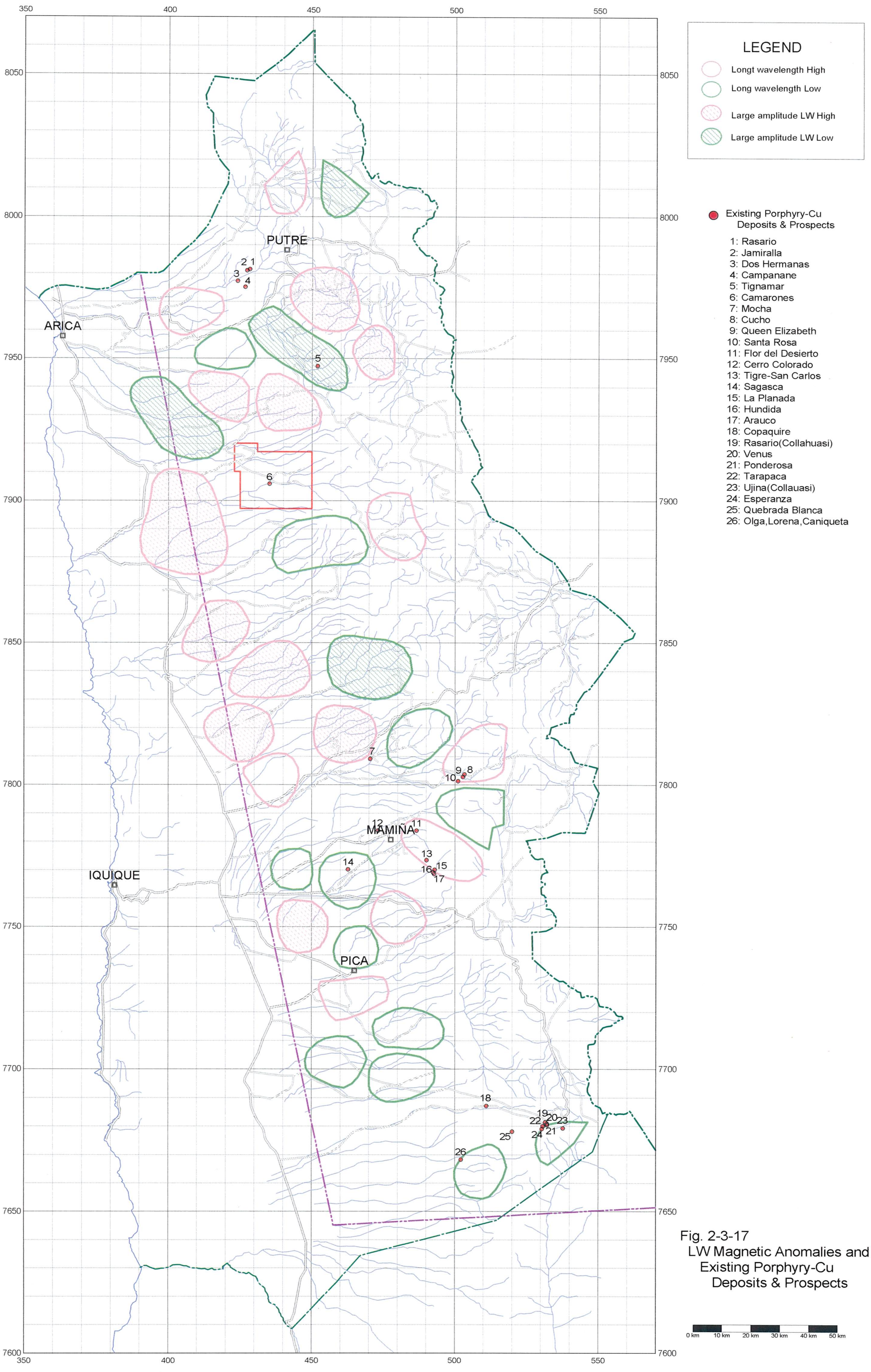


Fig. 2-3-17
LW Magnetic Anomalies and
Existing Porphyry-Cu
Deposits & Prospects

3-3 Measurement of Rock Magnetism

3-3-1 Results of magnetic susceptibility measurements of rocks

Magnetic susceptibility of rocks were measured at 873 outcrops near the center of short wavelength magnetic anomalies. The results are shown in AP-56. The measurements were made at 10 sites within an area of several meters square for each outcrop, and the mean values, outcrop number, the coordinates of the outcrop, stratigraphic division, rock species, type of alteration if any, for all measurements are laid out in AP-56.

The above results were statistically processed such as the frequency of mean values by stratigraphic division and rock species, and alteration types were counted. The mean magnetic susceptibility by stratigraphic horizon and rock species are shown in Table 2-3-1 and the mean susceptibility of non alteration rock by rock species in Table 2-3-2. Histograms by stratigraphic horizon are shown in Figure 2-3-18 and those by stratigraphic horizon and alteration type in Figure 2-3-19.

The following feature were clarified regarding the magnetism of the rocks of the survey area.

① The intensity of magnetic susceptibility decreases in the order of intrusive rocks, volcanic rocks, sedimentary rocks.
② The magnetic susceptibility of volcanic rocks changes significantly by the lithofacies (basaltic/andesitic), but the variation due to age (Tertiary/Cretaceous) of similar lithofacies rock is small.
③ Regarding sedimentary rocks, Tertiary conglomerate (sand intercalation measured) showed higher susceptibility than pre-Tertiary rocks.
④ Variation by lithofacies or age are small among pyroclastic rocks.

The relation between the magnetic susceptibility, rock species and alteration type for Cretaceous and Tertiary intrusive rocks is shown in Table 2-3-3. It is clear from this table that for intrusive rocks the mafic nature increases the magnetic susceptibility, and that magnetic susceptibility decreases significantly with the intensity of phyllic alteration, and also that clear correlation does not exist between the intensity of propylitic alteration and magnetic susceptibility.

Regarding Cretaceous intrusive rocks, variation of magnetic susceptibility by composition is not apparent for those which appear fresh by unaided eyes. But those strongly affected by phyllic alteration has lower susceptibility, while strongly propylitized rocks do not have lower values.

3-3-2 Rock susceptibility and magnetic anomaly

The magnetic susceptibility measured at 873 outcrops was divided into 7 ranks and they were given different colors, and were overlaid with short and medium wavelength magnetic anomalies on maps. They are shown in Figures 2-3-20 and 2-3-21.

Generally rock bodies with higher magnetic susceptibility show high anomalies, and low magnetic anomalies are considered to occur in rock bodies with high magnetic susceptibility and reverse remanent magnetism. This relation can be observed in many magnetic anomalies of Figures 2-3-20 and 2-3-21.

In these two figures, however, there are significant number of magnetic anomalies corresponding to low magnetic susceptibility. These anomalies are surrounded by circles (broken lines) in these figures. It is difficult theoretically to conceive rock bodies with low susceptibility to show magnetic anomalies, and it would be natural to consider these anomalies to be caused by strong remanent magnetism. As will be mentioned later in this report, strong remanent magnetism was measured for tuffs with low magnetic susceptibility, and these rocks provably cause magnetic anomalies similar to those by intrusive rocks with high susceptibility.

3-3-3 Magnetic susceptibility of drill holes

The results of magnetic susceptibility measurement of drill cuttings at every 20m interval are shown in AP-57 and Figure 2-3-22.

These measurements clarified the following features regarding the distribution of magnetic susceptibility to approximately 500m subsurface depth.

① There are parts of Quaternary gravel beds (Qcp(Grav)) and Tertiary conglomerate (Tc(cgl)) where high magnetic susceptibility close to 10^{-2} appear locally (MJC-2, 7, 8, 9).

② The magnetic susceptibility of Tertiary ignimbrite (Tig) is $0.5\sim5.0\times10^{-3}$ with the exception of altered parts. These values agree well with the values measured on the surface.

③ The magnetic susceptibility of the intrusive rocks and pre-Tertiary rocks (MJC-1, 11, 12) are low at less than 10^{-3} for parts affected by phyllic alteration, but propylitized parts show values mostly around 10^{-2}. These values agree well with those in Table 2-3-3.

Table 2-3-1 Average Magnetic Susceptibility of Formation by Alteration Type (SI units)

Formation	Nos.	Non alteration	Alteration Type											
			Nos.	Oxidation	Nos.	Acid alt.	Nos.	Silicification	Nos.	Propylite alt.	Nos.	Phyllic alt.	Nos.	Potassic alt.
Qv	91	0.01225	3	0.00396	10	0.00055	2	0.00022	5	0.02565	14	0.00592		–
Qcp,Qvc	17	0.00443		–	1	0.00012		–		–		–		–
Qvr	63	0.00327		–	4	0.00054	7	0.00027	5	0.00060	3	0.00086		–
Tig	130	0.00230		–	1	0.00029	1	0.00012		–	8	0.00129		–
Tc	2	0.00328		–		–		–		–		–		–
Tgd	24	0.01742	1	0.02659	3	0.00193	5	0.00262	40	0.01772	44	0.00520	2	0.03523
kgd	20	0.01723		–	1	0.00028	3	0.00173	21	0.01636	15	0.00454		–
Kv	88	0.00677	3	0.00094	5	0.00021	28	0.01039	77	0.01004	28	0.00266		–
Kc	6	0.00075	2	0.00142		–	13	0.00041	6	0.00146		–		–
Jc,Jm	23	0.00134		–		–		–	6	0.00536	2	0.00006		–
Jv	5	0.00783	1	0.00007		–	2	0.00011	2	0.02150		–		–
P	8	0.01003		–		–		–	2	0.00016	1	0.00025		–

Table 2-3-2 Average Magnetic Susceptibility of Non Alteration Rocks (SI units)

Rock Name	Geologic Age									
	No.	Quaternary	No.	Tertiary	No.	Cretaceous	No.	Jurassic	No.	Paleozoic
Andesite	20	0.01111		–	24	0.00765	3	0.01270		–
Basalt	50	0.01509		–	7	0.01876		–		–
Dacite	4	0.01229		–	4	0.01181		–		–
Ignimbrite	25	0.00503	65	0.00221		–		–		–
Lap. tuff	2	0.00507	5	0.00119		–		–		–
Pum. tuff	23	0.00172	28	0.00122		–		–		–
Tuff	4	0.00078	11	0.00277	12	0.00177		–		–
Welded tuff	3	0.00826	11	0.00260		–		–		–
Sandstone	9	0.00706		–	8	0.00122	9	0.00033		–
Conglomerate	2	0.00211		–		–		–		–
Shale		–		–	2	0.00043	6	0.00091		–
Granite		–	3	0.01089	3	0.01089		–		–
granodiorite		–	11	0.01980	12	0.01730		–		–
Diorite		–	3	0.01908	3	0.04790		–		–
Schist		–		–		–		–	3	0.00026
Gneiss		–		–		–		–	2	0.00056

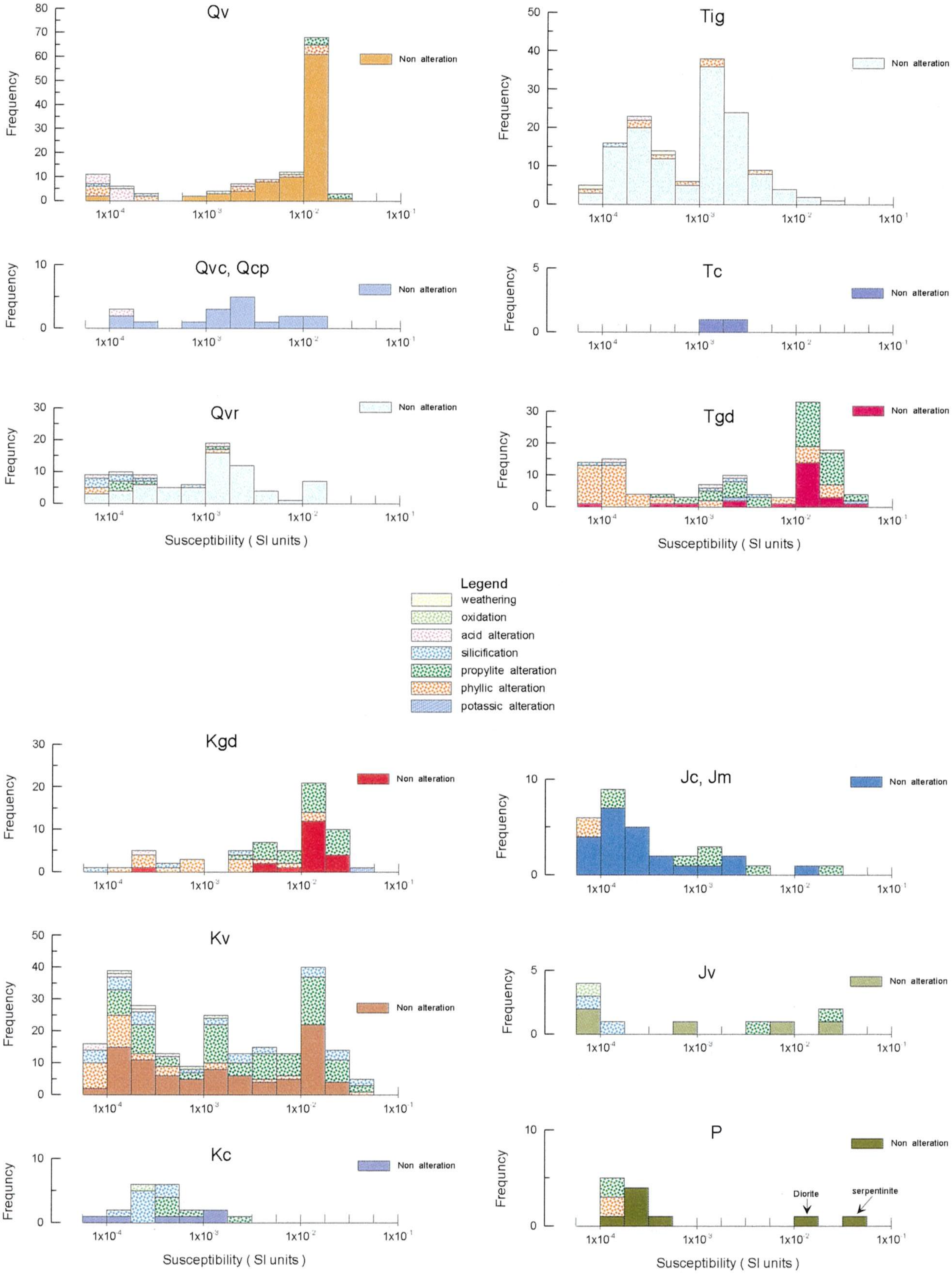


Fig. 2-3-18 Histogram of Susceptibility by Geologic Formation

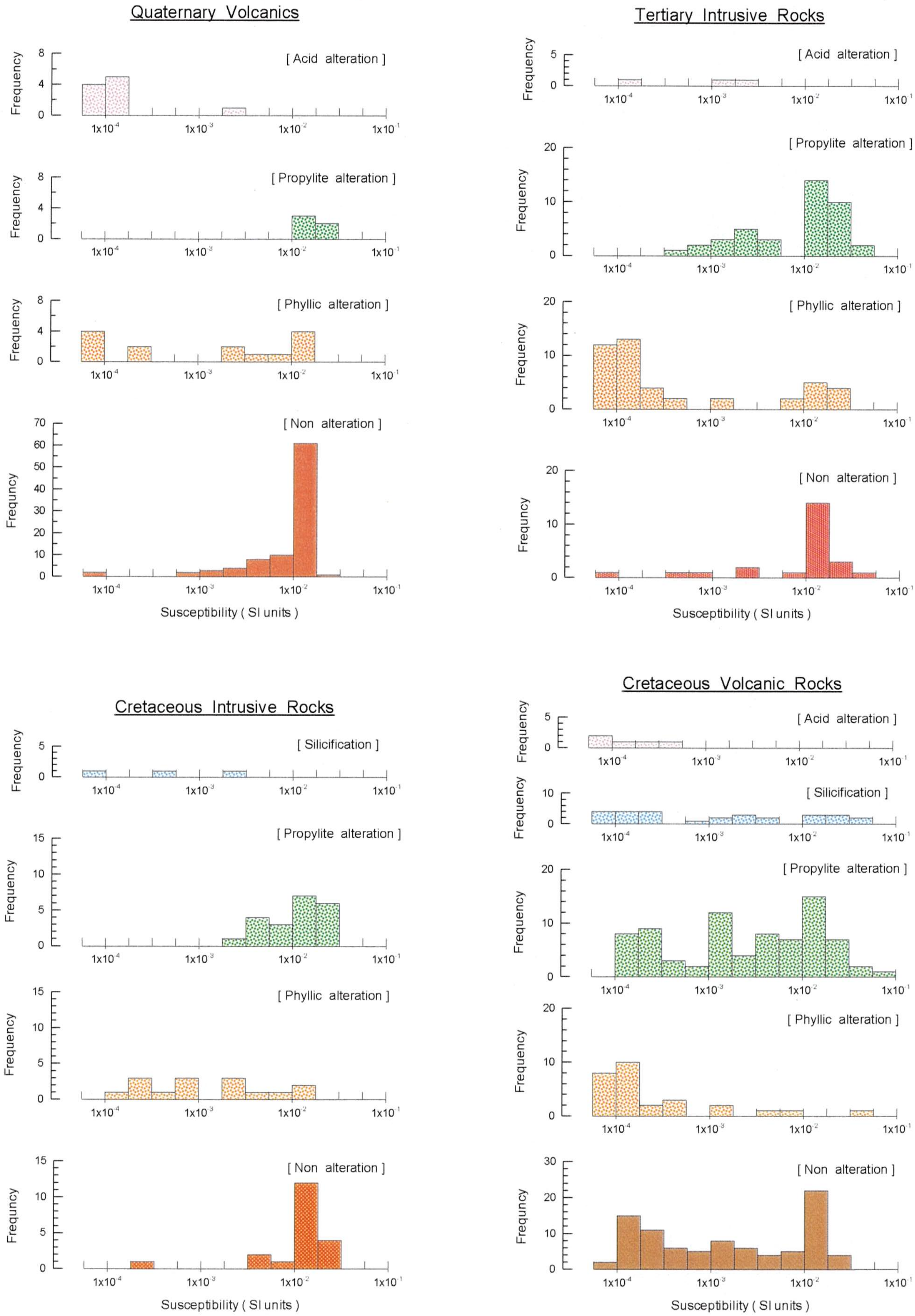


Fig. 2-3-19 Histogram of Susceptibility by Alteration Type

Table 2-3-3 Variation of Magnetic Susceptibility in Tertiary Intrusive Rocks (Tgd) and Cretaceous Intrusive Rocks (Kgd)

Tgd-G,Qp Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h	m/m-s	s	h	m	s	m	s	
Maximum	0.33	13.24	2.35	–		5.66		0.56	28.4
Minimum	0.04	0.03	0.04	–		0.60		0.12	0.9
Average	0.15	3.61	0.56	–		2.52		0.34	10.0
Median	0.12	0.81	0.10	–	2.56	1.83	0.03	0.34	0.9
Number	11	7	5	–	1	5	1	2	3

Tgd-Gd,Da Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h	m/m-s	s	h	m/m-s	s	m	s	
Maximum	–	27.96	14.07	46.4	26.5	31.37	–		48.0
Minimum	–	0.12	12.59	20.0	0.8	1.84	–		0.1
Average	–	5.63	13.33	33.2	12.0	11.83	–		16.0
Median	–	0.58	13.33	33.2	11.6	7.57	–	7.75	16.6
Number	–	9	2	2	6	8	–	1	10

Tgd-Di,Qdi Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h	m/m-s	s	h/h-m	m/m-s	s	m	s	
Maximum	28.09	10.69	46.66	41.4	50.1	57.64	–	–	50.4
Minimum	0.61	0.16	38.08	0.9	10.2	6.37	–	–	15.4
Average	14.35	3.57	42.37	23.1	32.1	25.26	–	–	24.9
Median	14.35	1.72	42.37	18.3	33.5	19.78	–	–	20.9
Number	2	4	2	5	6	10	–	–	6

Kgd-G,Qp Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h	m/m-s	s	h	m	s	m	s	
Maximum	8.24	–	–	–	–	7.66	–	–	40.0
Minimum		–	–	–	–	6.48	–	–	0.5
Average		–	–	–	–	7.25	–	–	18.2
Median		–	–	–	–	7.61	–	–	16.1
Number	1	–	–	–	–	3	–	–	4

Kgd-Gd,Da Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h/h-m	m/m-s	s	h	m/m-s	s	m	s	
Maximum		16.68		27.6	15.1	26.81	–	–	26.8
Minimum		0.28		10.7	5.6	7.00	–	–	5.5
Average		3.64		21.5	9.8	15.09	–	–	17.7
Median	0.32	2.00	22.00	26.1	9.2	11.46	–	–	18.8
Number	1	10	1	3	4	3	–	–	11

Kgd-Di,Qdi Alteration Type	acidic / phyilic			propylitic			silicification		fresh
Intensity	h	m/m-s	s	h/h-m	m/m-s	s	m	s	
Maximum	–	–	–						
Minimum	–	–	–		–		–	–	
Average	–	–	–		–		–	–	
Median	–	–	–	12.0	–	4.38	–	–	11.9
Number	–	–	–	1	–	1	–	–	1

Abbr. : h=high, m=moderate, s=small, Susceptibility=10^{-3}SI
G=granite, Qp=quartz porphyry, Gd=granodiorite, Da=dacite, Di=diorite, Qd=quartz diorite

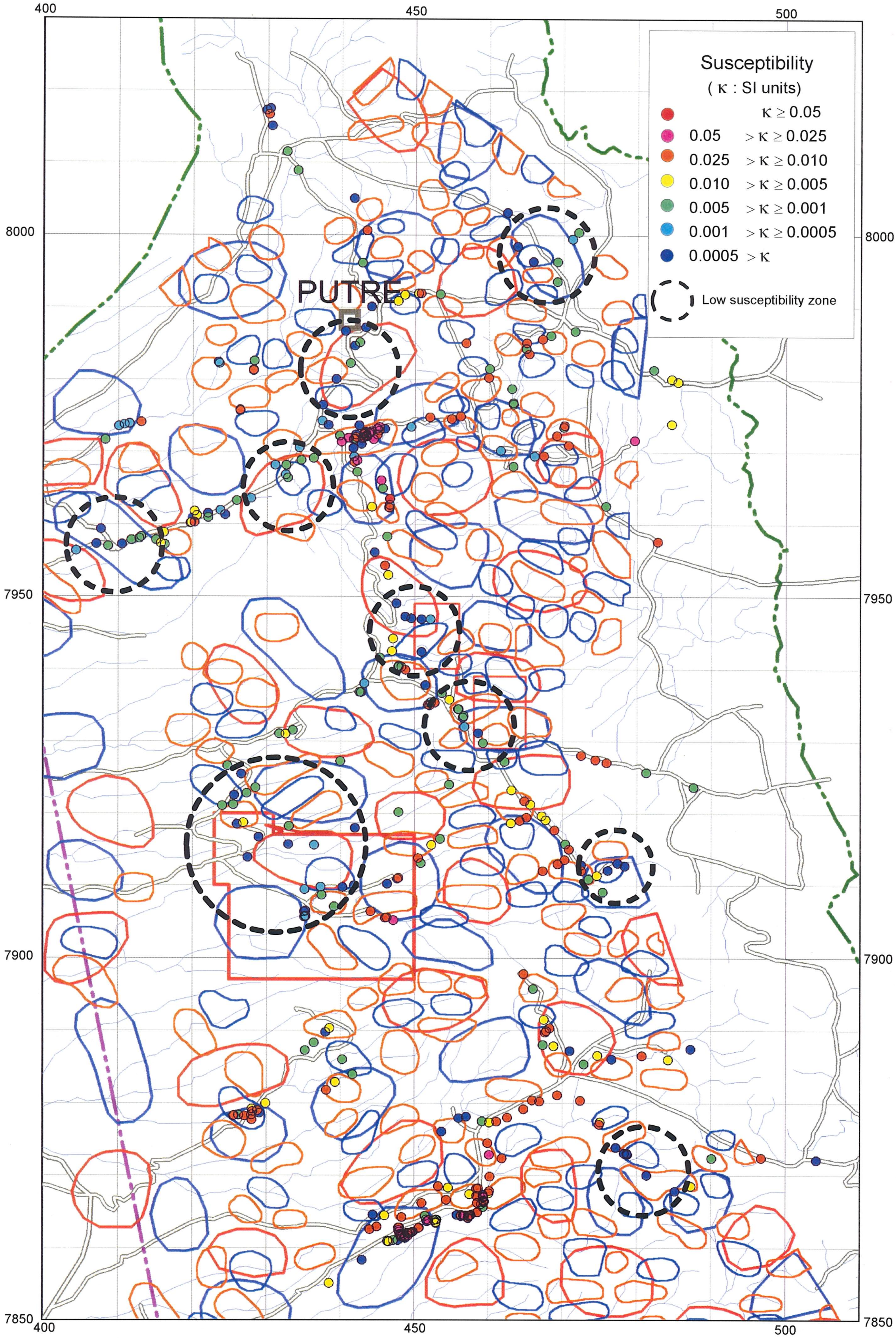


Fig. 2-3-20 Distribution of Classified Susceptibility (Northern Part)

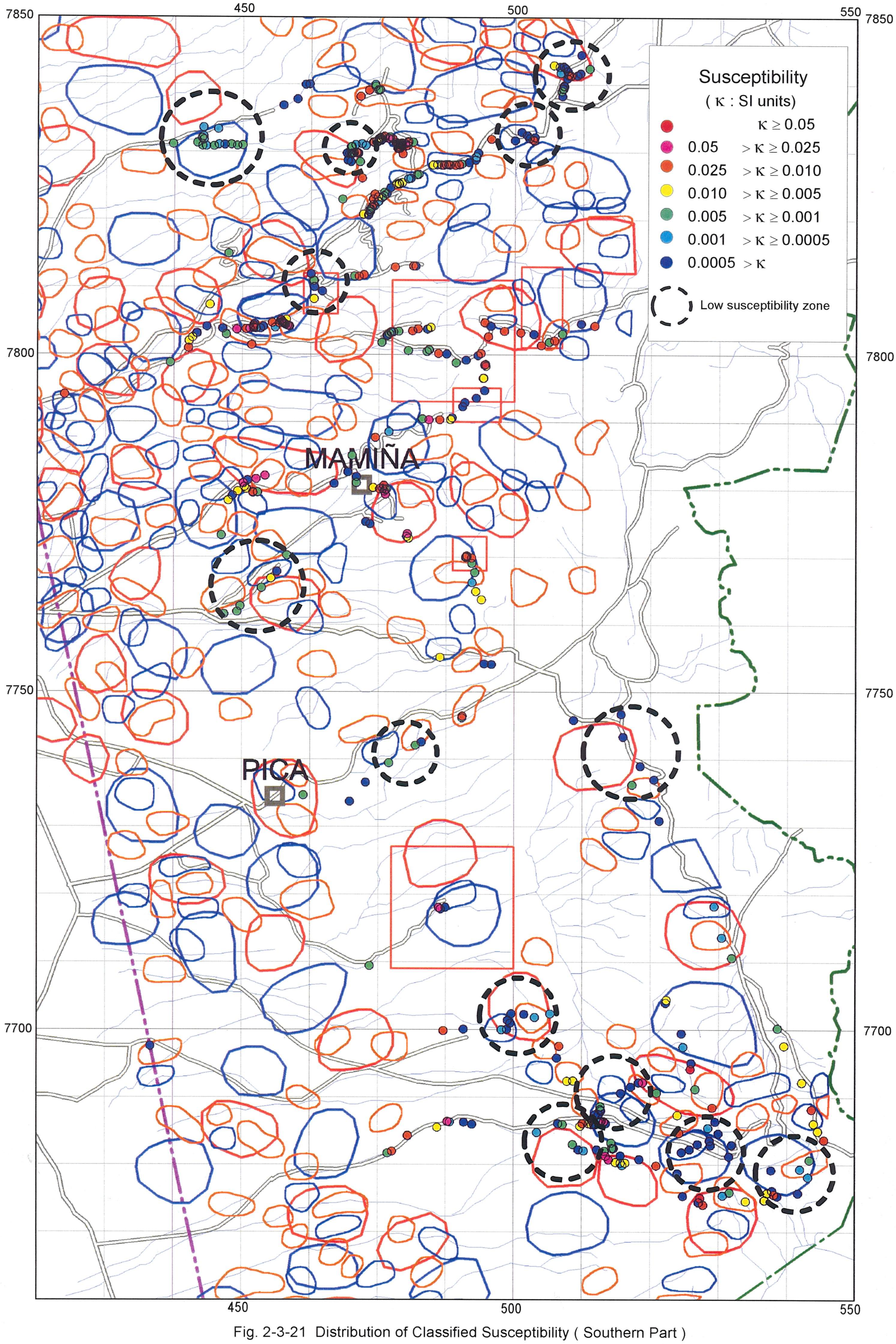
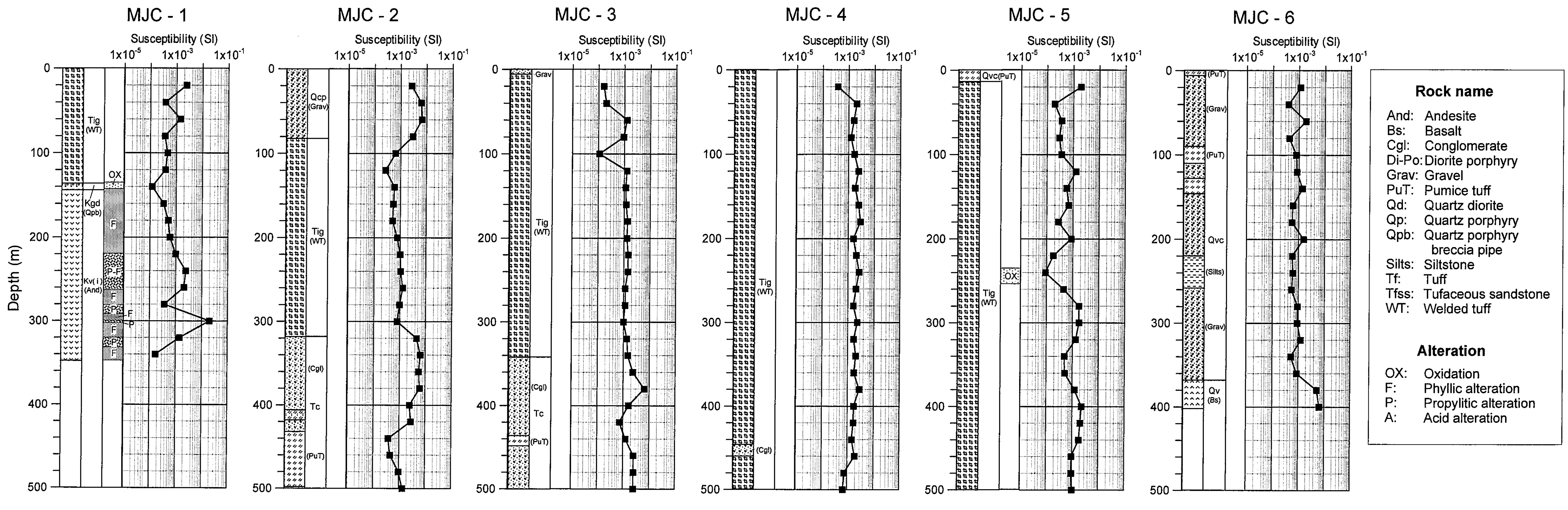


Fig. 2-3-21 Distribution of Classified Susceptibility (Southern Part)



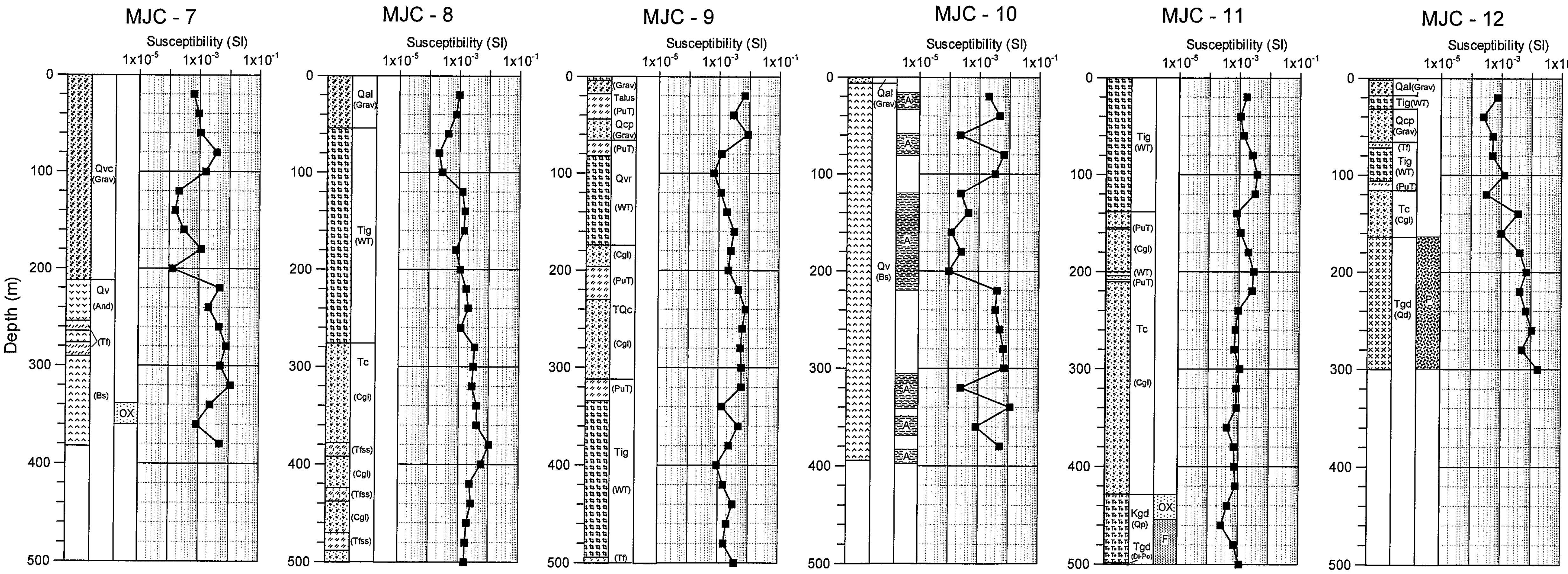


Fig.2-3-22
Susceptibility Profiles
of Drill hole

3-3-4 Remanent magnetization measurements

The 14 sampling sites for remanent magnetism measurements are shown in Figure 3-4-23. The details of the measurement results are shown in AP-57. Ten samples were measured for each site and the mean values are shown in Table 2-3-4. In this table, the initial remanent magnetic values (INIT), values after 30mT alternating field demagnetization, polarity of remanent magnetism, Q values, and magnetic susceptibility are shown. Magnetic susceptibility was measured on cylindrical (25mm diameter, 22mm high) test piece used for remanent magnetic measurement. Magnetic susceptibility meter Bartington MS-2 was used. Also the test piece is in a weak magnetic field during the measurement and thus it was done after remanent magnetization measurement so as not to affect the latter operation.

Q value is also called Königsberger ratio and is defined as follows (Nagata, 1961).

$$Q = M/kH$$

Q: Q value
M: remanent magnetization intensity (usually initial value)
k : magnetic susceptibility
H: geomagnetic field

The Q value indicates the ratio of induced magnetization (kH) to remanent magnetization (M), and where this value is greater than 1.0, the contribution of remanent magnetization is greater than induced magnetization to airborne magnetic maps.

It is known that magnetic susceptibility k of rocks is almost proportionate to the volume of magnetite contained. On the other hand, from the mechanism of acquiring remanent magnetism, the intensity increases with smaller grain size of magnetite and with larger amount of the mineral. In igneous rocks, it is also shown from the mechanism that the intensity increases with the cooling rate of magma (Nagata, 1961).

According to Table 2-3-4, the polarity of remanent magnetism is normal at 8 localities out of 14 and is reverse at 6 localities. Thus the occurrence of normal and reverse magnetization is about the same.

The magnetic declination of normal polarity is within 6° ±20° and those of reverse polarity are in two directions of 183° ±15° (4 localities) and 239° ±17° (2 localities).

The Q values of 3 tuff samples with low magnetic susceptibility are all high at 28, 15, and 10. This indicates that Tertiary and Quaternary ignimbrites which show low magnetic susceptibility in the order of 10^{-3} at outcrops and cuttings, if they have remanent magnetization, can show strong magnetic anomaly similar to those by intrusive and volcanic rocks with high susceptibility.

The Q values of pre-Tertiary to Tertiary intrusive rocks are 0.22 to 18. Of the 10 samples measured, 4 had Q values of less than 1.0 indicating a number of cases with lower remanent magnetization than induced magnetization. These 4 samples, however, have very high magnetic susceptibility of $3 \sim 6 \times 10^{-2}$, and this is considered to have caused the low Q below 1.0.

3-3-5 Remanent magnetization and magnetic anomaly

The results of remanent magnetism measurements are plotted on short and medium wavelength magnetic anomalies (Fig. 2-3-24). The normal/reverse polarity of remanent magnetization coincides well with the high/low anomaly of the short and medium wavelength anomalies near the sampling sites. This fact indicates that the cause of the low magnetic anomalies is the reverse polarity of the remanent magnetism.

Regarding a medium wavelength low magnetic anomaly in the central part, remanent magnetism has been measured for 3 samples (LS-105, LS-120, LK-187), and 2 of them have normal polarity and the other reverse. Now, comparing the intensity of the remanent magnetism by "Q value × magnetic susceptibility", the reverse polarity sample LK-187 is 0.3, while the normal LS-105 and LS-120 are 0.02 and 0.08 respectively. The reverse remanent magnetism is four times stronger than the normal value. These facts do not contradict the occurrence of low magnetism. This example show clearly that one magnetic anomaly does not necessarily correspond to one magnetic rock body and can be formed by the interaction of magnetism of more than one rock body.

Table 2-3-4 Results of Remanent Magnetization Measurement

Outcrop No.	Sample No.	Rock facies			Lab. No.	INIT					After AFDEMAG (30 mT)					Po	Q	Susceptibility
		Formation/Intrusive	Rock Name	K-Ar age (Ma)		D°	I°	k	α	R	D°	I°	k	α	R			($\times 10^{-3}$ SI unit)
LQ-268	Q-149	Qvr	Dacitic Tuff	–	8492	116	-57	37	8.1	9.756	353	-28	542	2.1	9.983	N	28	3.92
LQ-269	Q-150	Qvr	Pumice Tuff	–	9501	186	31	2271	1.0	9.996	190	25	1530	1.2	9.994	R	15	3.94
LS-133	S-047	Tig	Welded Tuff	–	0471	354	-50	260	3.0	9.965	355	-49	264	3.0	9.966	N	10	2.40
LK-056	K-016	Tgd	Granodiorite	44.6±1.1	5162	007	-55	161	3.8	9.944	009	-54	145	4.0	9.938	N	2.2	11.00
LS-052	S-010	Tgd	Granite	–	6010	247	-19	7	19.0	8.784	198	57	631	1.9	9.986	R	0.22	52.90
LK-187	K-084	Tgd	meta-Diorite porphyry	58.1±1.9	7842	183	27	129	4.3	9.930	173	32	137	4.1	9.935	R	15	21.00
LS-105	S-034	Tgd	Diorite porphyry	–	0341	040	-56	67	6.0	9.865	014	-24	229	3.2	9.961	N	0.39	51.90
LS-120	S-045	Tgd	Diorite	58.8±2	0452	025	-71	47	7.1	9.807	002	-48	300	2.8	9.970	N	5.3	15.00
LS-132	S-046	Tgd	Quartzdiorite	–	0462	003	-63	788	1.7	9.989	007	-61	1415	1.3	9.994	N	2.0	4.80
LT-212	T-080	Tgd	Porphyry	–	0801	231	49	4	29.7	7.501	170	45	156	3.9	9.942	R	0.27	38.40
LQ-048	Q-011	Kgd	Microdiorite	–	1111	065	-24	24	10.0	9.631	026	-4	6	21.9	8.458	N	16	7.90
LQ-056	Q-013	Kgd	Granite porphyry	–	2131	353	-69	64	6.1	9.860	004	-61	557	2.0	9.984	N	0.64	60.20
LT-077	T-020	Kv(i)	Sandstone	–	3202	225	-24	2	48.1	5.430	222	44	14	13.2	9.370	R	0.43	0.95
LK-023	K-011	Pzg	Diorite	300±7	4111	268	26	50	6.9	9.819	256	50	5	25.3	8.040	R	18	26.10

D°: Declination
I°: Inclination
k: Fisher's best estimation of precision (Fisher, 1953)
α: Half angle of the corn of confidence at p=0.95
R: Resultant of vector sum
Po: Polarity (N: Normal, R: Reverse)
Q: Q-value (Königsberger ratio)

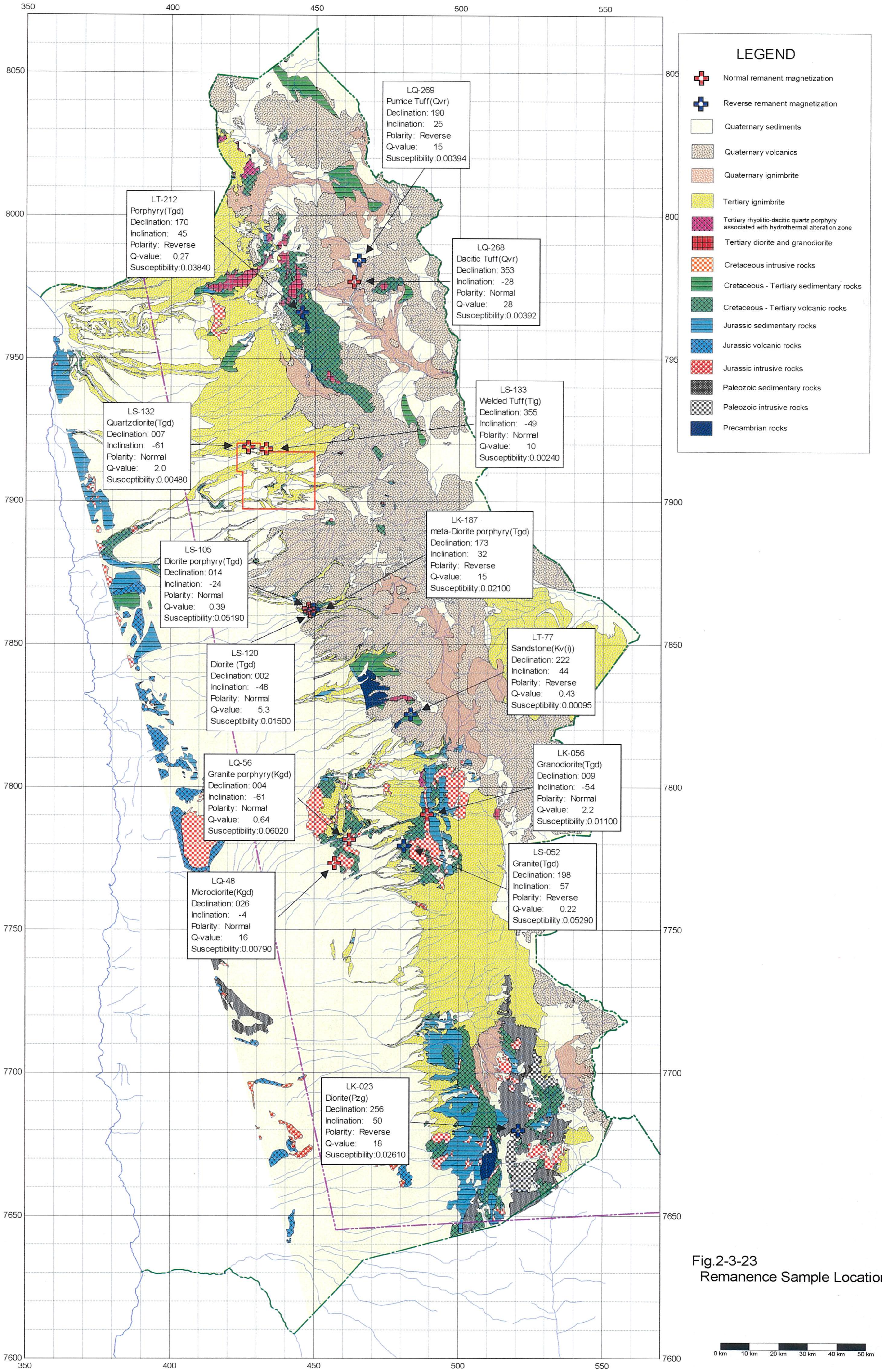
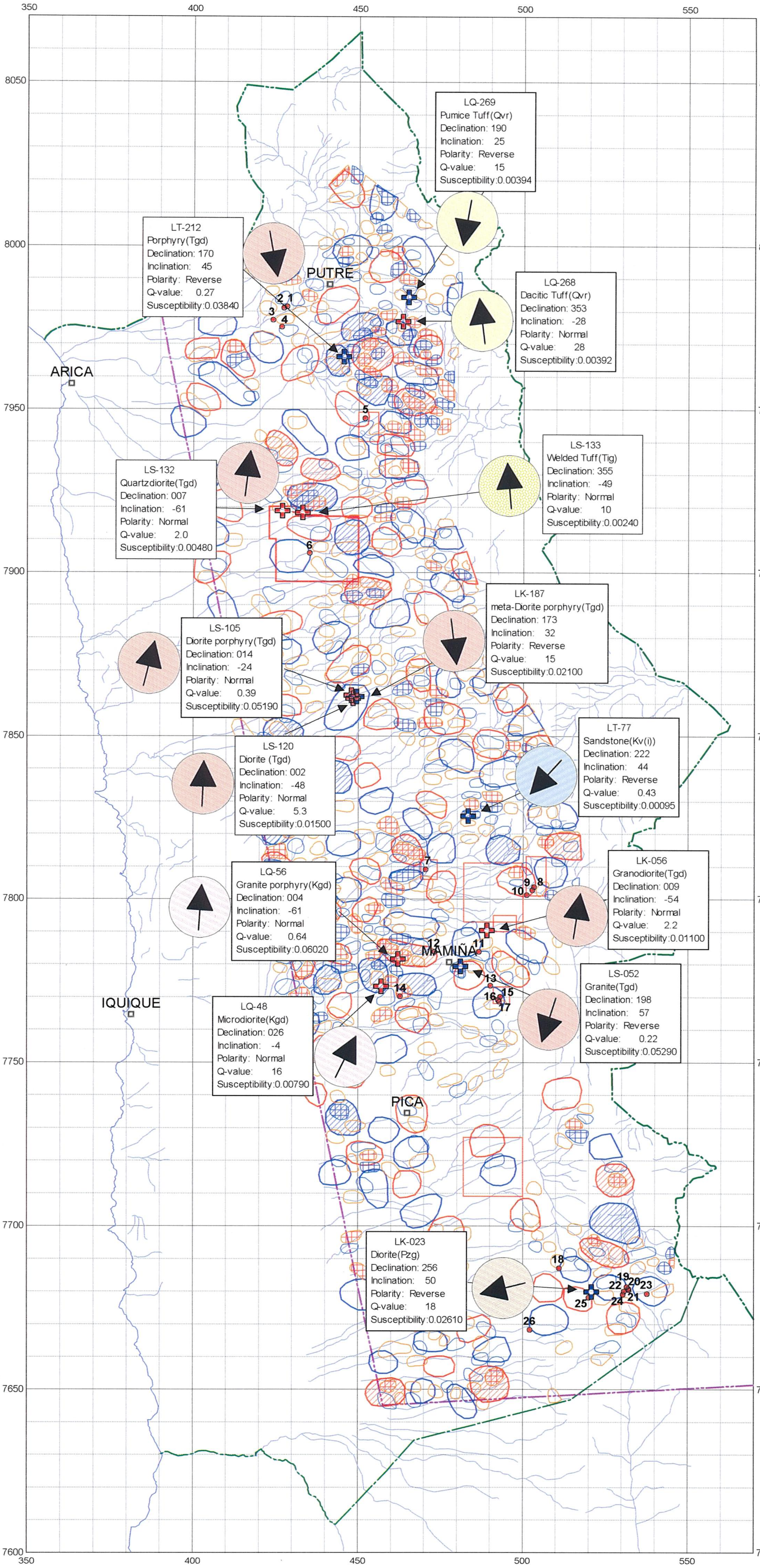


Fig.2-3-23
Remanence Sample Location



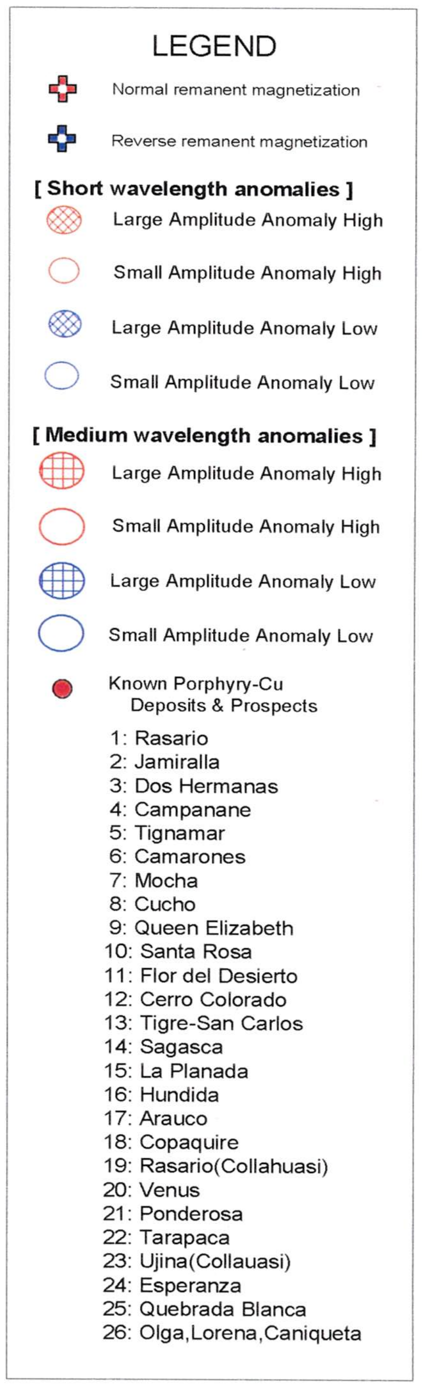


Fig.2-3-24
Remanence and SW & MW Magnetic Anomalies

3-4 Magnetic Anomalies and Geology

Figure 2-3-25 was prepared by expressing the short, medium, and long wavelength magnetic anomalies on a geological map. It is difficult to interpret the relation between magnetic anomalies and geology from this map, and thus specific geologic formations were extracted and anomalies were overlaid on it.

3-4-1 Magnetic anomalies and Quaternary volcanic rocks

Map of short and medium wavelength magnetic anomalies and Quaternary volcanic rocks (Qv) distribution is shown in Figure 2-3-26. Many short wavelength magnetic anomalies occur in the Quaternary volcanic rock area to the north of 7800km, and strong correlation between them is clearly observed. Of these short wavelength magnetic anomalies, those at topographic protrusion such as mountain summits and clear ridges are indicated by red marks. These were also observed in areas other than north of 7800km such as at the southeastern edge of the area where 3 were extracted and the total of the whole survey area became 63. About 70% of the extracted anomalies were high anomalies.

The short wavelength magnetic anomalies coinciding with topographic protrusion and not in Quaternary volcanics were also extracted and marked by a triangle. Of these, the anomalies south of 7800km are all located in the basement rocks with the exception of the 4 at 15km northeast and 30km north of Pica. The 4 anomalies near Pica and north of 7800km, many of them are in Tertiary ignimbrite area, and these are considered to be the cases where ignimbrites with generally magnetic susceptibility are showing magnetic anomaly by strong remanent magnetization.

3-4-2 Magnetic anomalies and Tertiary-Quaternary ignimbrites

Map of short and medium wavelength magnetic anomalies and Tertiary and Quaternary ignimbrite distribution are shown in Figure 2-3-27. Since Tertiary ignimbrite possibly occur under Quaternary sediments, the extraction included Quaternary sediment areas.

The area of Tertiary ignimbrite has low topographic relief, and the correlation of magnetic anomalies and topography is not clear. But deep valleys are often dissected in these rocks and magnetic anomalies on the plateaus between two valleys are not uncommon. These anomalies are believed to have been caused by ignimbrite and they are marked by red circles in Figure2-3-27. The red circles are all short wavelength anomalies and 11 of them are high and 4 are low anomalies.

Medium wavelength magnetic anomalies are not easy to extract, but those with some correlation to topography amounted to 5 high and 8 low anomalies and they are marked by red triangles.

In Quaternary ignimbrite areas, magnetic anomalies correlated to topography could not be extracted.

3-4-3 Magnetic anomalies and intrusive rocks

Map of medium and long wavelength magnetic anomalies and pre-Tertiary and Tertiary intrusive rock distribution are shown in Figure 2-3-28. Intrusive rocks occur collectively near Putre in the north, Mamiña in the central part, and near Collahuasi in the south.

About 60 to 70 percent of the intrusive rocks are correlated to medium or long wavelength magnetic anomalies, but some are not associated with magnetic anomalies, and these have been marked with triangles.

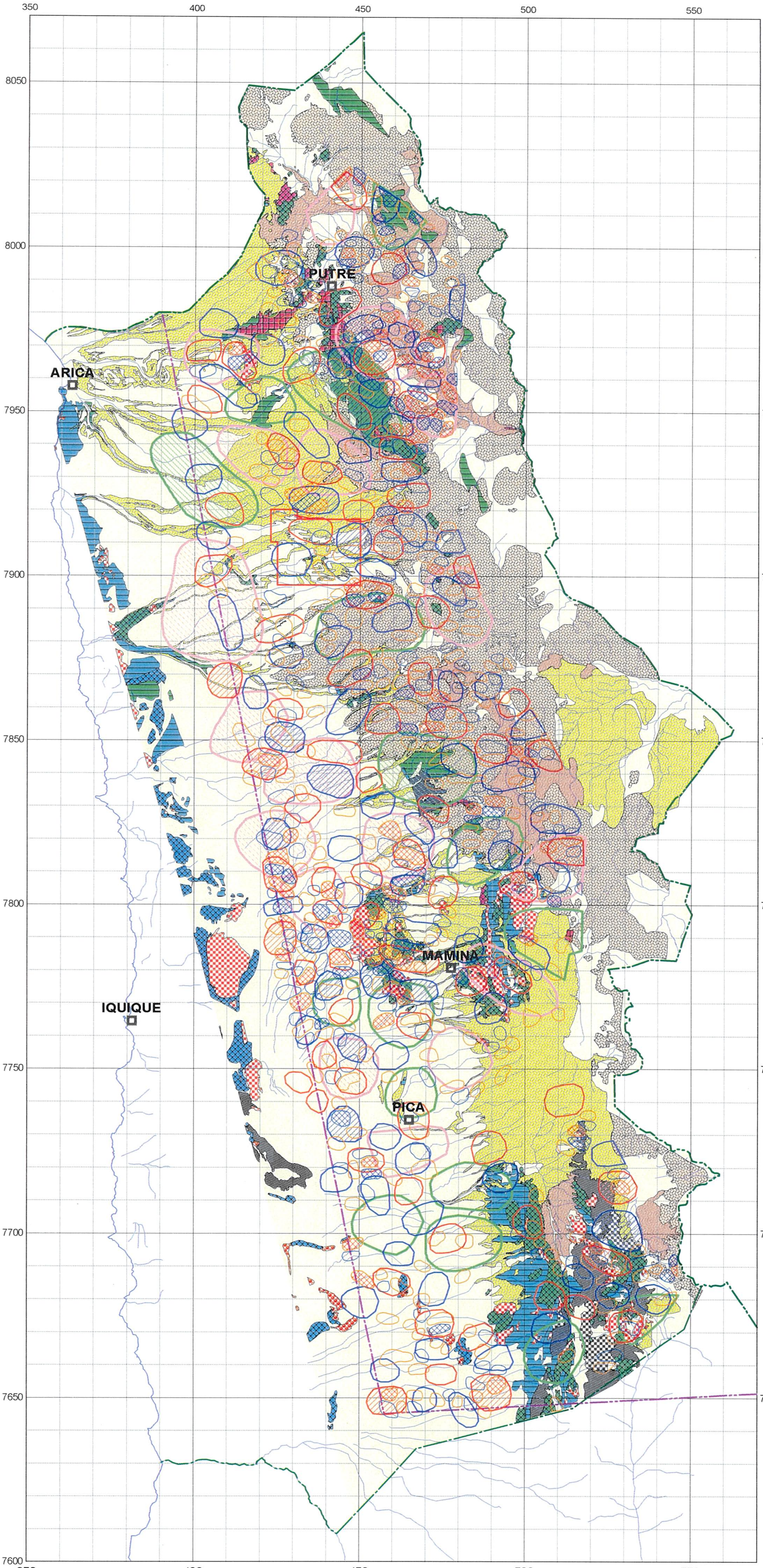
Many intrusive rocks generally show strong magnetism, but some show weak magnetism (Tgd, Kgd) as seen in Figure 2-3-18, and magnetism weakens with phyllic and acidic alteration. Thus there are cases where intrusive bodies do not show magnetic anomaly.

The Tertiary intrusive body southwest of Putre does not show magnetic anomaly. Theoretically, it is very possible that if the polarity of remanent magnetization is reverse and its Q value is close to 1.0, then the induced and remanent magnetization eliminate each other resulting in no anomaly. This intrusive body may well be such a case. Also reverse magnetic polarity and remanent magnetic measurement with Q value of 0.27 are obtained from a same Tertiary intrusive body to the south of Putre (Table 2-3-4).

3-4-4 Magnetic anomalies and basement rocks

Map of medium and long wavelength magnetic anomalies and pre-Tertiary basement rock distribution are shown in Figure 2-3-29. Basement rocks, like intrusive rocks, occur collectively near Putre in the north, near Mamiña in the south, and near Collahuasi in the south, but many small outcrops are confirmed in other areas.

Around 60 to 70% of the basement rocks are correlated to medium and long wavelength magnetic anomalies. The areas of basement rocks without magnetic anomalies are marked with triangles, and most of them are sedimentary rocks.



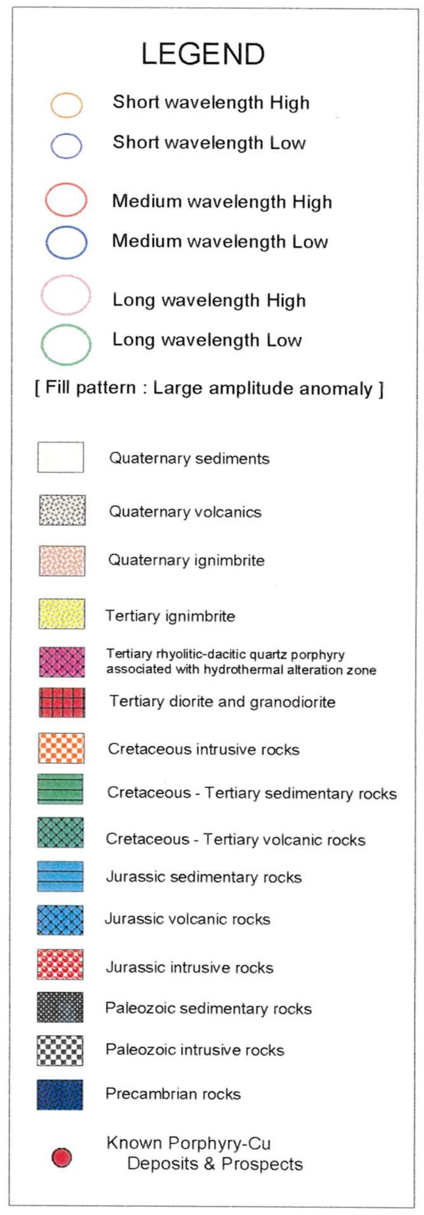


Fig.2-3-25
Magnetic Anomalies and Geology

0km 10km 20km 30km 40km 50km