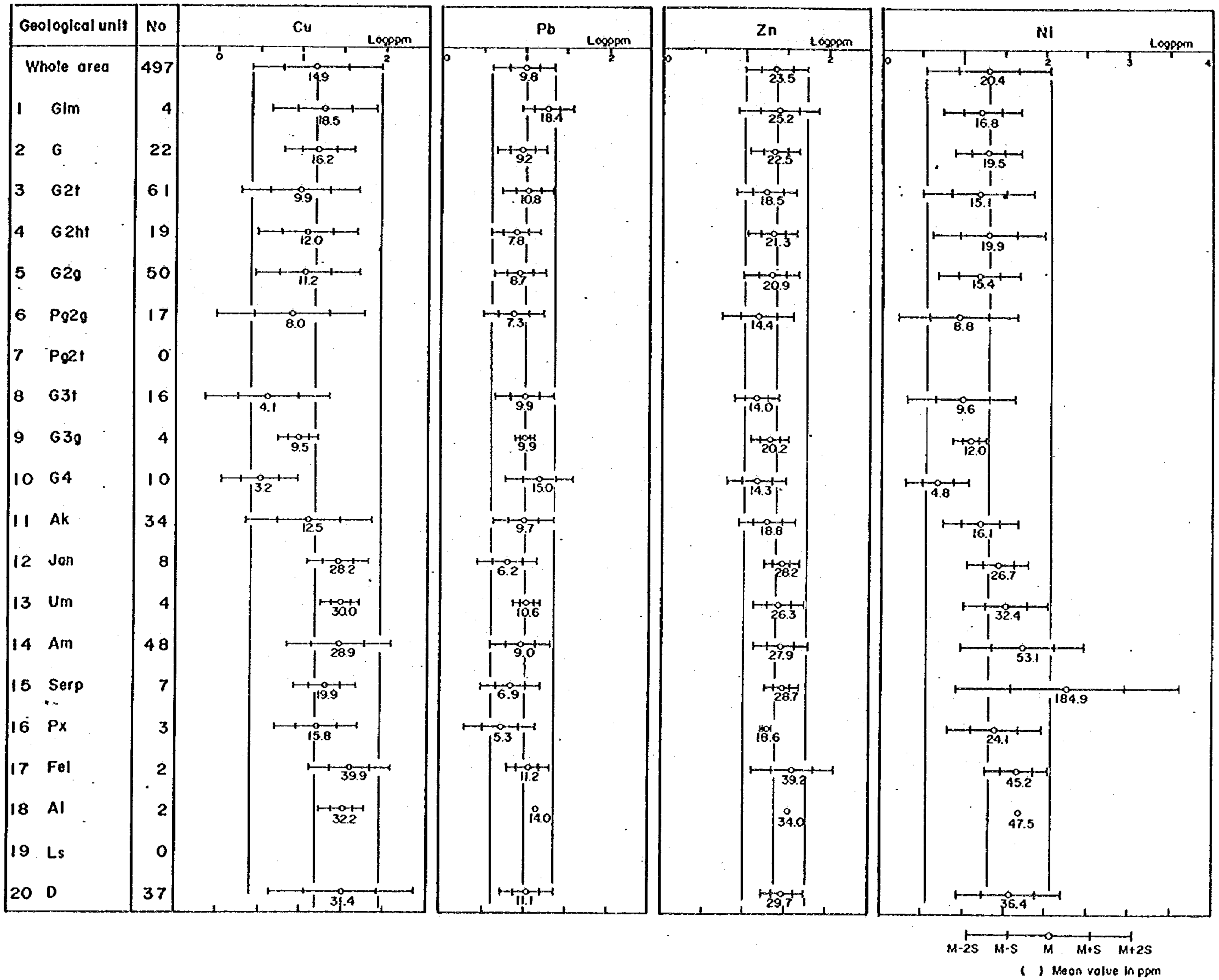


Fig. 16 Variation of some statistical values of Cu·Pb·Zn·Ni content in 18 geological units.

value of acidic rock from Code Nos. 1 to 11 is low, while that of basic to ultramafic rock from Code Nos. 12 to 20 is high. Zn indicates behavior close to those of Cu and Ni, but Code No. 16 (pyroxenite) indicates a low value. Pb, unlike Cu, Ni, and Zn, is not recognized to be corresponding to the geological units.

When the geological units are divided into two, the acidic gneiss group and basic to ultramafic rocks, with Cu, Zn and Ni, the difference is found that the value for the former is smaller than the mean logarithmic value of the total samples, while the value for the latter larger than the same. However, if the size of the population is restricted to the extent from M + S to M - S (the extent of one time the standard deviation centering around the mean value, equivalent to about 68% of the population), the distributions of these populations broadly divided in two come to overlap with each other.

On the other hand, when the 18 geological units are severally viewed, for the acidic gneiss group of G_{3t}, G_{3g} and G_4 and basic to ultramafic rocks, the populations overlap each other only in a small extent and it seems possible to make discrimination, but the small number of samples makes it unpractical. Therefore, to try to make discrimination of geological units on the samples from the western area occupying the one third where geological data are insufficient by using element contents is anticipated to produce a high probability of misdiscrimination and can be said to be not very effective. Further, when the distribution maps of the contents of elements are represented in ranking in which the statistical values of the total samples are used, assuming the values over M + 2S to be geochemically anomalous, only basic to ultramafic rocks will be extracted as anomalous in Cu and Ni.

2-3-2 Element Distribution for Each Color Tone of Soil

As the result of the study in the preceding paragraph, it has been found that there is a difference of element contents between the acidic gneiss group and basic to ultramafic rocks. Also it has been judged that, discrimination of geological units according to the element contents for the samples from the western area covering one third of the area, of which classification by lithofacies is insufficient, is not much effective. Accordingly, statistical distribution of elements has been studied here for each of the color tones of the soil which have been recorded for the samples covering the whole area and also generally correspond to the geological units.

Fig. 17 is like Fig. 16, plotting of the distribution of the mean logarithmic

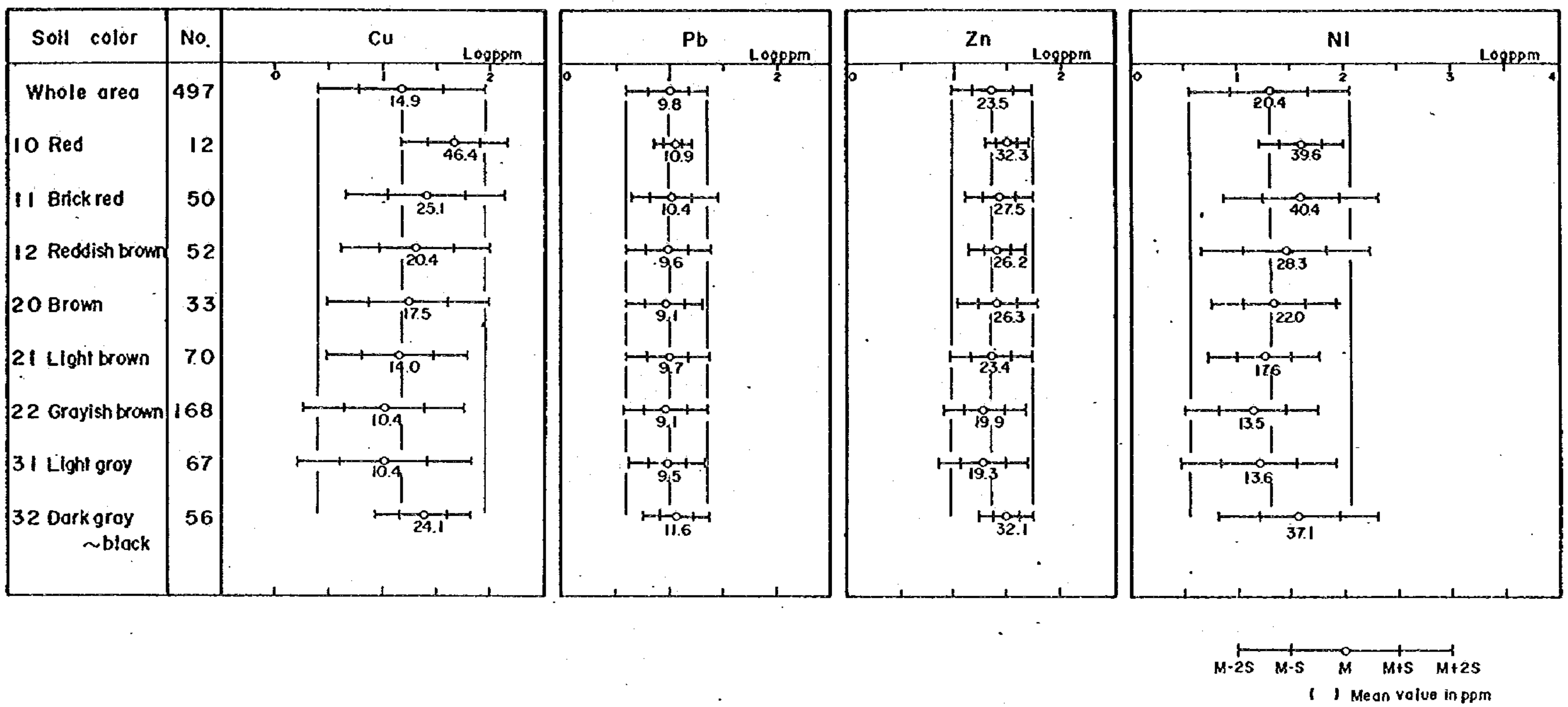


Fig. 17 Variation of some statistical values of Cu·Pb·Zn·Ni content in 8 color units.

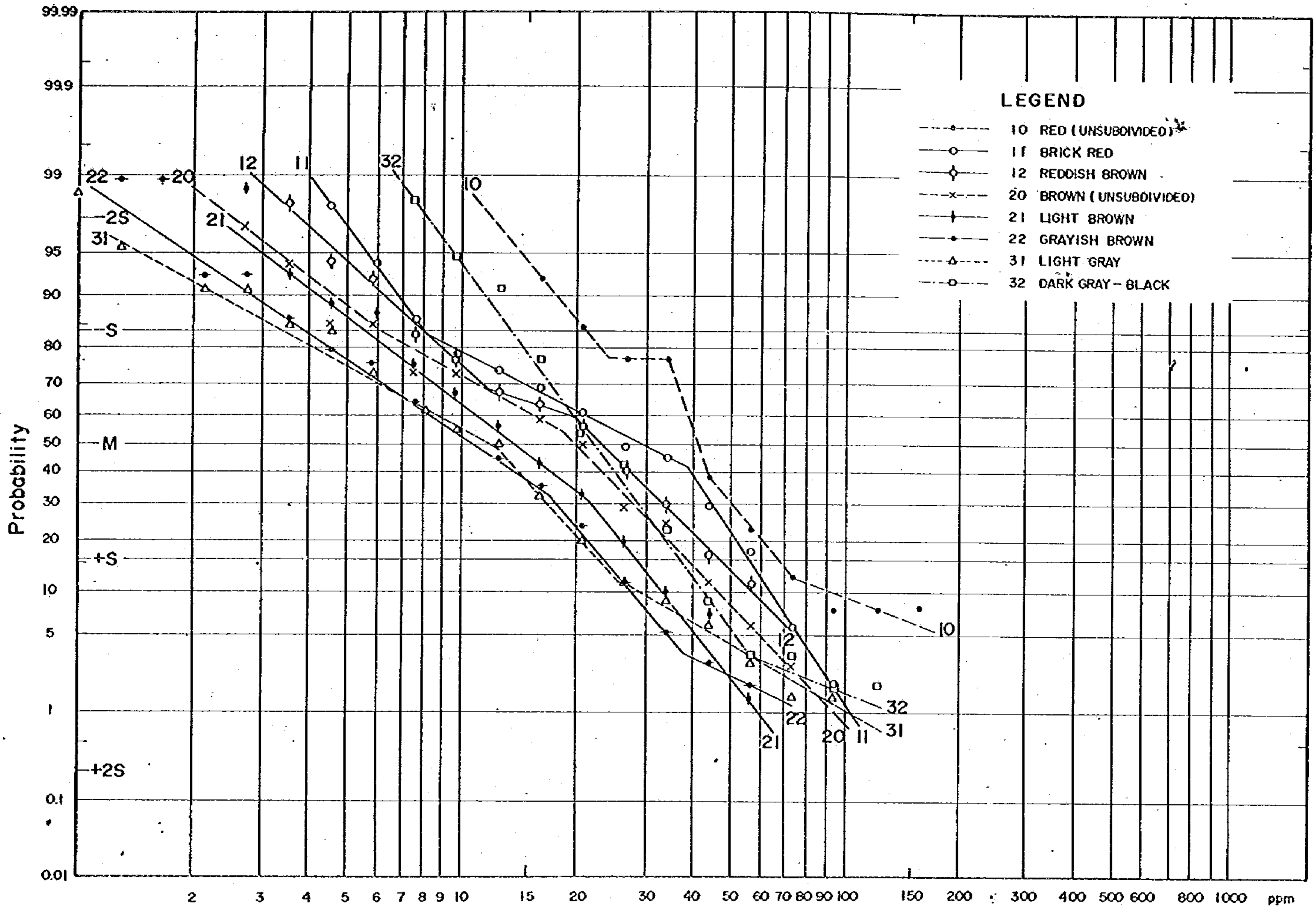


Fig. 18 Cumulative frequency distribution for Cu in 8 soil colors

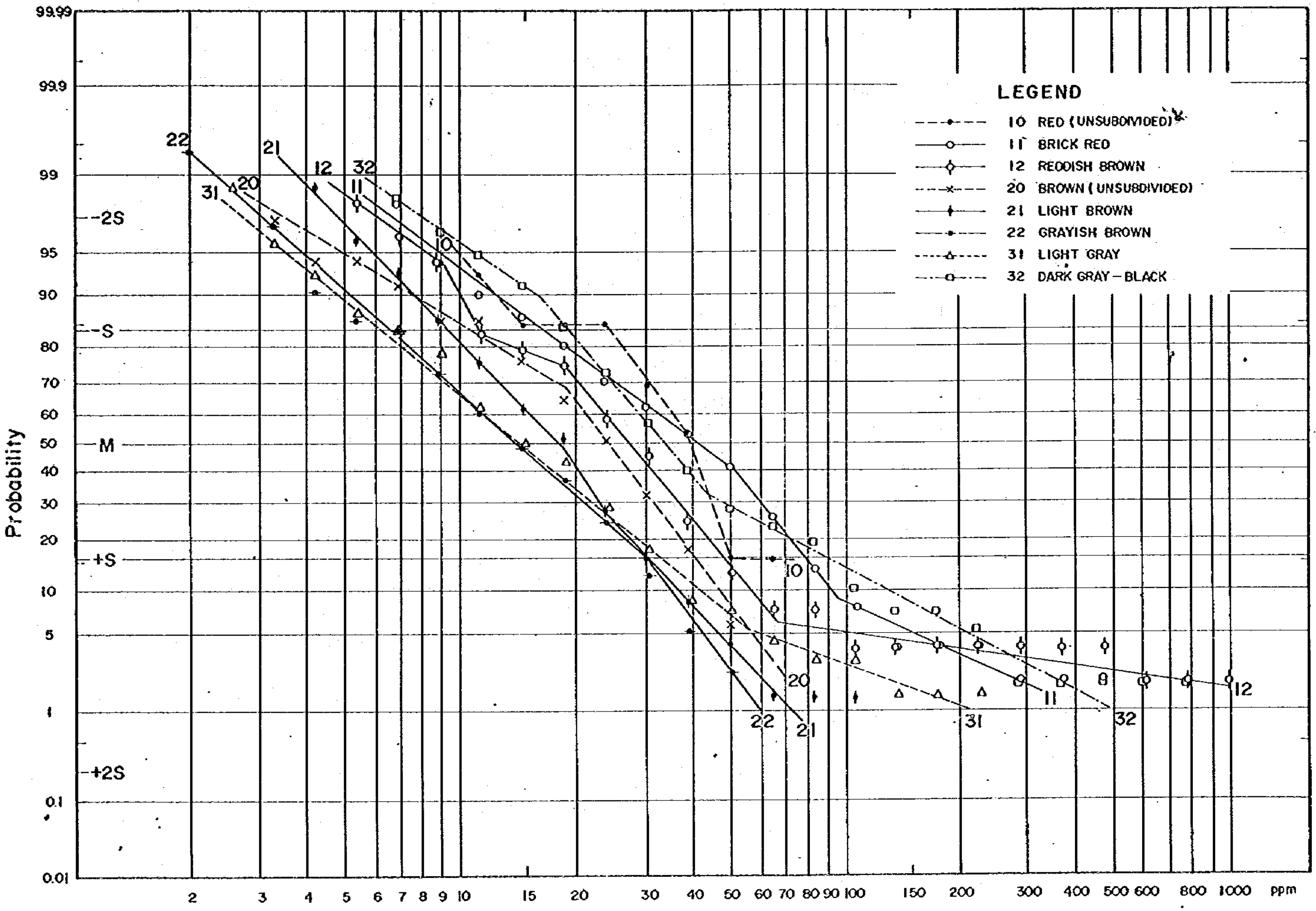


Fig. 19 Cumulative frequency distribution for Ni in 8 soil colors

values and the standard deviation of each of the element contents. In this figure, it is indicated that Pb, being hardly related to the color tones of the soil, has almost constant mean logarithmic values and variance.

In contrast with Pb, in Cu, Ni and Zn, their mean logarithmic values gradually become smaller from unsubdivided red of Code No. 10 toward grayish brown of Code No. 22. It was stated in 2-2-2 that the characters of light-gray soil resemble those of brown soil group, and in element contents too, light-gray soil has almost the same values as the ones of brown soil group. Also the element contents of dark-gray soil are in about the same measure as those of red soil group. This is considered to be the reflection of the fact that 48% of dark-gray soil stems from amphibolite (Table 12-9).

Then it has been studied whether each of the eight populations of the color tones of soil can be regarded as a homogeneous population, that is, whether they are in normal logarithmic distribution or not. Fig. 18 and Fig. 19, having the probability scale in their ordinates and logarithmic scale of the element contents in their abscissas, are the plotting of cumultative frequencies of Cu and Ni that have been ranked at logarithmic regular intervals. In these figures, when the points are in a linear distribution, it indicates normal logarithmic distribution, while, when they are skewed, complex populations.

In order to find the principal shape of the populations, the configuration of the points is checked by limiting the values to the extent of one time from the standard deviation (from M + S to M - S, equivalent to 68% of the population) centering around the mean value (M) in the figure. Within this extent, in the case of Cu in Fig. 18, what is considered to be in a normal logarithmic distribution is only the dark-gray soil of Code No. 32, and the other seven kinds of soil are judged to be of complex populations. In the case of Ni in Fig. 19, only the grayish brown soil of Code No. 22 and light-gray soil of No. 31 are in a normal logarithmic distribution, while the other ones are indicated as complex populations.

As the result of the above-mentioned study, it has been disclosed that the geochemical samples over the soil of this area differ in element contents according to the differences of the geological units and the color tones of the soil. However, since the differences in the geological units are not so much as to determine the geological unit from sample's analytical data, and also the populations classified by the color tones of soil are not homogeneous, it is concluded that the samples are not suitable for extraction of mineralization populations by a statistical method.

2-3-3 Determination of Anomalous Values

To find the regional distribution of each element content, the classification into anomalous and background values for each element was made by the following procedure:

First, the mean logarithmic values (M) and the standard deviation (S) of the contents of Cu, Pb, Zn and Ni were obtained for the regional survey area (with 383 samples) and the sub-regional survey area (with 188 samples) respectively. From these coefficients, the element contents corresponding to M, M ± S, M ± 2S, and M ± 3S were calculated (Table 13). Next, Figures of distribution of cumulative frequencies of elements (Fig. 20, 21) were made, and the shapes of the populations of these were studied.

As a result of it, for each of the elements, the shape of a complex population composed of two or three populations was indicated. The boundary points between the inner populations composing the complex population, that is, the skew points in the graph, are marked with arrows together with the element contents in the figure. Here, attention is paid to the positions of the skew points. It is found that such points are classified into the ones that lie outside M + S, the ones that lie between M and M + S, and the ones that lie between M and M – S (Table 13). Then, by jointly using the values of M, M ± S, M ± 2S, M ± 3S, and the skew points that have been obtained by calculation, the ranking as anomalous values and background values is made as follows (Table 14): Taking the value of M + S as the threshold value, those exceeding it is taken as anomalous values and the ones less than it as background values. As for the ranks within the anomalous values, those of M + 3S and over are ranked as Rank A, M + 2S and over Rank B, and those from less than M + 2S to the threshold value as Rank C. Regarding the ranking of the background values, they are classified into Ranks D, E, F, and G on the basis of the values of the skew point between M and M + S, the values of M and those of M – S.

Using the ranks of the element contents as above mentioned, the distribution maps of Cu, Pb, Zn and Ni contents for each region (PL. 7 – Pl. 8) have been prepared. As explained in details, until the preceding paragraph, it should be noted that the anomalies delineated on these maps cannot be said to identify geochemical anomalies

Table 13. Statistical Values of Cu · Pb · Zn · Ni Content in Regional and Sub-regional Survey Areas

	Area	Min.	M-3S	M-2S	M-S	M	M+S	M+2S	M+3S	MAX
Cu	A	1	0.9	2.3	5.7	14.0	34.6	85.6	211.6	141
						(21.9)	(63.8)			
	B	2	1.3	3.3	7.7	18.2	42.9	101.0	237.7	181
						(24.4)	(93.3)			
Pb	A	3	2.5	4.0	6.2	9.6	15.0	23.3	36.3	46
								(26.3)		
	B	3	3.1	4.6	6.8	10.0	14.8	21.8	32.1	34
					(7.3)					
Zn	A	8	6.6	10.2	15.6	23.9	36.6	56.0	85.8	71
						(31.6)	(47.9)			
	B	6	6.4	9.9	15.3	23.6	36.5	56.4	87.2	59
					(22.4)	(36.5)				
Ni	A	2	1.7	3.8	8.3	18.4	40.5	89.2	196.7	883
						(25.1)		(112.2)		
	B	3	1.5	4.0	10.7	28.6	76.2	203.0	540.9	1,000
						(29.2)	(95.5)			
		Background						Anomaly		

Note: The values in brackets shows the skew point values from Fig. 20 and 21.
Area-A: Regional Survey Area
Area-B: Sub-regional Survey Area

Table 14. Classification of Cu · Pb · Zn · Ni Content Grade

	Class	Background				Anomaly		
	Area	G	F	E	D	C	B	A
Cu	A	6	14	22	35	64		
	B	8	18	24	43	93		
Pb	A	6	10	–	15	23	36	
	B	7	10	–	15	22	32	
Zn	A	16	24	32	37	48		
	B	15	24	–	37	56		
Ni	A	8	18	25	41	89	197	
	B	11	29	29	76	96	541	

Note: Each class has a range that is upper from the lower limit and less than the upper limit.

Area-A : Regional Survey Area
Area-B : Sub-regional Survey Area

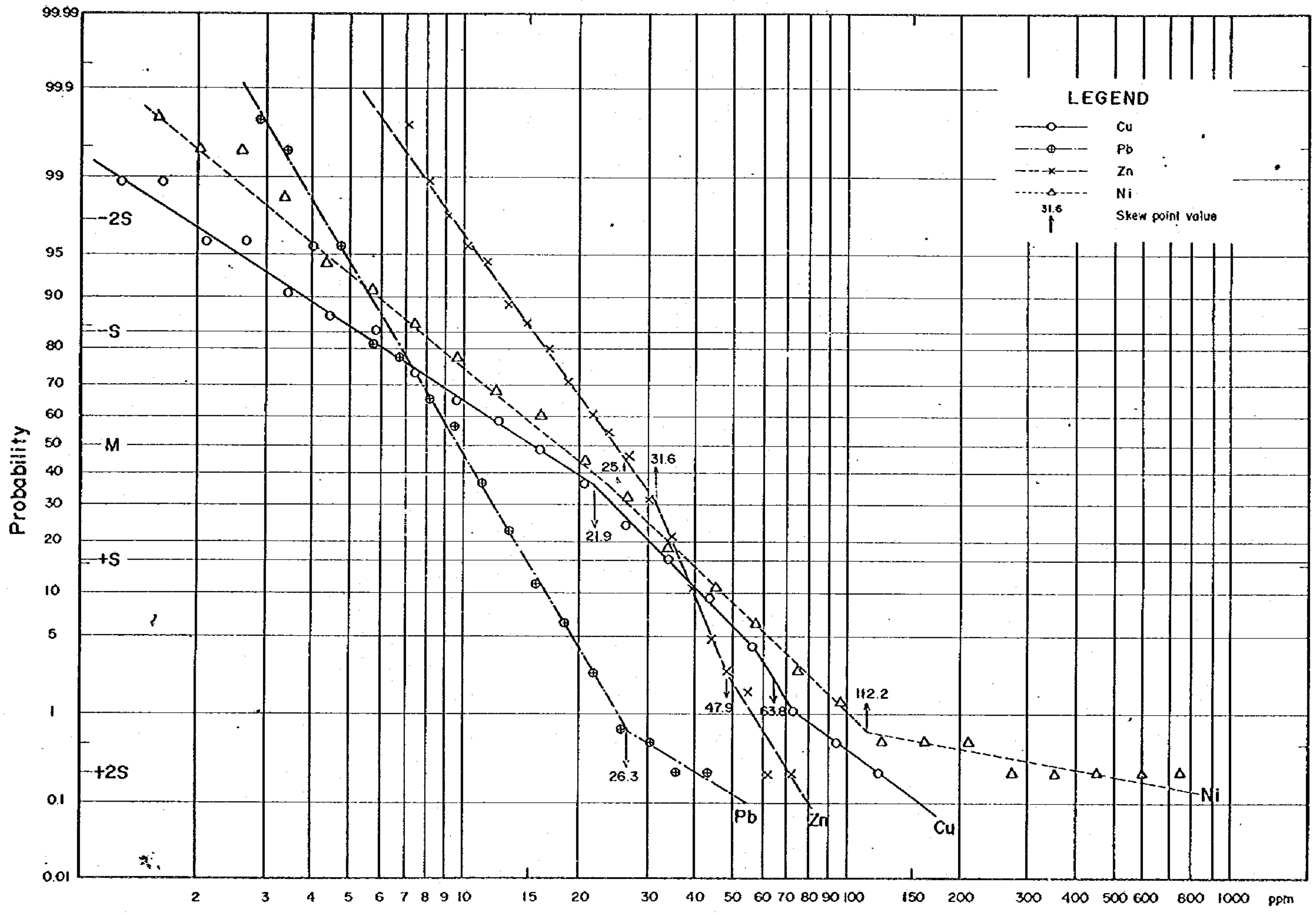


Fig. 20 Cumulative frequency distribution for Cu·Pb·Zn·Ni in regional survey area

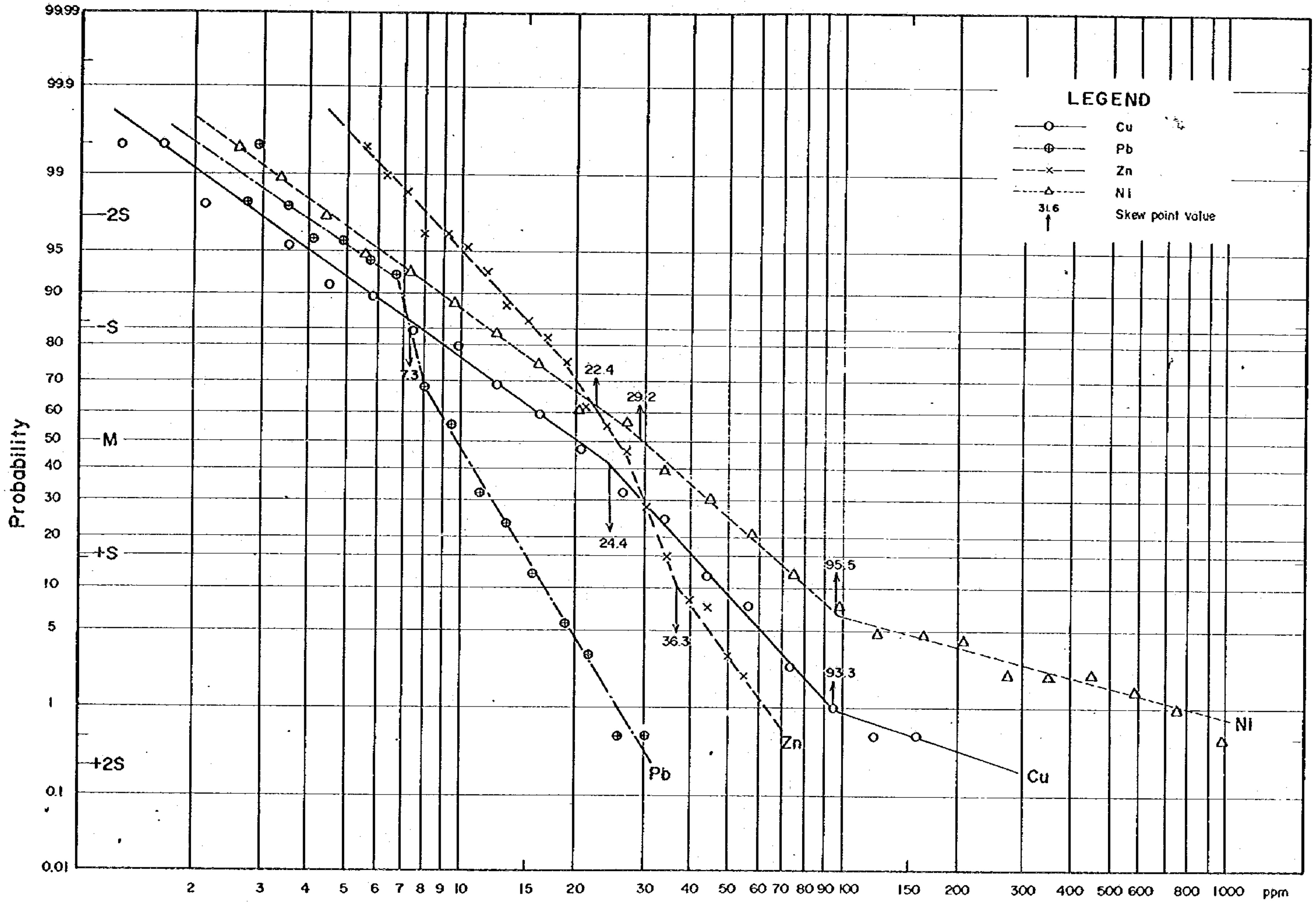


Fig. 21 Cumulative frequency distribution for Cu·Pb·Zn·Ni in sub-regional survey area

based on mineralization, but include apparent geochemical anomalies brough about by distribution of rocks with different chemical components.

2-4 Analysis of Principal Components

It has been known that the geochemical anomalies delineated on the distribution maps of element contents (PL. 7 – PL. 8) do not indicate the geochemical anomalies due to mineralization alone. So that, accordingly, an analysis by the principal component analysis method was made. The method is that the comprehensive characteristics of the analysis values of some components are obtained, and their relations with the existing mineral deposits are judged, to search for areas indicating similar tendencies.

2-4-1 Outline of Principal Component Analysis

The principal component analysis method is to obtain a small number of characteristic values not interrelated with each other from some variables (such as chemical analysis values) and make an analysis about these.

(1) Deduction of Principal Components

It is assumed that from four variables two comprehensive variables which are called the 1st and 2nd principal components, are sought. Here, since each variable (such as an analysis value) is known to be in distribution close to normal logarrithmic distribution, it is convenient for calculation to assume that the four variables are expressed as X_1 = Log Cu, X_2 = Log Pb, X_3 = Log Zn, and X_4 = Log Ni, and X_1, X_2, X_3 and X_4 are normalized (the mean value = 0 and variance = 1).

The 1st and 2nd principal components are expressed as follows, taking the coordinate rotation vector as ℓ.

$$Z_1 = \ell_{11}X_1 + \ell_{12}X_2 + \ell_{13}X_3 + \ell_{14}X_4 = \sum_i^4 \ell_{1i}X_i$$

$$Z_2 = \ell_{21}X_1 + \ell_{22}X_2 + \ell_{23}X_3 + \ell_{24}X_4 = \sum_i^4 \ell_{2i}X_i \quad \cdots\cdots\cdots\cdots (1)$$

Here, it is conditioned:

$$\ell k_1^2 + \ell k_2^2 + \ell k_3^2 + \ell k_4^2 = \sum_i^4 \ell k_i^2 = 1, \ (k = 1, 2 \ldots\ldots) \quad \cdots\cdots\cdots\cdots (2)$$

In Formula (2), (ℓ_{11}, ℓ_{12}, ℓ_{13} and ℓ_{14}) which make variance of Z_1, $V[Z_1]$ maximum is sought.

$$V[Z_1] = \sum_{\alpha}^{n} \frac{(Z_1 - \bar{Z}_1)^2}{n-1} = \sum_{i}^{4} \sum_{j}^{4} \sum_{\alpha}^{n} \cdot \ell_{1i} \ell_{1j} (X_{\alpha i} - \bar{X}_i) \frac{(X_{\alpha j} - \bar{X}_j)}{n-1}$$

$$= \sum_{i}^{4} \sum_{j}^{4} \ell_{1i} \ell_{1j} V_{ij}$$

(V_{ij} means covariance of X_i and X_j)

From the method of undetermined multiplier of Lagrange, the maximization of $V[Z_1]$ is:

$$Q = \sum_{i}^{4} \sum_{j}^{4} \ell_{1i} \ell_{1j} V_{ij} - \lambda \left(\sum_{i}^{4} \ell_{1i}^2 - 1 \right) \rightarrow \text{Max}$$

(λ is the multiplier of Lagrange.)

Partially differentiating Q with respect to ℓ_{1i},

$$\frac{\partial Q}{\partial \ell_{1i}} = 2 \left(\sum_{j} \ell_{1j} V_{ij} - \lambda \ell_{1i} \right) = 0$$

$$\sum_{j} \ell_{1j} V_{ij} = \lambda \ell_{1i} \quad \text{.....................} \quad (3)$$

which leads to:

$$\ell_{11} V_{11} + \ell_{12} V_{12} + \ell_{13} V_{13} + \ell_{14} V_{14} = \lambda \ell_{11}$$
$$\ell_{11} V_{12} + \ell_{12} V_{22} + \ell_{13} V_{23} + \ell_{14} V_{24} = \lambda \ell_{12}$$
$$\ell_{11} V_{13} + \ell_{12} V_{23} + \ell_{13} V_{33} + \ell_{14} V_{34} = \lambda \ell_{13}$$
$$\ell_{11} V_{14} + \ell_{12} V_{24} + \ell_{13} V_{43} + \ell_{14} V_{44} = \lambda \ell_{14}$$

In order to have significant radicals except $\ell_{11} = \ell_{12} = \ell_{13} = \ell_{14} = 0$, the following condition is to be met.

$$\begin{vmatrix} V_{11} - \lambda & V_{12} & V_{13} & V_{14} \\ V_{12} & V_{22} - \lambda & V_{23} & V_{24} \\ V_{13} & V_{23} & V_{33} - \lambda & V_{34} \\ V_{14} & V_{23} & V_{33} & V_{44} - \lambda \end{vmatrix} = 0$$

From the above, $\lambda_1 \geqq \lambda_2 \geqq \lambda_3 \geqq \lambda_4 \geqq 0$ is obtained; and by solving the simultaneous equations of (2) and (3) above $\ell_{11}, \ell_{12}, \ell_{13}$ and ℓ_{14} are obtained. Further, similar operation with regard to λ_2 produces $\ell_{21}, \ell_{22}, \ell_{23}$ and ℓ_{24}.

(2) Characteristics of Principal Components

a. The variance of the principal component Zk (V[Zk]) is given as the eigenvalue λk from Equations (2) and (3). So that, with regard to Z_1,

$$V[Z_1] = \sum_i^4 \sum_j^4 \ell_{1i} \ell_{ij} V_{ij} = \sum_i^4 \ell_{1i}^2 \lambda_1 = \lambda_1$$

b. The correlation between principal component Zk and variable X_i is given by the following equation. This correlation is called factor loading.

$$\gamma(Zk, X_i) = \frac{C_{ov}[Zk, X_i]}{\sqrt{V[Zk]\, V[X_i]}} = \frac{\Sigma \ell_{kj} V_{ij}}{\sqrt{\lambda_k}} = \frac{\lambda_k \ell_{ki}}{\sqrt{\lambda_k}} = \sqrt{\lambda_k}\, \ell_{ki}$$

c. The cumulative contribution ratio C_2, when two of the principal components are taken, is:

$$C_2 = \frac{V[Z_1] + V[Z_2]}{V[X_1] + V[X_2] + V[X_3] + V[X_4]} = \frac{\lambda_1 + \lambda_2}{4}$$

d. The ratio of contribution to X_i, when two of the principal components are taken, D_i is:

$$D_i = \gamma^2 (Z_1, X_i) + \gamma^2 (Z_2, X_i) = \lambda_1 \ell_{1i}^2 + \lambda_2 \ell_{2i}^2$$

2-4-2 Results of Principal Component Analysis and Interpretation

(1) Principal Components in Survey Area

The substance of the results of calculation of the principal component analysis in the regional survey area and sub-regional survey area is arranged collectively in Table 15 and Fig. 22.

Table 15. Result of PCA for Areal Populations

Population	PC	Eigen Value	CCR	Factor Loading				Contribution Ratio for Variable				Correlation Coefficient					R %
				Log Cu	Log Pb	Log Zn	Log Ni	Log Cu	Log Pb	Log Zn	Log Ni		Log Cu	Log Pb	Log Zn	Log Ni	
												Log Cu	1.00				
Area-A	Z_1	2.66	0.66	0.91	0.51	0.89	0.88	0.83	0.26	0.79	0.77						
												Log Pb	0.31	1.00			
	Z_2	0.85	0.88	−0.19	0.85	−0.01	−0.28	0.04	0.72	0.00	0.08						0.232
												Log Zn	0.75	0.40	1.00		
(383)	Z_3	1.30	0.95	0.07	0.11	−0.43	0.31	0.00	0.01	0.18	0.10						
												Log Ni	0.79	0.24	0.68	1.00	
												Log Cu	1.00				
Area-B	Z_1	2.43	0.61	0.92	0.03	0.90	0.87	0.85	0.00	0.81	0.76						
												Log Pb	0.04	1.00			
	Z_2	1.08	0.88	0.03	0.99	0.19	−0.26	0.00	0.98	0.04	0.07						0.143
												Log Zn	0.77	0.16	1.00		
(188)	Z_3	0.27	0.94	−0.16	0.16	−0.23	0.41	0.03	0.03	0.05	0.17						
												Log Ni	0.71	−0.17	0.66	1.00	
												Log Cu	1.00				
Matsitama	Z_1	2.51	0.63	0.89	0.95	0.89	0.16	0.79	0.90	0.79	0.03						
												Log Pb	0.84	1.00			
Area	Z_2	1.07	0.90	−0.25	−0.14	0.22	0.97	0.06	0.02	0.05	0.94						0.368
												Log Zn	0.63	0.76	1.00		
(27)	Z_3	0.29	0.97	−0.32	−0.03	0.39	−0.18	0.10	0.00	0.15	0.03						
												Log Ni	−0.04	0.03	0.28	1.00	

PC: Principal component, PCA: Principal component analysis, CCR: Cumulative contribution ratio.

(383): Figure in branket is number of samples of population, R: Significant level of correlation coefficient from R-table.

Area-A: Regional survey area, Area-B: Sub-regional survey area.

Table 16. Statistical Values of Cu · Pb · Zn · Ni · Co Content in Matsitama Mineralized Area

	Min.	M - 3S	M - 2S	M - S	M	M + S	M + 2S	M + 3S	Max.
Cu	33	4.7	14.6	45.2	139.9 (117)	432.9 (182)	1,339.0 (355)	4,143.0 (610)	3,644
Pb	8	3.4	6.2	11.5	21.1 (21)	38.9 (30)	71.5 (48)	131.7 (76)	109
Zn	22	12.0	20.4	34.6	58.8	100.0	170.0	288.9	133
Ni	22	16.9	21.5	27.3	34.6	44.0	55.9	71.0	57
Co	7	6.3	8.1	10.4	13.4 (13)	17.2	22.2	28.5	24

Note: The values in brackets show the skew point values and others given by main branch in Fig. 23.

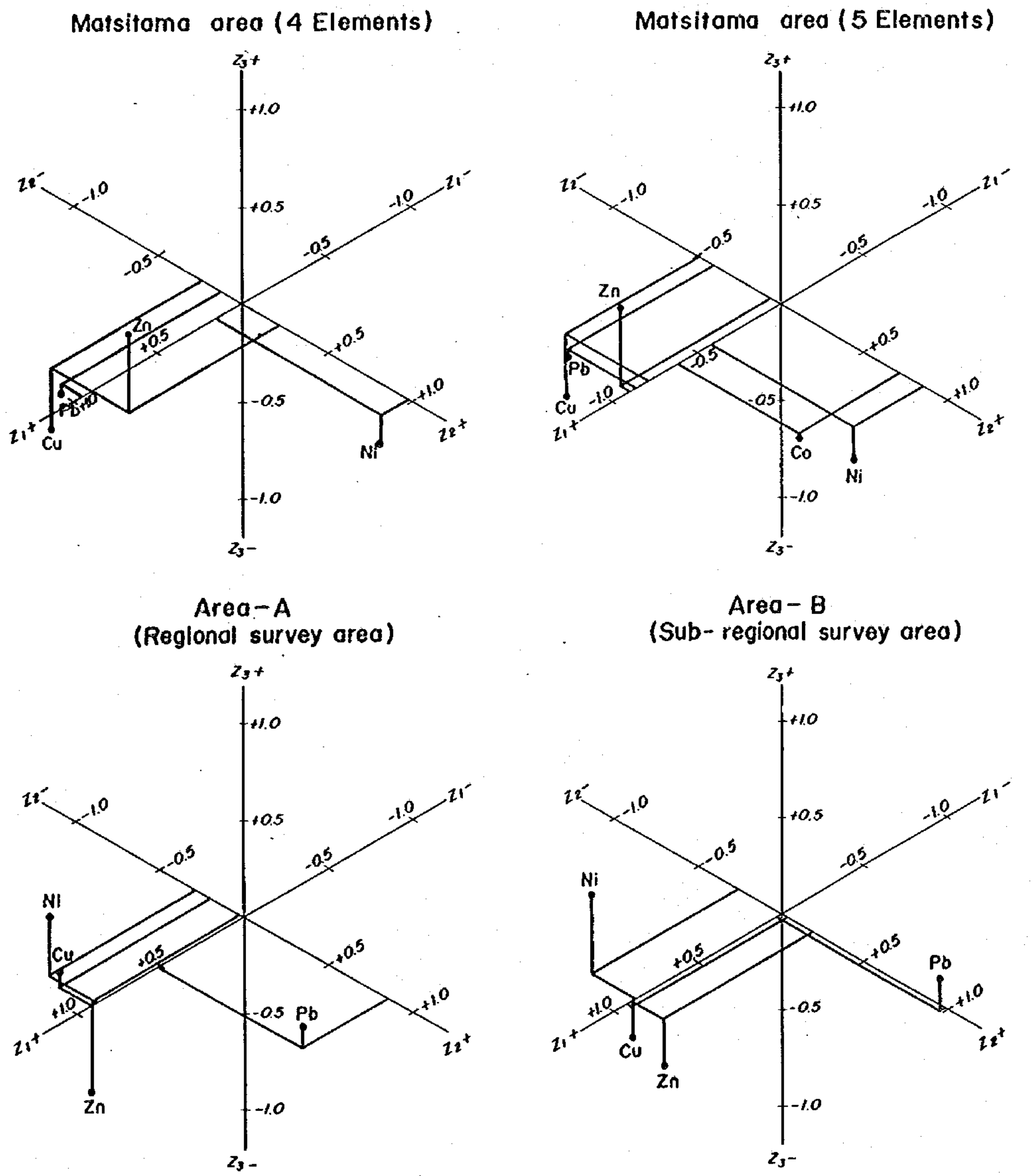


Fig.22 Three dimensional plot of factor loadings for areal populations.

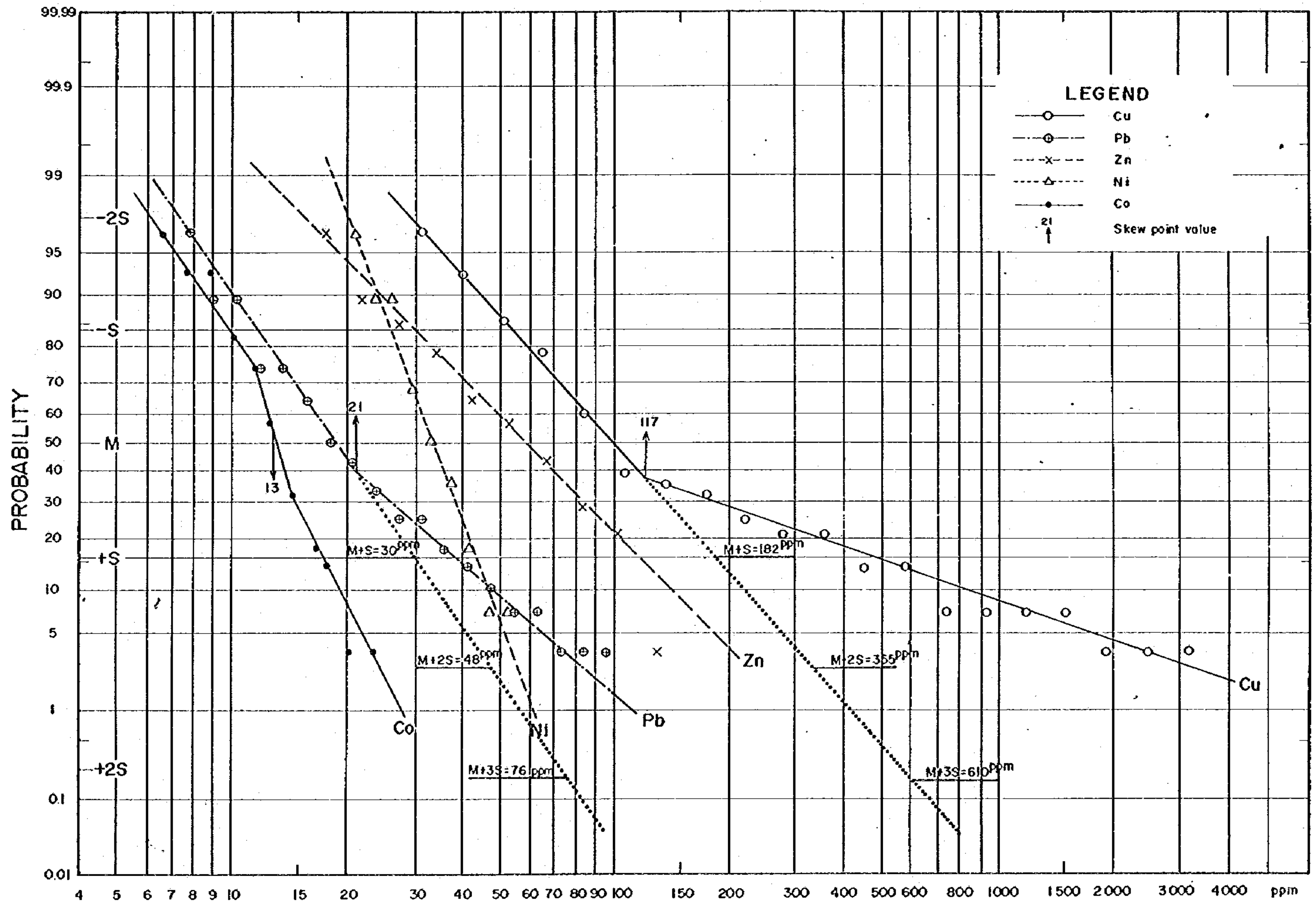


Fig.23 Cumulative frequency distribution for Cu·Pb·Zn·Ni·Co· in Matsitama mineralized area

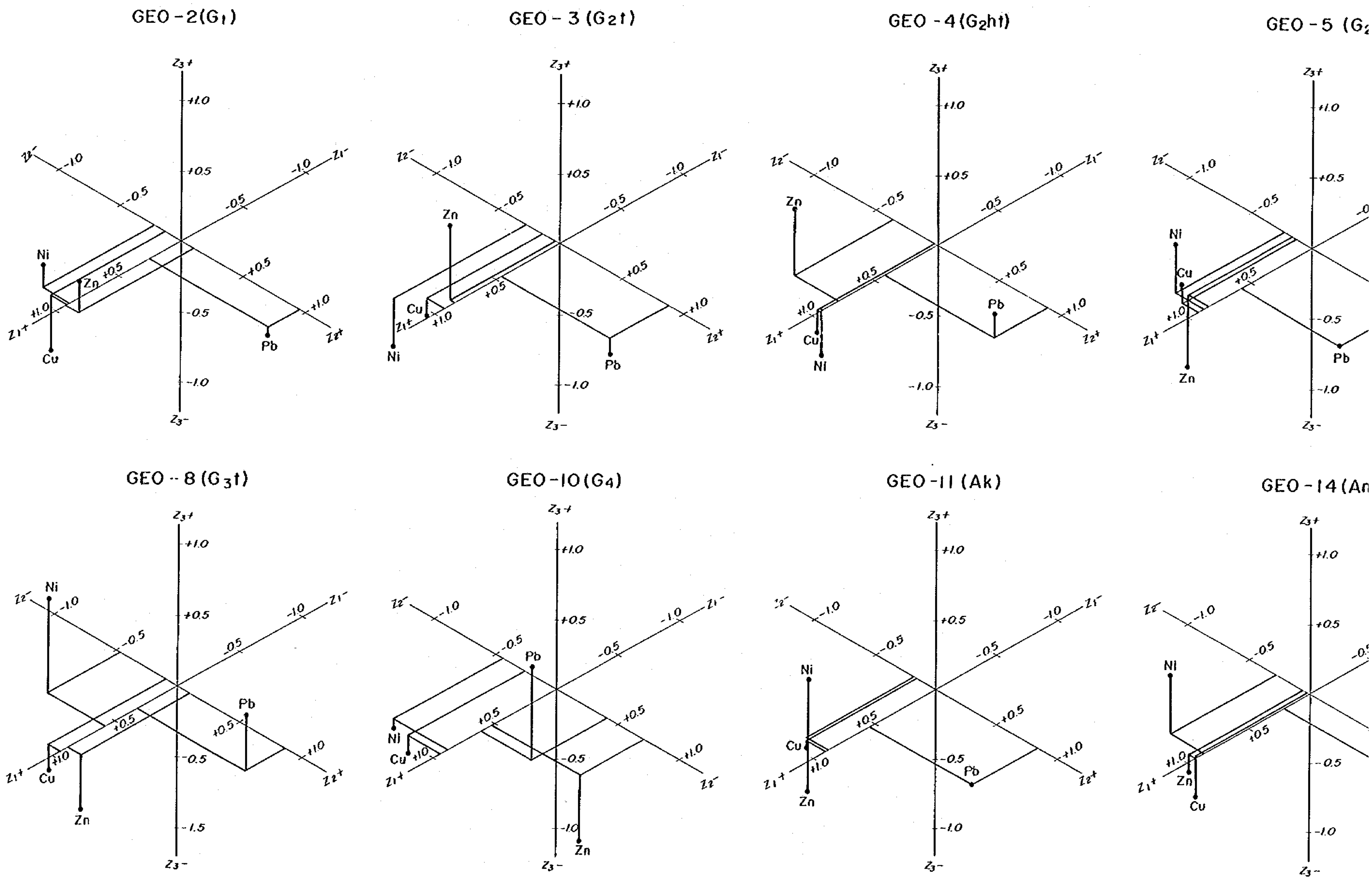
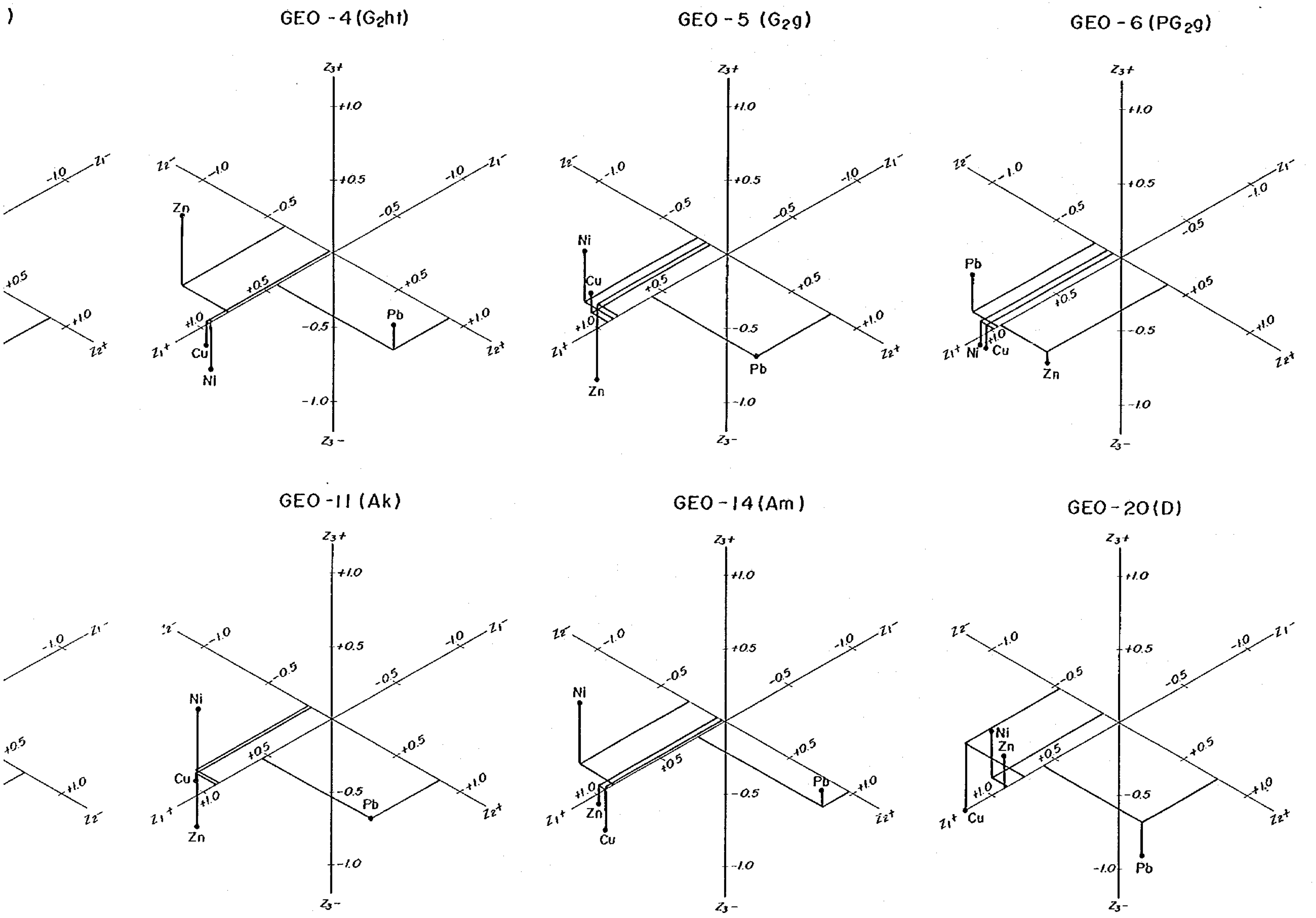


Fig. 24 Three dimensional plot of factor loadings for geologically separated populations



e dimensional plot of factor loadings for geologically separated populations

In regional survey area, the eigen values of the principal components Z_1, Z_2 and Z_3 are 2.66, 0.85 and 0.30 respectively, which makes one consider that the aggregate of Cu, Pb, Zn and Ni contents is large in variance of the 1st principal component Z_1, that is, it is in a slender spherioid.

The cumulative contribution ratios of the principal components Z_1, Z_2 and Z_3 are 0.66, 0.88 and 0.95 respectively. That is to say, the aggregate of Cu, Pb, Zn and Ni contents can be accounted for up to 66% with Z_1 alone, and up to 88% when Z_2 is included. Therefore, as the principal component analysis method, adoption up to Z_2 suffices.

The correlation between the principal components and variables is indicated by factor loading. The factor loading of the 1st principal component Z_1 is: 0.91 for Cu, 0.51 for Pb, 0.89 for Zn, and 0.88 for Ni; Cu, Zn and Ni correlate with Z_1 in the same measure of greatness, while Pb too correlates with Z_1 though in a little less measure. These signs are all positive equally and indicate that the vectors are in the same direction.

The factor loading of the 2nd principal component is; -0.19 for Cu, 0.85 for Pb, -0.01 for Zn, and -0.28 for Ni. With Z_2, Cu, Zn and Ni do not correlate or correlate in an extremely small measure, but Pb correlates in an extremely large measure; the vectors of these two are in the opposite directions of positive and negative. To help understand these relations, they are set forth in Fig. 22.

With regard to the contribution ratio to the variables of the principal components, 1st principal component Z_1, is 0.83 for Cu, 0.26 for Pb, 0.79 for Zn and 0.77 for Ni; Z_1 has a big explanatory component to Cu, Zn and Ni. On the other hand, the contribution ratio of the 2nd principal component Z_2 to the variables are: 0.04 for Cu, 0.72 for Pb, 0.00 for Zn, and 0.08 for Ni; in comparison to Pb, the contents of Cu, Zn and Ni are ignorably small. That means Z_2 is an explanatory component of Pb.

The principal components in the sub-regional survey area indicate a character similar to those in the regional survey area. The contribution ratio of the principal components to the variables is, in Z_1, 0.85 for Cu, 0.00 for Pb, 0.81 for Zn, and 0.76 for Ni; Z_1 is an explanatory component of Cu, Zn and Ni. The contribution ratio of Z_2 to the variables are: 0.00 for Cu, 0.98 for Pb, 0.04 for Zn, and 0.07 for Ni; Z_2 is an explanatory component of Pb.

(2) Distribution of Elements and Principal Components in Mineralization Areas

As for the known mineral deposits in the survey area, there are eleven gold indications located to the north of Vumba Hill in the middle of the east of the area and one copper indication located in the western extremity of the area. The number of samples required for disclosing the geochemical characters of these mineral indications was not acquired because of the wide intervals of the survey lines in this survey and the large spacing of sampling spots. Therefore, application of the principal component analysis was excluded to the gold indications. For the copper deposits, the 27 samples taken at Matsitama mineralization area situated about 5 km to the south from the southwest end of the survey area were used as reference samples for the principal component analysis.

In the first place, statistical distribution of the indicative elements in Matsitama mineralization area and its relation with the mineral deposit are observed. The statistically classified values from the mean logarithmic values and standard deviation of the elements (Table 16) are high compared with those of the regional survey area; the mean values of Cu are about ten times larger than the latter and, those of Pb, Zn and Ni are about double. As seen in Cumulative Frequency Distribution Figure of Elements (Fig. 23), Cu and Pb have populations of high content of about 40%, while Zn and Ni are in a normal logarithmic distribution. Besides these elements, Co which was analyzed for reference divided into two populations by the border of 55%. As set forth in the Element Content Distribution Figures from Fig. 25-1 to Fig. 25-5, Cu, Pb and Zn have relations with the mineralization zone; in particular Cu and Pb clearly indicate the relations. In comparison to these, Ni and Co have no distinct relations with the mineralization zone.

Next the characteristics of the principal components are observed (Table 15 and Fig. 22). The factor loading of the 1st principal component Z_1, when Cu, Pb, Zn and Ni are taken as variables, is, unlike the regional survey area and sub-regional survey area, 0.89 for Cu, 0.95 for Pb, 0.89 for Zn, and 0.16 for Ni; Cu, Pb and Zn greatly correlate with Z_1 in about the same measure, while Ni hardly correlates. All of these signs are same (positive) and vectors are in the same direction. The factor loading of the 2nd principal component Z_2 is -0.25 for Cu, -0.14 for Pb, 0.22 for Zn, and 0.97 for Ni. Only Ni strongly correlates. As for the vectors, those of Cu and Pb are in the opposite direction to those of Zn and Ni. However, it can be disregarded as the correlation of Z_2 with Cu, Pb and Zn is extremely weak.

When the contribution ratios of the principal components to the variables

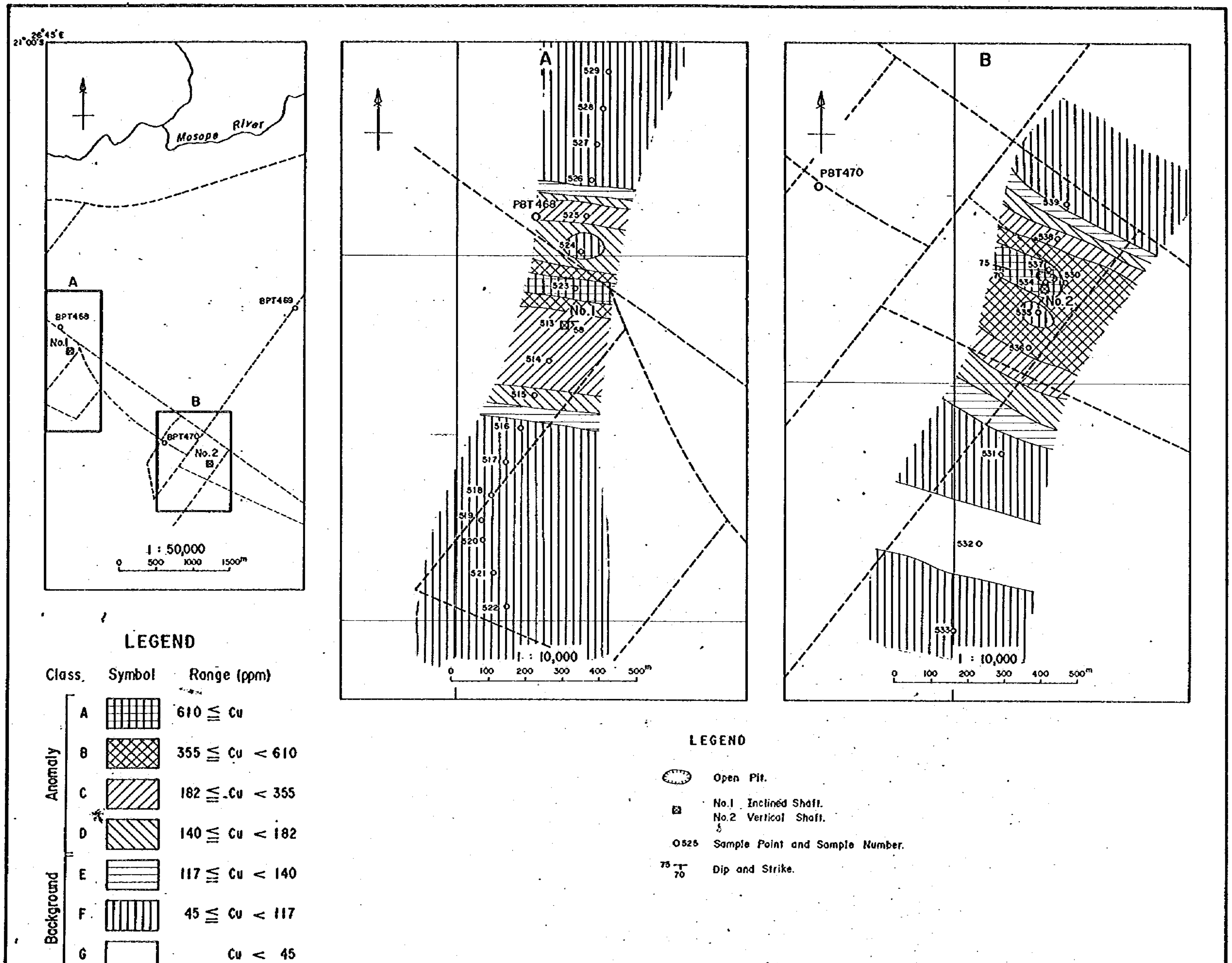


Fig. 25-1 Cu content distribution map in Matsitama minerailzed area

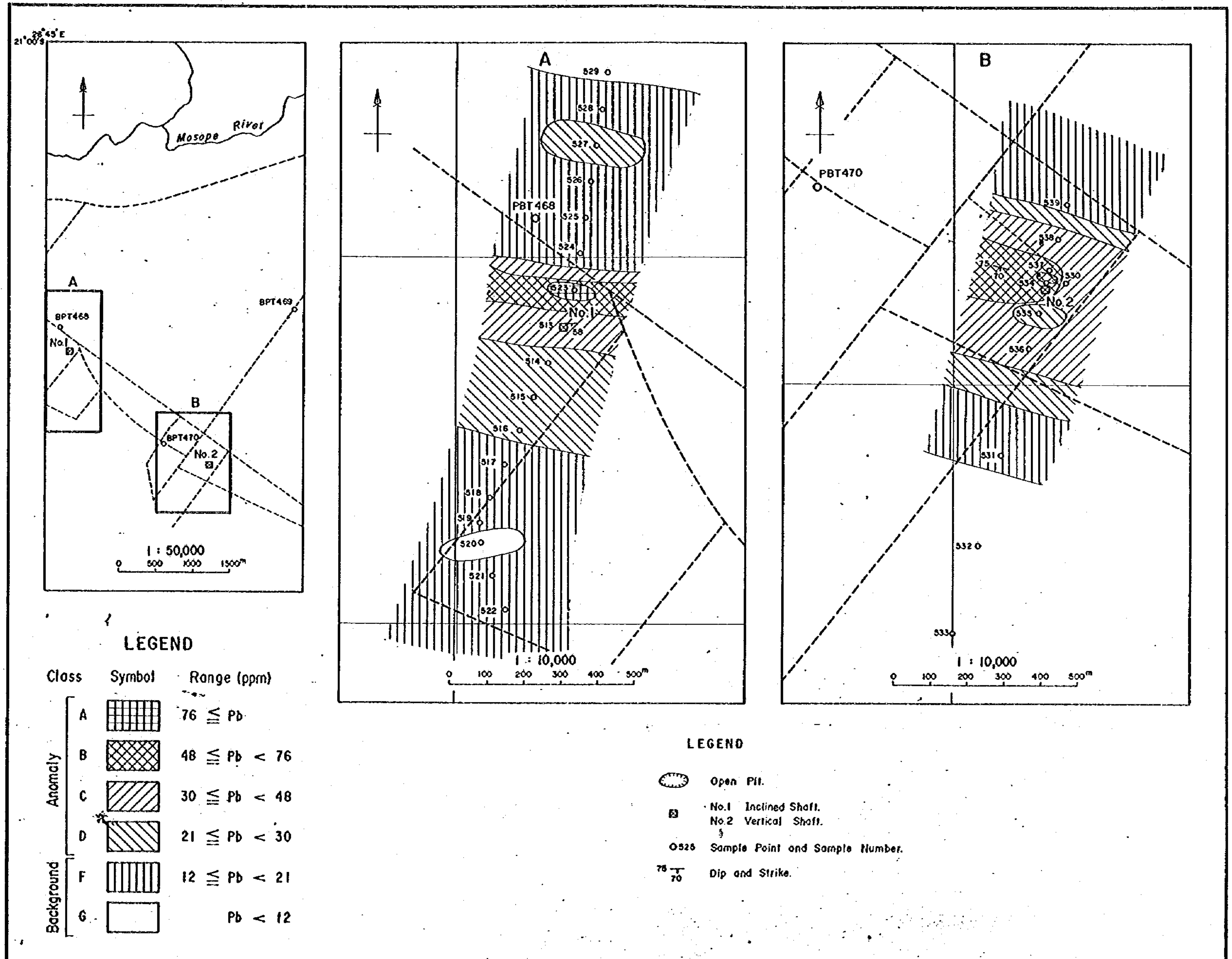


Fig.25-2 Pb content distribution map in Matsitoma minerailzed area

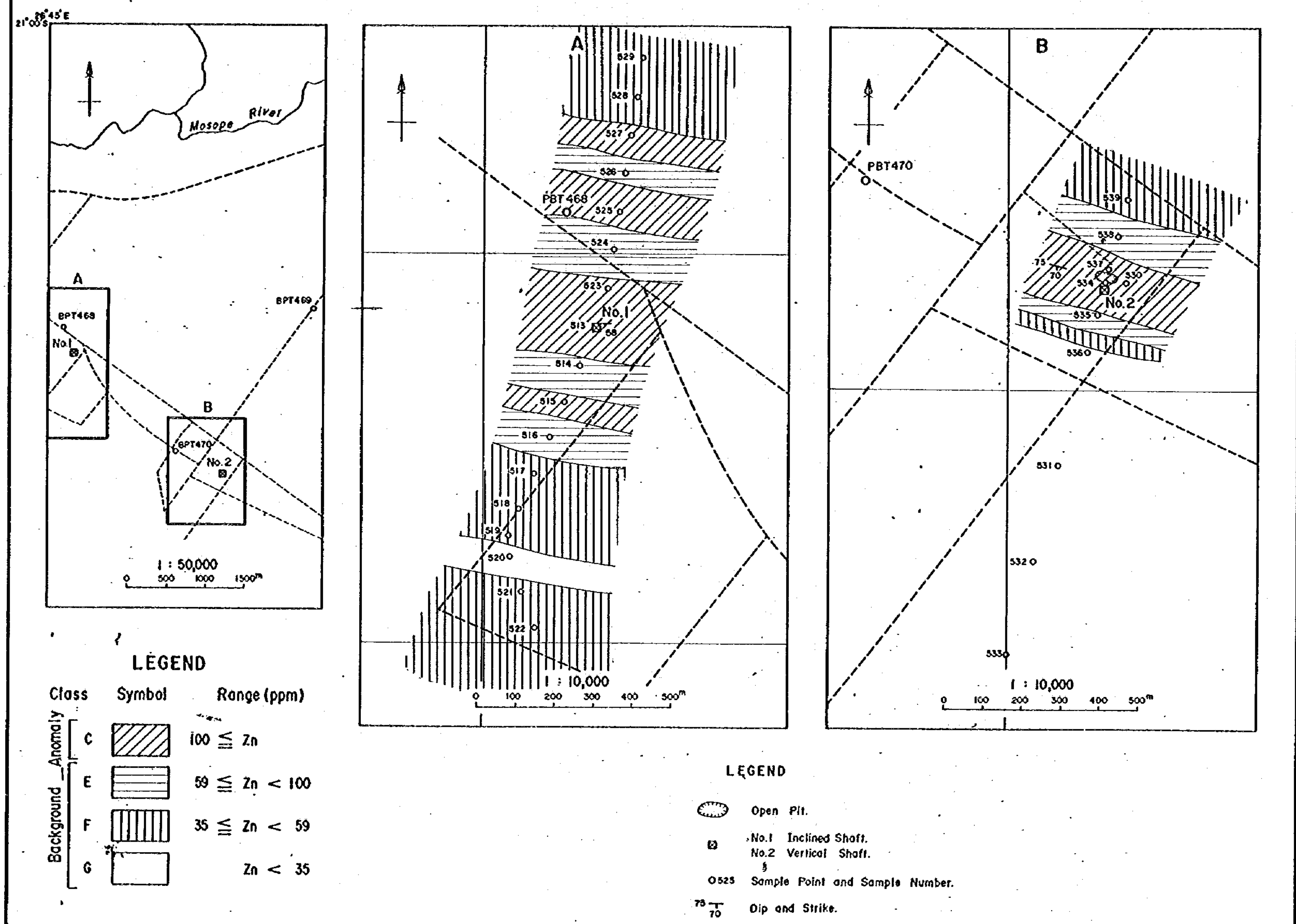


Fig.25-3 Zn content distribution map in Matsitoma mineralized area

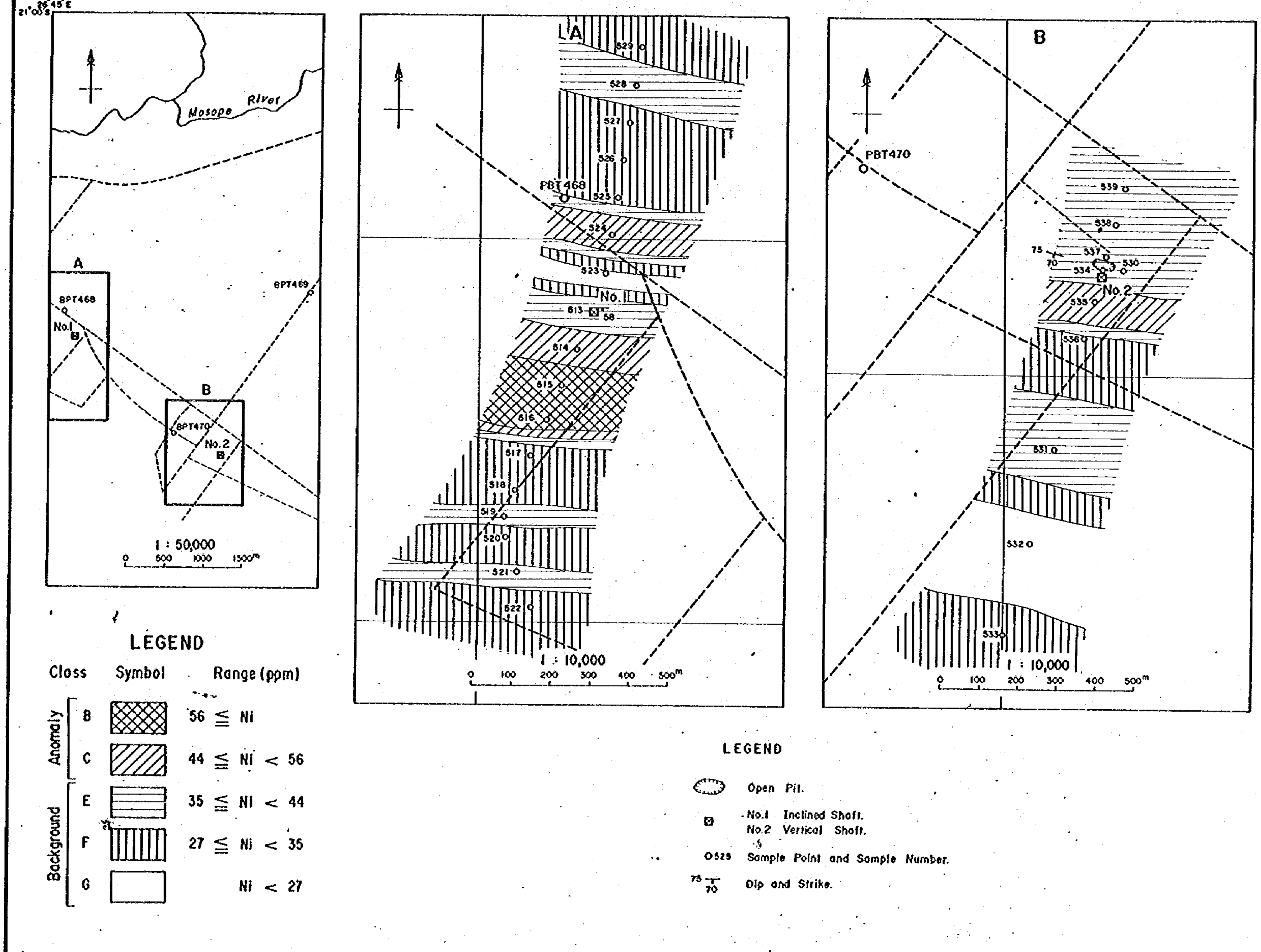


Fig. 25-4 Ni content distribution map in Matsitama mineralized area

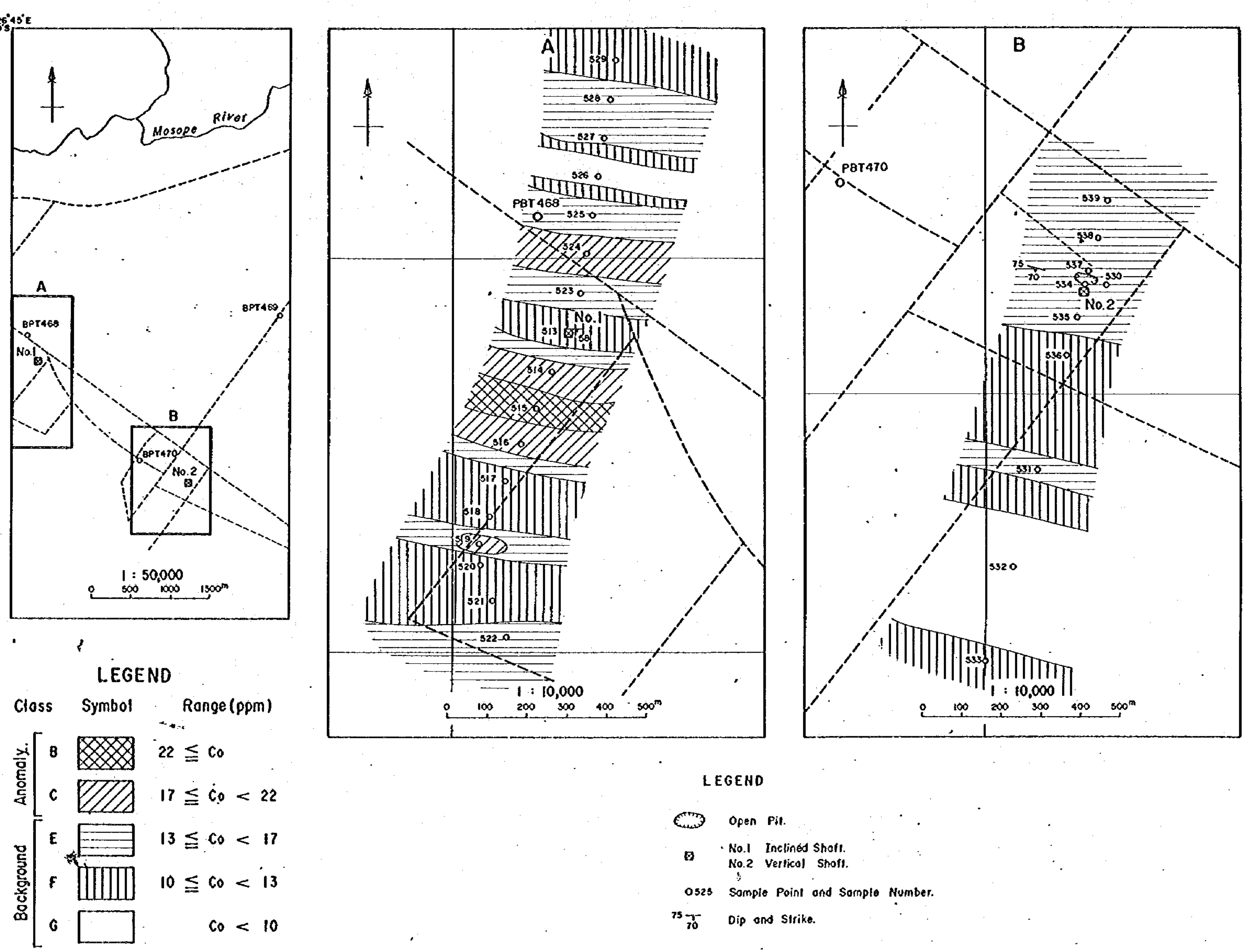


Fig.25-5 Co content distribution map in Matsitama mineralized area

are observed, the 1st principal component Z_1 is 0.79 for Cu, 0.90 for Pb, 0.79 for Zn, and 0.03 for Ni; Z_1 is an explanatory component of Cu, Pb and Zn. The 2nd principal component Z_2 is 0.06 for Cu, 0.02 for Pb, 0.05 for Zn, and 0.94 for Ni; Z_2 is an explanatory variate of Ni. As the result of making the principal component analysis for the case of being formed of five variables including Co which had been analyzed for reference, it was found that Co has a character similar to Ni and has been represented by the 2nd principal component Z_2, as indicated in Fig. 22.

Thus the principal components of Matsitama copper mineralization has been found to be distinctly different from Z_1 of the regional survey area and sub-regional survey area being the explanatory component of Cu, Zn and Ni and Z_2 of the same areas being the explanatory component of Pb.

(3) Principal Components of Populations for Each Geological Unit

Table 17 shows the substance of the results of conducting the principal component analysis on the 10 geological units for which the number of samples are 10 or over out of 18 geological units covering the eastern area occupying the two thirds of the survey area. Fig. 24 is three-dimensional plotting of the factor loading for the purpose of facilitating comprehension of the table. Among the 10 geological units, eight units of G_1, G_{2t}, G_{2ht}, G_{2g}, G_{3t}, A_k, Am and D indicate the same tendency as the regional survey area and sub-regional survey area. That is, Z_1 is an explanatory component of Cu, Zn and Ni, while Z_2 is that of Pb. With regard to the remaining two geological units, in Geo–6 (PG_{2g}), Z_1 is an explanatory component of all of Cu, Pb, Zn and Ni; in Geo–10 (G_4), Z_1 is an explanatory component of mainly Cu and Ni, while Z_2 is an explanatory component of mainly Zn, Pb being included to a considerable measure in the 3rd principal component Z_3. The geochemical significance of the principal components of these two units is not clear. However, it can be presumed that the populations are not homogeneous because of the small number of samples, only 16 and 11, for the two units.

Most of these 10 geological units resemble the characteristics of the principal components of the regional survey area and sub-regional survey area, and any geological unit that has characteristics resembling the principal components of Matsitama mineralization area has not been found. Accordingly, the principal components of this area are considered to be related with mineralization.

Table 17. Results of PCA for Geologically Separated Populations

Population	PC	Eigen Value	CCR	Factor Loading				Contribution Ratio for Variables				Corelation Coefficient					R 95%
				Log Cu	Log Pb	Log Zn	Log Ni	Log Cu	Log Pb	Log Zn	Log Ni		Log Cu	Log Pb	Log Zn	Log Ni	
GE0-2	Z_1	2.55	0.64	0.91	0.25	0.92	0.90	0.83	0.06	0.85	0.81	Log Cu	1.00				0.406
(G_1)	Z_2	1.01	0.89	-0.14	0.96	0.10	-0.22	0.02	0.92	0.01	0.05	Log Pb	0.98	1.00			
(22)	Z_3	0.24	0.95	-0.39	-0.04	0.23	0.17	0.15	0.00	0.05	0.03	Log Zn	0.74	0.29	1.00		
												Log Ni	0.77	0.03	0.75	1.00	
GE0-3	Z_1	2.53	0.63	0.93	0.46	0.84	0.87	0.86	0.01	0.71	0.76	Log Cu	1.00				0.252
(G_2t)	Z_2	0.88	0.85	-0.15	0.88	-0.04	-0.27	0.02	0.77	0.00	0.07	Log Pb	0.30	1.00			
(61)	Z_3	0.42	0.96	-0.12	-0.10	0.53	-0.33	0.01	0.01	0.28	0.11	Log Zn	0.69	0.30	1.00		
												Log Ni	0.80	0.20	0.58	1.00	
GE0-4	Z_1	2.55	0.64	0.95	0.43	0.79	0.91	0.90	0.18	0.62	0.83	Log Cu	1.00				0.433
(G_2ht)	Z_2	0.93	0.87	-0.01	0.89	-0.36	-0.08	0.00	0.79	0.13	0.01	Log Pb	0.36	1.00			
(19)	Z_3	0.40	0.97	-0.16	0.17	0.48	-0.33	0.03	0.03	0.23	0.11	Log Zn	0.67	-0.09	1.00		
												Log Ni	0.87	0.27	0.61	1.00	
GE0-5	Z_1	2.68	0.67	0.93	0.58	0.84	0.88	0.86	0.34	0.71	0.77	Log Cu	1.00				0.298
(G_2g)	Z_2	0.76	0.86	-0.13	0.81	-0.18	-0.23	0.02	0.66	0.03	0.05	Log Pb	0.42	1.00			
(48)	Z_3	0.39	0.97	0.13	0.01	-0.51	0.34	0.02	0.00	0.26	0.12	Log Zn	0.71	0.34	1.00		
												Log Ni	0.81	0.33	0.63	1.00	
GE0-6	Z_1	3.68	0.92	0.98	0.95	0.93	0.98	0.96	0.90	0.86	0.96	Log Cu	1.00				0.468
(PG_2g)	Z_2	0.18	0.96	-0.06	-0.19	0.36	-0.10	0.00	0.03	0.13	0.01	Log Pb	0.90	1.00			
(16)	Z_3	0.13	0.99	-0.16	0.26	0.07	-0.16	0.03	0.07	0.00	0.03	Log Zn	0.88	0.83	1.00		
												Log Ni	0.98	0.90	0.86	1.00	
GE0-8	Z_1	2.07	0.52	0.93	0.31	0.88	0.58	0.86	0.10	0.77	0.34	Log Cu	1.00				0.468
(G_3t)	Z_2	1.00	0.77	-0.10	0.87	0.12	-0.47	0.01	0.76	0.01	0.22	Log Pb	0.14	1.00			
(16)	Z_3	0.76	0.96	-0.30	-0.02	0.27	0.09	0.09	0.00	0.07	0.01	Log Zu	0.79	0.22	1.00		
												Log Ni	0.45	0.02	0.23	1.00	
GE0-10	Z_1	2.31	0.58	0.94	0.61	0.52	0.88	0.88	0.37	0.27	0.77	Log Cu	1.00				0.553
(G_4)	Z_2	0.93	0.81	-0.26	0.41	0.71	-0.44	0.07	0.17	0.50	0.19	Log Pb	0.39	1.00			
(11)	Z_3	0.69	0.98	-0.12	0.67	-0.47	-0.06	0.01	0.45	0.22	0.00	Log Zn	0.36	0.30	1.00		
												Log Ni	0.91	0.32	0.19	1.00	
GE0-11	Z_1	2.63	0.66	0.90	0.54	0.88	0.87	0.81	0.29	0.77	0.76	Log Cu	1.00				0.396
(Ak)	Z_2	0.79	0.86	-0.16	0.84	-0.18	-0.18	0.03	0.71	0.03	0.03	Log Pb	0.35	1.00			
(34)	Z_3	0.32	0.94	-0.05	0.00	-0.38	0.42	0.00	0.00	0.14	0.18	Log Zn	0.73	0.33	1.00		
												Log Ni	0.72	0.33	0.68	1.00	
GW0-14	Z_1	2.48	0.62	0.91	0.21	0.93	0.86	0.83	0.04	0.86	0.74	Log Cu	1.00				0.295
(Am)	Z_2	1.02	0.87	-0.02	0.97	0.06	-0.28	0.00	0.94	0.00	0.08	Log Pb	0.15	1.00			
(47)	Z_3	0.30	0.95	-0.29	0.12	-0.13	0.42	0.08	0.01	0.02	0.18	Log Zn	0.79	0.22	1.00		
												Log Ni	0.69	-0.04	0.70	1.00	
GE0-20	Z_1	2.51	0.63	0.75	0.59	0.90	0.88	0.56	0.35	0.81	0.77	Log Cu	1.00				0.321
(D)	Z_2	0.82	0.83	-0.46	0.77	0.00	-0.12	0.21	0.59	0.00	0.01	Log Pb	0.20	1.00			
(36)	Z_3	0.42	0.94	-0.46	-0.23	0.22	0.32	0.21	0.05	0.05	0.10	Log Zn	0.57	0.46	1.00		
												Log Ni	0.58	0.37	0.75	1.00	

PC : Principal component
PCA : Principal component analysis
CCR : Cumulative contribution ratio
(22) : Figures in brackets are number of samples of population.
R : Significant level of correlation coefficient from R-table

2-4-3 Extraction of Anomalous Zones

As mentioned in the preceding section, it has been found that the principal components of Matsitama mineralization area are related with mineralization. Therefore, extraction of samples with characters similar to Matsitama mineralization area from the regional survey area and sub-regional survey area, that is, extraction of mineralization anomaly zones was attempted. It should be noted that the mineralization anomalies mentioned here are, as a matter of course, to be restricted to geochemical anomalies similar to the copper mineralization anomalies in Matsitama, without any relations with the gold indications near Vumba Hill.

(1) Fig. 26-1 represents the distribution of the 1st principal component Z_1 in Matsitama mineralization area; the ranking depends on the cumulative frequency distribution map. It can be read that the geochemical anomalies expressed in the ranks of Z_1 (Ranks A, B, C and D) well indicate the mineralization zones and comprehensively represent the anomalous zones of Cu, Pb and Zn shown in Fig. 25-1 to Fig. 25-3. Fig. 26-2 is the distribution map of the 2nd principal component Z_2, which better corresponds to the Ni distribution map than the distribution of mineralization zones.

The chart of dispersion of the scores of Z_1, which well indicates the mineralization zones as above-mentioned and is an explanatory component of Cu, Pb and Zn, and of Z_2, which is an explanatory component of Ni, is shown in Fig. 27. In this chart, the composite value of Cu, Pb and Zn becomes higher in proportion to moving in the positive direction of Z_1 axis and becomes lower in proportion to moving in the negative direction. Also with Z_2 axis alike, Ni content increases in the positive direction and decreases in the negative direction. (see 2-4-2 (2))

Now notice is directed to the sample points where the score of Z_1 is -0.25 or over. These points belong in the mineralization anomalous zones (Fig. 26-1), and Z_1 and Z_2 indicate a negative correlation, that is, as Cu, Pb and Zn increase Ni decreases. Next, the sample points where the score of Z_1 is -0.25 or lower belong in the background value zone, and Z_1 and Z_2 of them are in a positive correlation, that is, all of Cu, Pb, Zn and Ni increase or decrease simultaneously. Thus the sample population of Matsitama mineralization area are formed of two populations in which the correlation of Z_1 and Z_2 is opposite, positive to negative. Consequently, Z_1 and Z_2 of this composite population are found to be uncorrelated to each other.

(2) The procedure to extract samples with characters similar to Matsitama mineralization area from the sample populations of the regional survey area and sub-regional survey area is described in the following:

The sample population consisting of four variables (the logarithmic values of the element contents) of Matsitama mineralization area forms a rotation spheroid with four coordinate axes which are uncorrelated to each other. To know whether a certain sample belongs to the above-mentioned population or not, the position taken by a new sample point on these coordinate axes should be found. It is to say that the score of the principal components of the new sample should be obtained on the basis of the coordinate rotation vectors of Matsitama area.

Taking the coordinate rotation vectors of Matsitama area as A_1, A_2, A_3, and A_4 and the variables of the new sample as X_1, X_2, X_3, and X_4, the principal component of the sample Z is given by the following:

$$Z = A_1X_1 + A_2X_2 + A_3X_3 + A_4X_4$$

Here it is conditioned that Xi si normalized using the mean value (m) of the variables of Matsitama area and the standard deviation, that is:

$$X_i = \frac{X_i - m_i}{\partial_i}$$

(3) The results of calculating the scores of the principal components with the use of the above equation about the samples of the regional survey area and sub-regional survey area are shown in Fig. 28 and Fig. 29 as the dispersion charts of Z_1 and Z_2.

In the next place, equal density distribution maps expressing the density of the sample points per unit area were prepared from the above-mentioned dispersion charts. The overlapping of the maps and the sample points of Matsitama mineralization area is shown as Fig. 30 and Fig. 31. From these one can tell that, in both the areas, there are few points similar to the sample points indicating the mineralization zones of Matsitama area ($Z_1 \geqq -0.25$). As for the amount of points similar to the sample points with background values, when the extents of the lines of equal density of 2%, for example, are compared, it is found that the amount tends to be larger in the regional survey area.

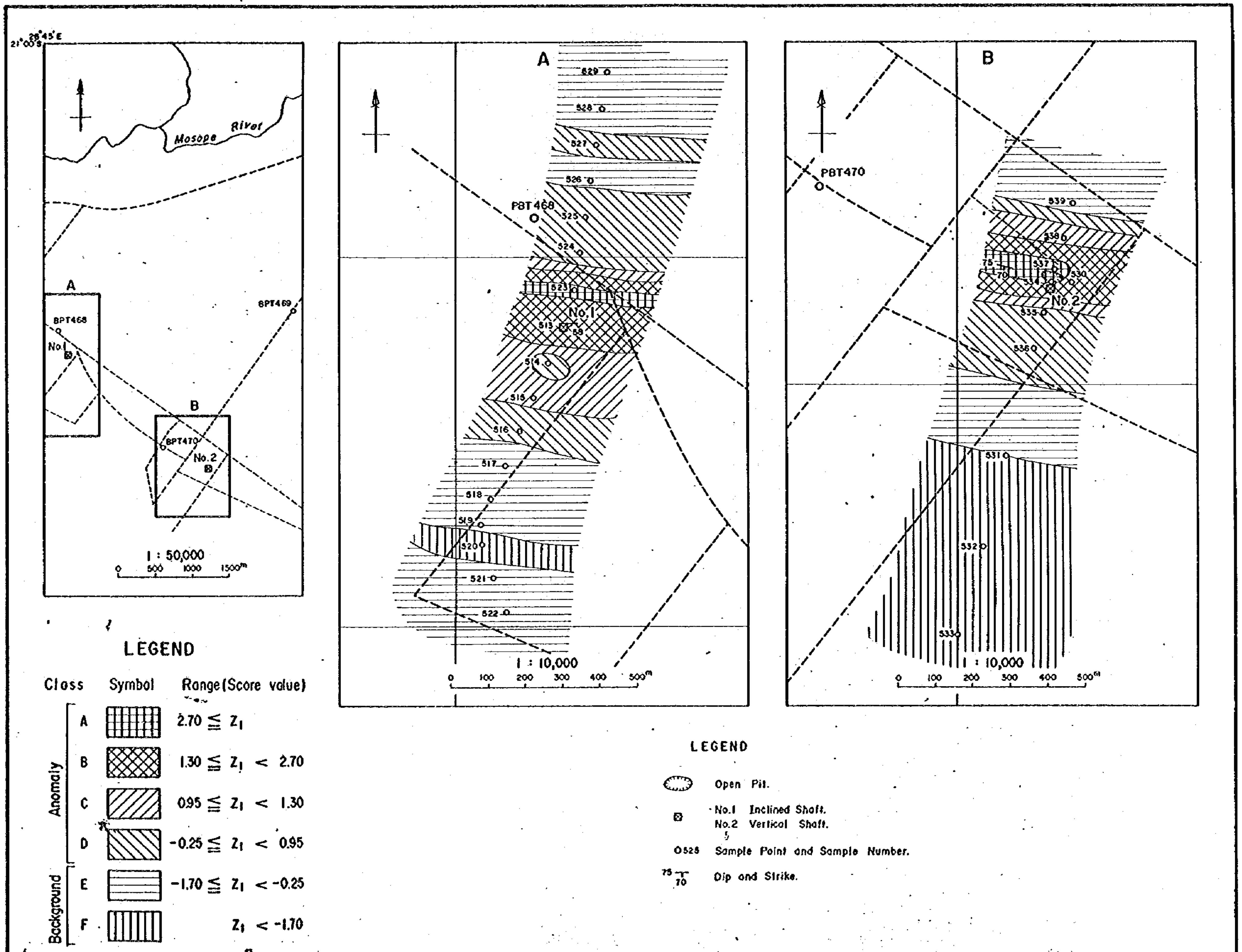


Fig.26-1 Z_1 score distrbution map in Matsitama mineralized area.

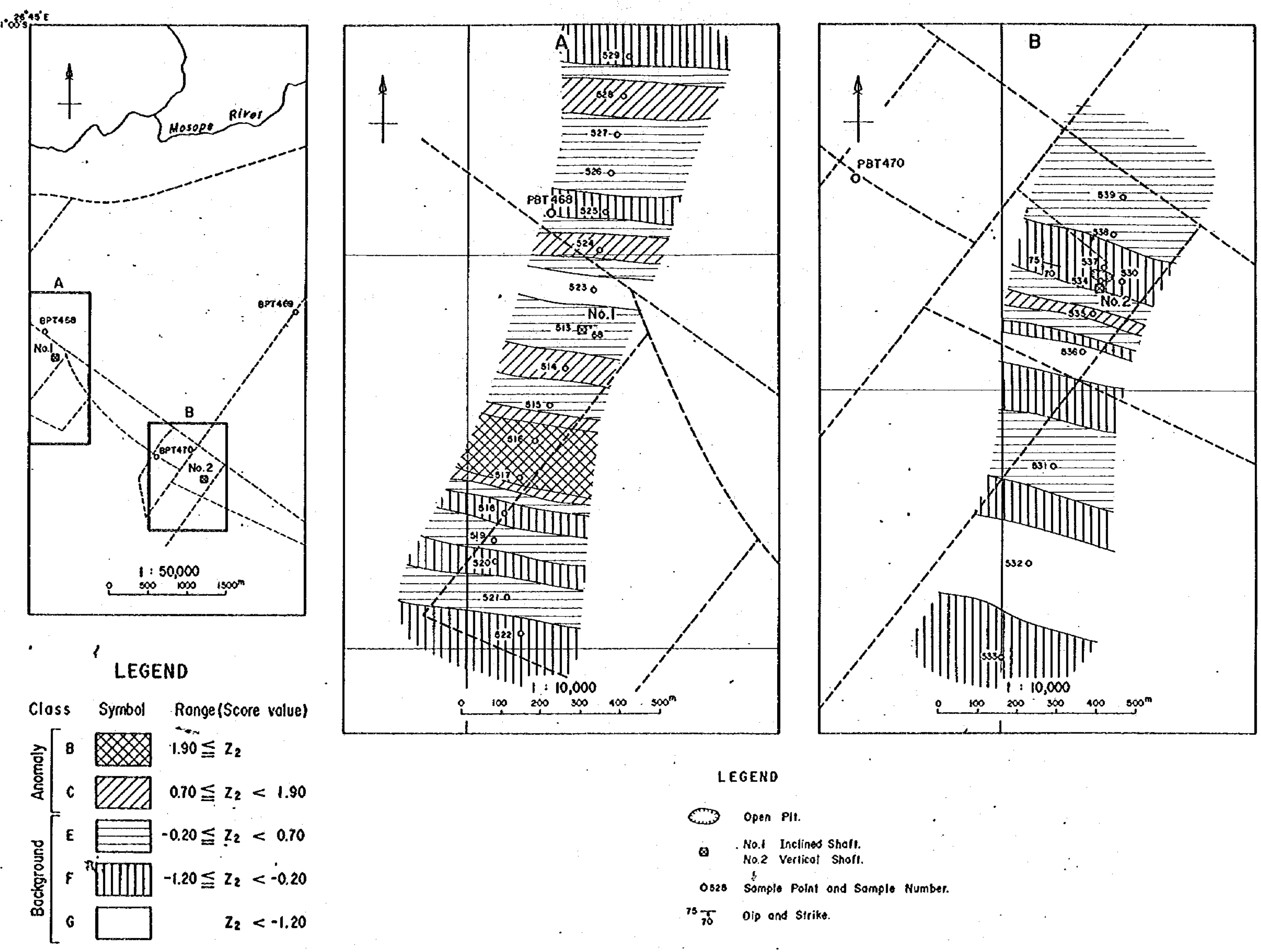


Fig.26-2 Z_2 score distrbution map in Matsitama mineralized area.

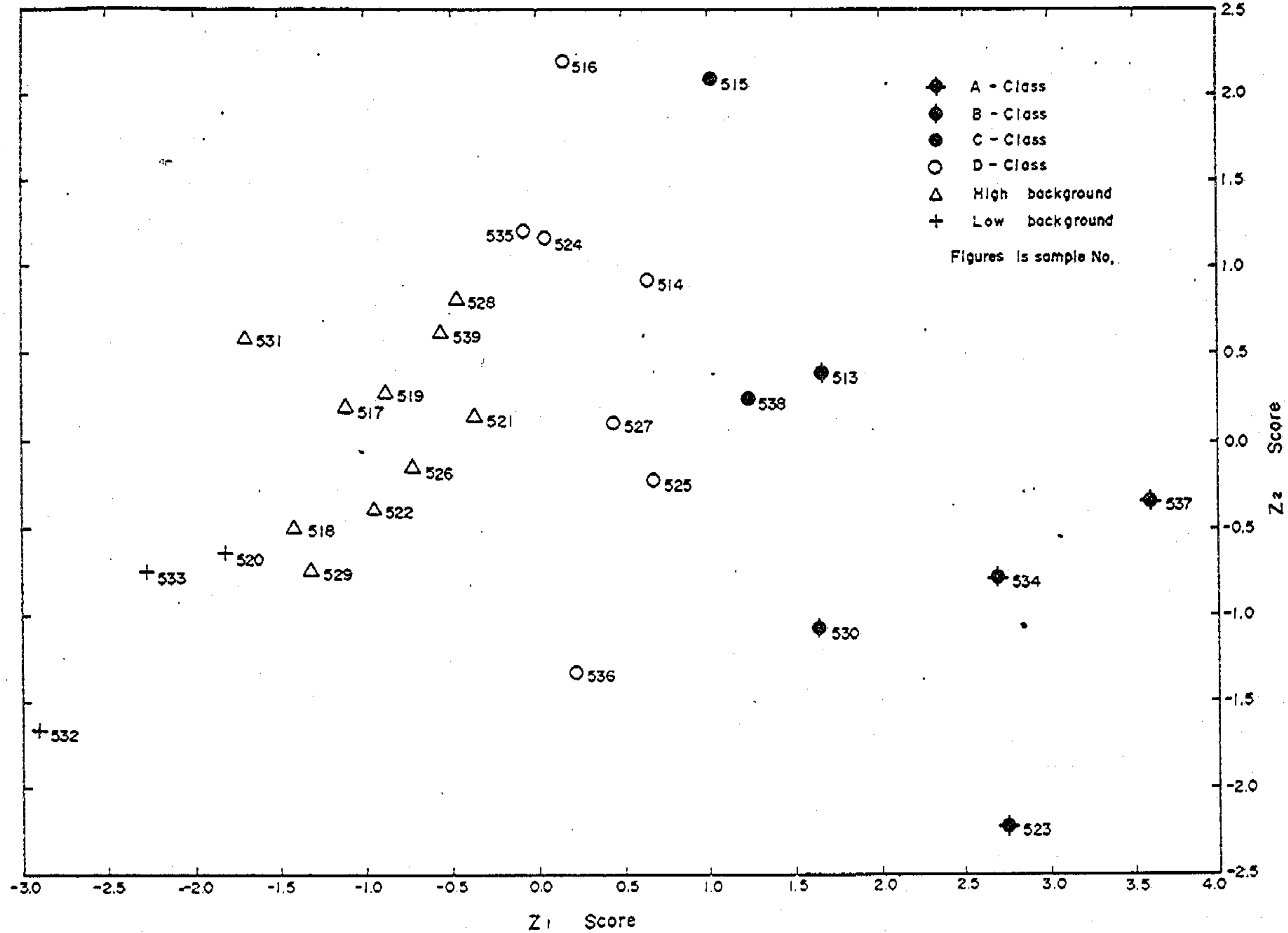


Fig.27 Score plot of $Z_1 \cdot Z_2$ by PCA in Matsitama mineralized area

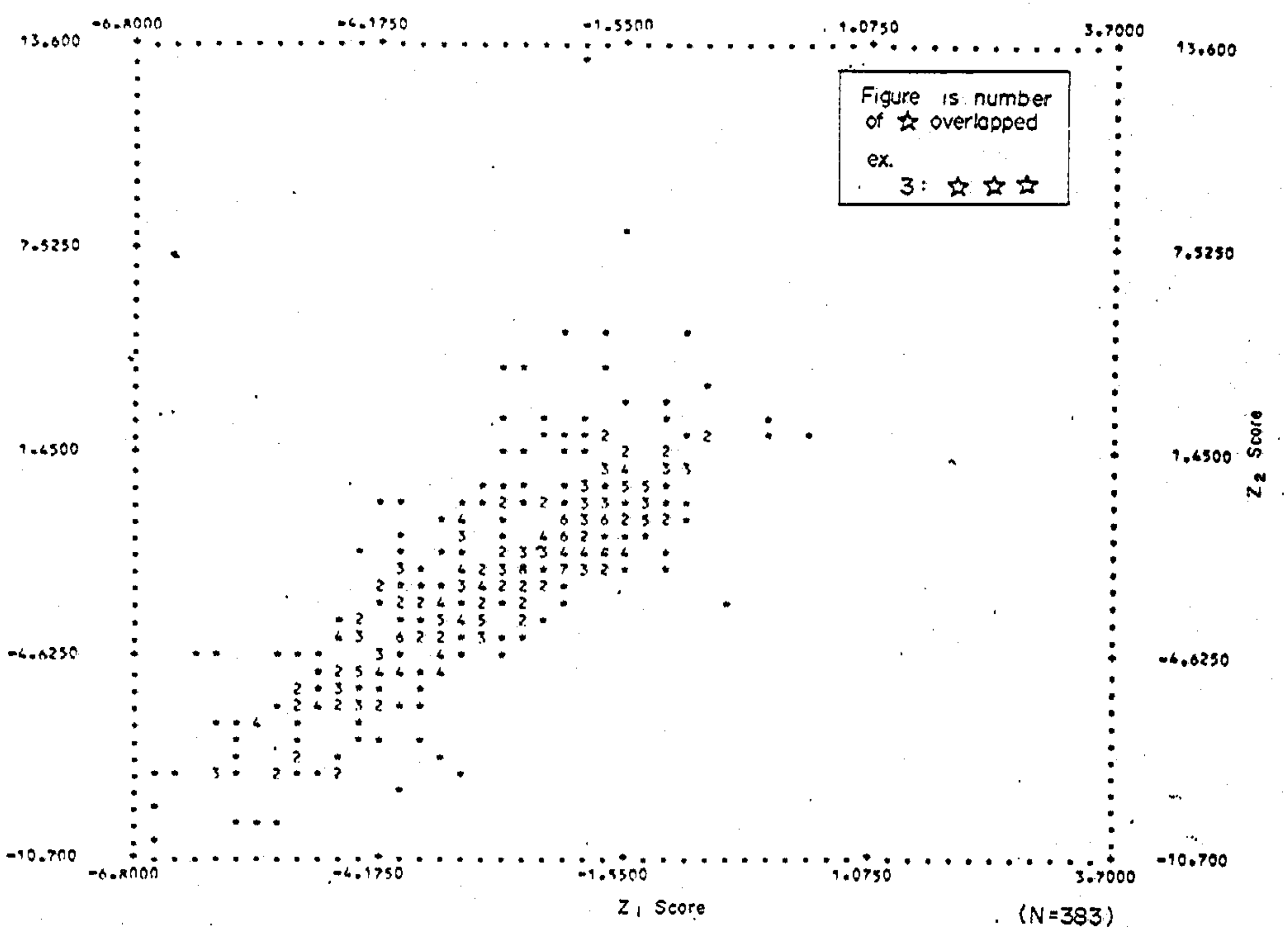


Fig. 28 Score plot of $Z_1 \cdot Z_2$ on Matsitama vector in regional survey area

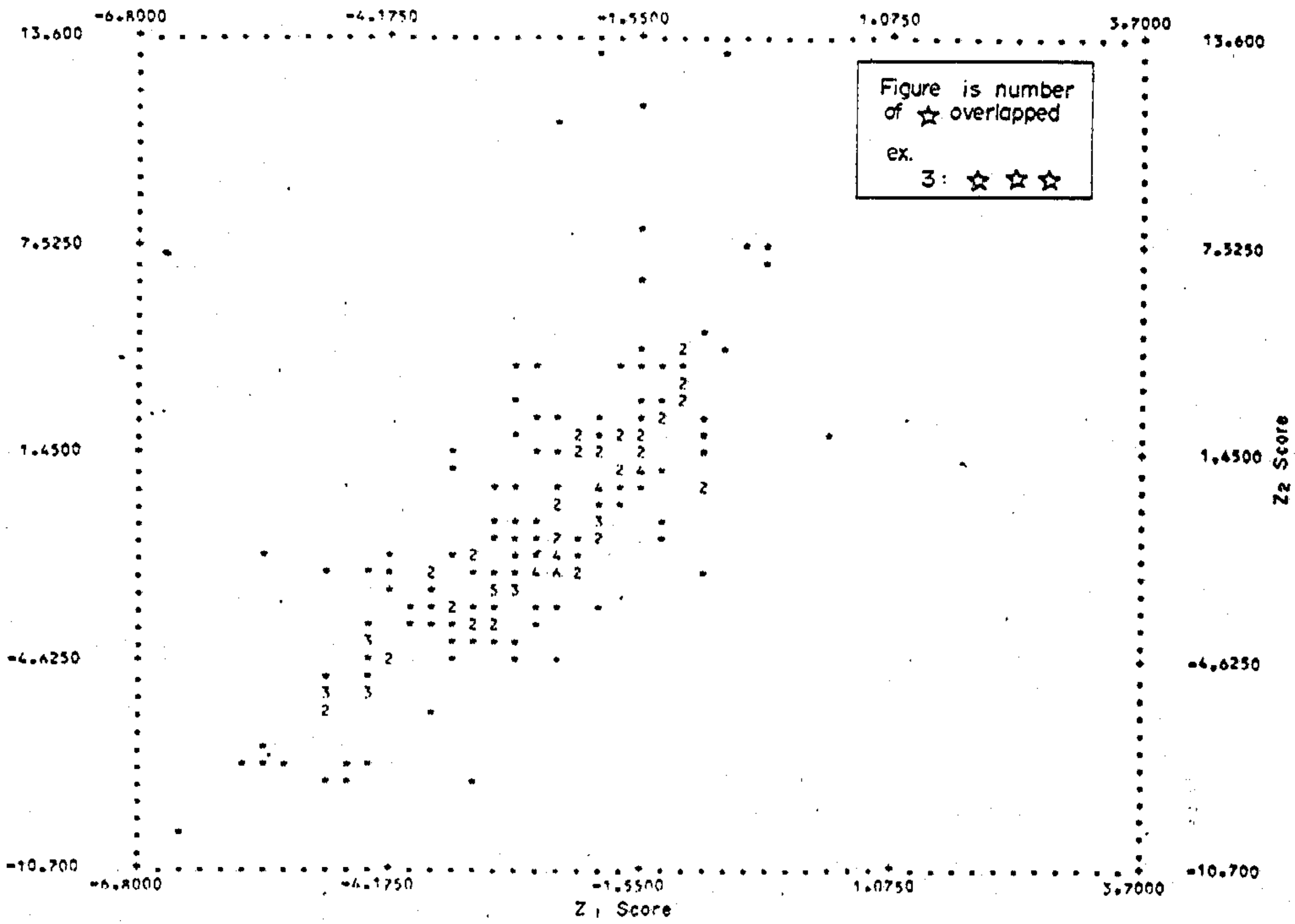


Fig.29 Score plot of $Z_1 \cdot Z_2$ on Matsitama vector in sub-regional area

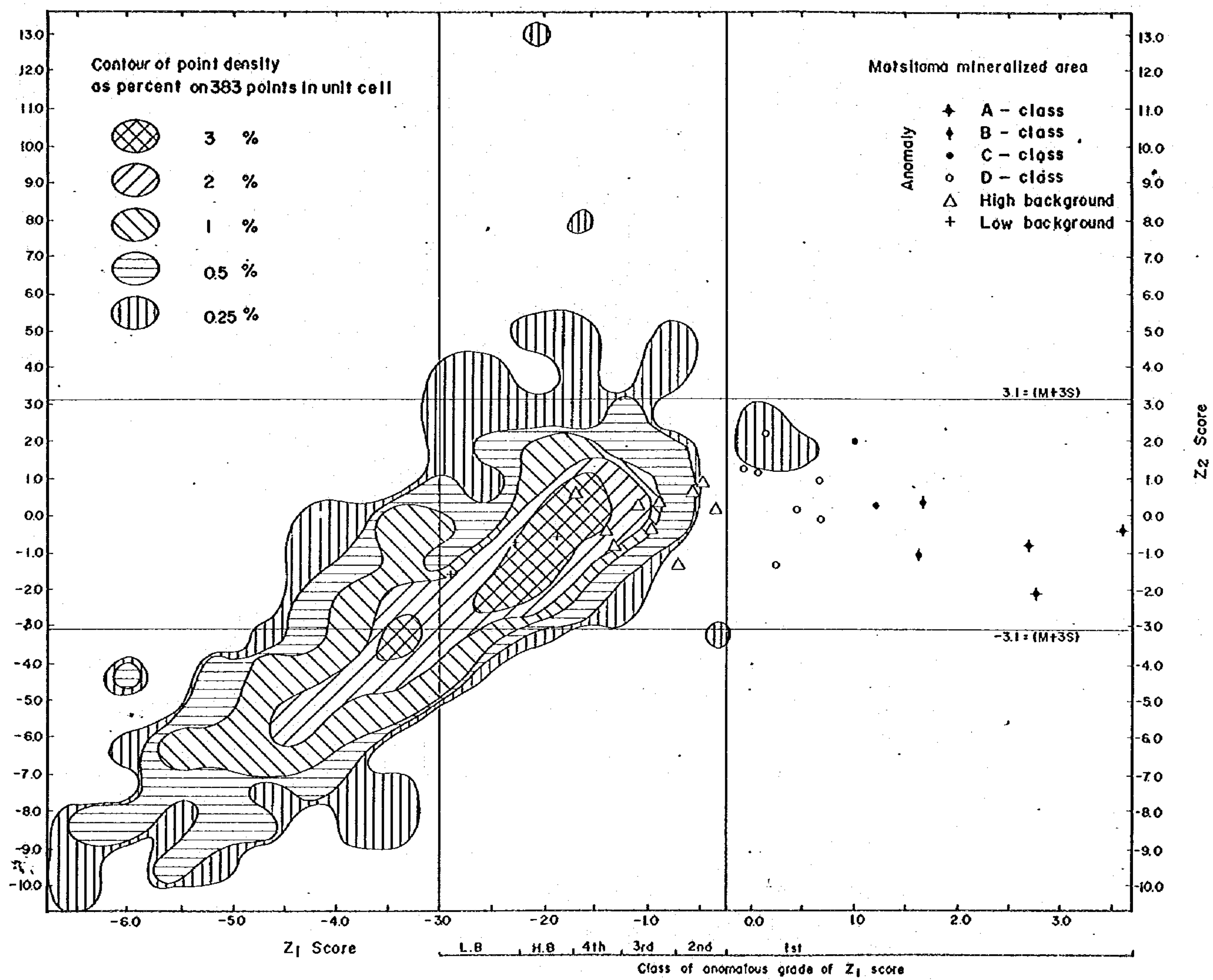


Fig. 30 Relation of $Z_1 \cdot Z_2$ scores distributed in Matsitama mineralized area and regional survey area

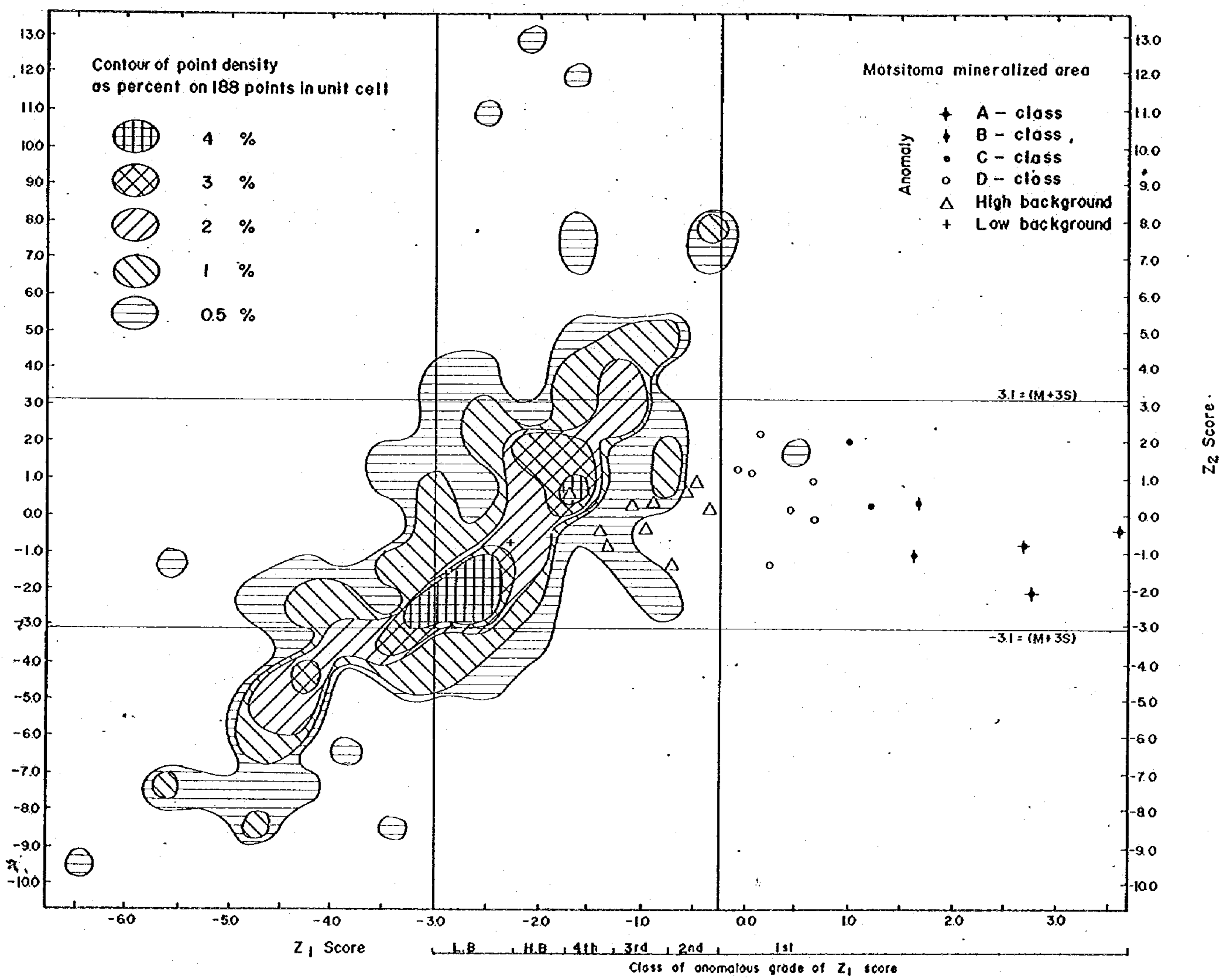


Fig. 31 Relation of $Z_1 \cdot Z_2$ scores distributed in Matsitoma mineralized area and sub-regional survey area

The extent and rank of Z_1 and Z_2 which similar to the populations of Matsitama area are determined as follows:

First, the extent of Z_1 is taken at -3.0 which is almost equal to the minimum value of Z_1 of Matsitama area. For the ranking, the threshold value of mineralization anomalies, Z_1 = -0.25, or more of Matsitama area is ranked as 1st class, and for the values less than -0.25, the 2nd, 3rd, and 4th class anomalies are designated at the intervals of 0.50; the values from -1.75 to -2.25 are designated as high background values, and those from -2.25 to -3.0 as low background values. Anomalies of 2nd class and lower are equivalent to the high background values of Matsitama area.

The extent of Z_2 involves a difficult problem, which is the fact that the mineralization population and the background value population of Matsitama area are in the opposite correlation. Accordingly, as a whole, they are uncorrelated, and ranking of Z_2 is impossible. Therefore, for convenience, centering around the mean value of Z_2 population of Matsitama area, the extents of 3S on both sides ($-3.1 \leqq Z_2 \leqq 3.1$) have been assumed as the population of Matsitama area. However, this will produce extraction errors to some measure because of restriction of the extent to M ± 3S.

(4) Using the extent of Z_1 and the ranking set forth in (3) above, the distribution map of the scores of Z_1 has been made for each area (PL. 9 and PL.10). Then, extracting only the scores in which Z_2 indicates the values of $-3.1 \leqq Z_2 \leqq 3.1$ in these maps, Geochemical interpretation maps by PCA (PL. 11 and PL. 12) were made.

2-5 Geochemical Anomalous Zones

Distribution of geochemical anomaly zones for the zones delineated as having characters similar to those of Matsitama mineralization area is described for each survey area, using Geochemical interpretation maps by PCA (PL. 11, 12) and Element contents distribution maps (PL. 7, 8), in the following. The definition of anomalous zone is here laid down as the scale of having not less than 2 anomalous points of the 4th class or above and being surrounded by high background values.

2-5-1 Regional Survey Area

In the regional survey area, there are eight geochemical anomalous zones that have been extracted as having characters similar to those of Matsitama mineralization area.

The locations, scale, and the number of the anomalous values for each rank of such anomaly zones together with some remarks are set forth collectively in Table 18.

Among the eight anomalous zones, the southwestern anomaly zone has the highest anomaly and the largest scale of anomaly zone compared with the others. It is an anomalous zone that arouses interest, in respect that it adjoins Matsitama area as well.

Tikitiki River anomalous zone is distributed around a small rock body which was described by Bennett (1970) as granite gneiss poor in schistose structure.

Tutume River anomalous zone is formed mainly of Pb and Zn. The anomaly of Zn is distributed in a manner of forming a halo in the surrounding of Pb anomaly. This anomalous zone possibly indicates distribution of debris from Karroo System (D. Green, 1966) distributed to the north. In any case it is an anomalous zone different in nature from the southwestern anomaly zone.

South-1 anomalous zone is a small scale of anomaly in porphyroblast granitic gneiss (PG_{2g}). Since small-scale dikes of dolerite have much developed in this vicinity, some extension of them can be inferred.

The anomalous zones of South-2, Sechele, and East End stem all from country rock of dolerite.

Vumba anomalous zone consists of five kinds of country rock, i.e., amphibolite, dolerite, ultramafic rock, G_{1m} (monzonite), and felsic metavolcanic rock. This anomaly zone is the product of extracting, by the principal component analysis, what was included in the large-scale anomaly zone of Cu and Ni which were indicating amphibolite of Vumba area, and it is possible that an error in Z_2 extraction is involved in it.

2-5-2 Sub-Regional Survey Area

In the sub-regional survey area, there are six anomalous zones that have been extracted as zones similar to Matsitama mineralization area. As for four zones of these, their general shapes have already grasped as anomalous zones in the regional survey area.

Table 18. List of Geochemical Anomalous Zone in Regional Survey Area

Anomaly	Location		No. of point	Anomalous points				Remarks	Priority	Factor to make anomaly
	Line	Samp. No.		1st	2nd	3rd	4th			
Southwestern Anomalous Zone	X1	1 – 18	10	1	1	5	3	Geology isn't defined.	1	Cu horizon (?)
	X2	31 – 47	6			3	3	One Cu showing is known.		on its extension (?)
	X3	63 – 71	4				4	Grade: Cu > Zn > Ni > Pb		
	X4	91 – 96	2				2			
	X5	121 – 126	3				3			
			25	1	1	8	15			
Tikitiki river Anomalous Zone	X-4	108 – 110	1				1	Geology: Poorly foliated granite	2	Amphibolite (?)
	X-5	137 – 141	3			2	1	gneiss and G_2g		
	X-6	168 – 172	2				2	Grade: Cu = Pb = Zn = Ni		
			6							
Tutume Anomalous Zone	X-3	87 – 90	3				3	Geology: Mosetse river group is	3	Karroo deposits (?)
	X-4	116 – 120	3				3	covered with debris of Karroo system.		
	X-5	145 – 149	2				2	Grade: Pb > Zn ≫ Ni = Cu		
			8				8	Pb has a halo of Zn to the south		
South-1 Anomalous Zone	X-8	211 – 216	3				3	Geology: PG_2g, D etc.	4	Dolerite (?)
			3				3	Grade: Cu = Zn > Ni > Pb		
South-2 Anomalous Zone	X-10	263 – 265	1				1	Geology: D, Ak	4	Dolerite
	X-11	283 – 285	1				1	Grade: Cu = Zn = Ni = Pb		
			2				2			
Sechele Anomalous Zone	X-12	307 – 311	3			1	2	Geology: D, G_4, Am, G_2t	4	Dolerite
			3			1	2	Grade: Cu > Ni > Zn > Pb		
Vumba Anomalous Zone	X-10	276 – 278	1				1	Geology: Am, G_4, Fel, Al, G_{1m},	4	Dolerite and other rocks
	X-11	294 – 297	2	1			1	D, etc.		
	X-12	315 – 316	1				1	Grade: Zn = Pb > Ni > Cu		
			4	1			3			
East end Anomalous Zone	X-14	347 – 350	3		1		2	Geology: G_3t, D, G_2t	4	Dolerite
			3		1		2	Grade: Cu > Zn ≫ Ni = Pb		

Geological abbreviation : refer to Table 12-9

Table 19. List of Geochemical Anomalous Zone in Sub-regional Survey Area

Anomaly	Location		No. of points	Anomalous points				Remarks	Priority	Factor to make anomaly
	Line	Samp. No.		1st	2nd	3rd	4th			
Ikura river Anomalous Zone	X-8	220 – 227	3				3	Geology: G_2t, Um, G_1, D	2	Amphibolite, Dolerite
	A-1	384 – 387	1				1	Grade: Ni > Cu > Zn ≫ Pb		
	A-2	394 – 397	1				1			
	A-3	404 – 407	2				2			
	X-10	269 – 270	1				1			
			8				8			
Vumba Anomalous Zone	A-3	408 – 410	1				1	Geology: Am, G_4, D, Fel., Al, Ser,	4	Dolerite and other rocks
	X-10	276 – 278	1				1	Ls, G_{1m}, etc.		
	A-5	429 – 431	1				1	Grade: Pb = Zn > Cu > Ni		
	A-6	438 – 441	2			1	1			
	X-11	294 – 297	2	1			1			
	A-7	454 – 456	1			1				
	A-8	474 – 475	1			1				
	X-12	315 – 316	1				1			
			10	1		3	6			
Schele-1 Anomalous Zone	A-7	451 – 453	1				1	Geology: Am, Pel., Ls, G_2ht	4	Amphibolite
			1				1	Grade: Ni > Cu > Zn > Pb		
Sechele-2 Anomalous Zone	X-12	307 – 311	3			1	2	Geology: G_2t, G_2ht, D, G_4	4	Dolerite
	A-9	484 – 485	1				1	Grade: Pb > Cu > Ni > Zn		
			4			1	3			
South-2-A Anomalous Zone	X-11	284	1			1		Geology: D, G_2t	4	Dolerite
	X-12	305	1				1	Grade: Ni > Cu > Zn > Pb		
	A-9	481	1				1			
			3				3			
South-2-B Anomalous Zone	A-10	486	1			1		Geology: D.	4	Dolerite
			1			1		Grade: Cu ≫ Ni > Zn > Pb		

Geological abbreviation : refer to Table 12-9

Accordingly the names of these anomalous zones are made common (Table 19).

Ikula River anomalous zone is formed mainly of dolerite and ultramafic rock Two points formed of amphibolite are of 4th class anomaly.

In Vumba anomalous zone, 1st class anomalous point is formed of dolerite. The other anomaly zones of 4th class or above are formed of a variety of geology, i.e., amphibolite, aluminous metasedimentary rock, felsic metasedimentary rock, and G_{1m} (monzonite) etc.

Sechele-1 anomalous zone is formed of amphibolite, dolerite, and tonalite gneiss. One point occupied by amphibolite is of 4th class anomaly.

The three anomalous zone of Sechele-2 and South-2-A and B are formed mainly of dolerite and tonalite gneiss; they are considered to be of less importance.

Among the eleven gold indications to the north of Vumba Hill, the northern two are included in a high background value area in Vumba anomaly zone, but cannot be said to reflect the distribution of the gold indications. Also, in Elements contents distribution map, any elements to denote these mineral indication zones are not recognized.

In an molybdenum indications that has been found about 2.5 km to the west of Dombashaba Hill in the middle of the survey area, four soil samples (Sample Nos. 509 to 512) were taken and analyzed, but no geochemical anomaly was detected.

2-5-3 Summary

More than 500 soil samples were taken from the intersecting points of rectangule-patterned grids, and the contents of Cu, Pb, Zn, Mo and Ni were analyzed by the atomic absorption spectroscopy method. As for Mo, in all the samples the content was not more than 3 ppm; it can be said that any molybdenum mineralization that deserves expectation has not been found. As the result of studying the relations of Cu, Pb, Zn and Ni contents to geological units and color tones of soil, it has been found that basic to ultramafic rocks have high values and that soil of red group and part of dark-gray to black soil shows high values. Thus grasping of mineralization anomalies by the method of analysis for each indicative element having been made impossible, the method was used that areas similar to Matsitama copper mineralization area lying close to the southerwest are extracted by the principal component analysis method.

As the result of applying this method, eight anomalous zones (Table 18) were extracted within the regional survey area; among them, the southwestern anomalous zone indicated the strongest anomaly which is extensive as well as interesting.

In the sub-regional survey area six anomalous zone (Table 19) were extracted; out of them Vumba anomalous zone was found strong and extensive, but the strongest anomalous point in this zone is underlain by dolerite. Many of anomalies in the survey area see to derive from dolerite.

Our of the regional and sub-regional survey areas, the zone of the strongest anomaly and the broadest zone is the southwestern anomaly zone. Further surveys are desired on this zone.

RECOMMENDATION

Recommendation

Among three mineralized zones in the survey area – Vumba, Timbale and Northern Matsitama -- the most promising zone is Northern Matsitama, southwest part of the survey area, where more detailed survey is desired to be made in the following years.

The results of the LANDSAT data analysis and geological survey suggest that the east wing of the copper bearing horizon of Matsitama schist and metasedimentary group may extends to the Northern Matsitama Zone. The results of the geochemical survey done by the method of principal component analysis indicate the anomalies in the zone.

Recommendable area and method for the second year's survey are as follows:

Area: About 800 km^2 in the Northern Matsitama Zone

Method:
1) Airborn integrated geophysical prospecting (3,000 line kilometres)
2) Geological and geochemical surveys

Upon deliberation of the results of the second year's survey, the third year's survey area (about 100 km^2) is to be selected from the above-mentioned 800 km^2.

In the Vumba Zone, unrecorded sulfide rich outcrops and old pits have been found scattered around Somerset Mine. However, since the Anglo-American group and others conducted surveys in the past for copper bearing nickel ore in this zone, it seems that further surveys are not requried.

As for the Timbale Zone, the results of the geological and geochemical surveys indicate little possibility of porphyry type copper-molybdenum ore deposits occurring in this zone, although this time investigation does not cover the zone sufficiently.

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