Sections in the central beforsite have low variation in content, but the contents does not increase with depth. Sections in the northeast beforsite tend to have an increase in content with depth.

2-5 Conclusions

1. Geochemical Survey

The Marinkas Quelle Carbonatite Complex (MQC) in the Orange area has a concentration of light REEs (La, Ce and Nd), niobium and phosphorus.

REEs are most concentrated in the carbnatite dyke (Mcd), followed in order of abundance by the central beforsite (Mcb1), the northeast beforsite (Mcb2) and the sovite (Mcs). But from an economical point of view, the carbonatite dyke is too small to exploit and the content in the sovite is not so very high. Therefore, two beforsites are the targets for REEs, which are concentrated in the outer zones of the two beforsites.

Light REEs (La, Cd and Nd) content in the central beforsite is the same as that in the northeast beforsite. But middle to heavy REEs (Eu, Tb, Yb and Lu) are concentrated in the north beforsite, compared with the central beforsite.

Nb is concentrated in the inner zone of the two beforsites and in the porphyritic nepheline syenite (Msp) with contents of over 1,000 ppm. The distribution of Nb is in distinct contrast with that of REEs, which are concentrated in the outer zone of the beforsites. Nb is concentrated in the northeast beforsite, compared with the central beforsite.

P is concentrated in the outer zone of the central beforsite, and in the northeast beforsite and its vicinity. Apatite bands, lenses or veinlets are observable zones with high content.

Rare-earths oxides are contained in the two beforsites at maximum values of from 2.7 to 3.2 %, with acreage values of from 0.12 to 0.16 %.

Nb is contained in the two beforsites at maximum values of from 0.5 to 0.5 % and at average values of from 0.08 to 0.12 %. P is contained in the two beforsites at a maximum value of 3.4 % and at an average value of 0.8 %.

Samples of the central beforsite were dated at 329 Ma by the Pb-Pb method in this survey. The central beforsite intrudes the Nama Sequence, which was deformed from 530 to 495 Ma. The beforsite is younger than the Nama Sequence. Beforsite age data are concordant the geological event. But, Smithies(1990) reported an Rb-Sr age of 505±18 Ma for a syenite of the MQC. The age of beforsite is somewhat younger than that of the syenite. More detailed age determination are needed to find the formation.

Bastnaesite has a composition of $(Ca,Nd,La,Pr,Ca,Fe,Sr)CO_3(F,OH)$ and is rich in Ce, Nd and La according to EPMA. Pyrochlore has a composition of $(Na,Ca)_2(Nb)_2O_6(F)$. The atomic ratio of Na:Ca is approximately 1:1. Pyrochlores on the surface has the same composition as that underground.

δ13C and δ18O values in dolomite and calcite of the sovite are the highest followed in order of abundance by that of the sovite, the northeast beforsite and the central beforsite. This order corresponds to that of intrusion stage. last intrusive, the carbonatite dyke, has a wide variation in δ13C and δ18O.

2. Drilling Survey

A drilling survey was performed in the two beforsites. The beforsites are mainly composed of dolomite. Based on the contents of accessory minerals, The beforsites are subdivided into ankeritic, sulphide-rich, Fe oxide-rich phlogopite-rich, apatite-rich, weathered, and normal beforsite.

The shallow zone of the central beforsite consists mainly of weathered or ankeritic beforsite. The deep zone consists mainly of Fe oxide-rich or sulphide-rich beofrsite. Magnetite is dominant as the Fe oxide. Pyrite, marcasite, pyrrhotite are dominant, and sphalerite and galena are subordinate as sulphides.

The shallow zone of the northeast beforsite consists mainly of weathered beforsite, which is not thick. The deep zone consists mainly of phlogopite-rich or apatite-rich beforsite, which is accompanied with alkali amphibole, alkali feldspar, pyrite, pyrrhotite, or magnetite. This beforsite is weakly weathered compared with the central beforsite.

The central beforsite is rich in normative magnetite and forsterite and poor in apatite compared with the northeast beforsite. This difference in composition between the two beforsites corresponds to the field observations of drill cores.

According to the geochemical analyses, the central beforsite is rich in Sc, U, Ta and Fe. The northeast beforsite is rich in Y and P. Contents of rare earth oxides, Th, Nb, Zr, Mn and Sr are the same in the two beforsites. This corresponds to the geochemical analyses in that the central beforsite is rich in magnetite, and the northeast beforsite is rich in apatite.

Pyrochlore form the central beforsite has the same composition, $(Na,Ca)_2(Nb)_2O^{26}(F)$, as that of the northeast beforsite. The atomic ratio of Na:Ca is approximately 1:1. Pyrochlore underground has the same composition as that on the surface.

Content of rare-earth oxides reached 2.7 % in MJNO-1, but the high values are not continuous at depth. MJNO-1 has an average values of 3,000 ppm of rare-earth oxides, but the others have averages less than 1,000 ppm. REEs contents in the central beforsite are the same as those of the northeast beforsite. But middle to heavy REEs (Eu, Tb, Yb and Lu) are concentrated in the north beforsite, compared with the central beforsite.

According to the distribution pattern of REEs, the distribution mode of carbonatite dyke is highest, followed in descending order by the sovite, the northeast beforsite, and the central beforsite. But the patterns of the two beforsites are distributed in the high content area.

Therefore, the average content in the carbonatite dyke is highest, followed in descending order by the two beforsites and the sovite.

Nb is contained in the two beforsites at average values of from 1,042 to 2,039 ppm. Sr is contained in the two beforsites at average values of from 5,993 to 6,209 ppm. P is contained in the two beforsites at average values of from 6,257 to 11,803 ppm. Nb and Sr contents of the central beforsite are the same as that of the northeast beforsite. P content of the northeast beforsite is grater than that of the central beforsite.

$\delta^{13}C$ values in dolomite and calcite of the central beforsite increase, while $\delta^{18}O$ values decrease with depth. $\delta^{13}C$ and $\delta^{18}O$ values of the central beforsite are higher than those of the northeast beforsite. This tendency corresponds with the results at the surface.

There is a possibility that $\delta^{13}C$ and $\delta^{18}O$ values of the outer zone of the central beforsite are higher than those of the inner zone, and that values of the boundary zone are lower than those of the outer zone.

According to the Th / Yb versus Y / Yb diagram in Fig.II–2–8, the sovite, the two beforsites and the carbonatite dyke have particular composition fields. Y has a similar chemical behavior to heavy rare–earth elements, such as Yb, and is concentrated in the solid phase. Th has a tendency to be concentrated into a liquid phase, though Th contents are variable in the central beforsite, Th content is highest in the carbonatite dyke, followed in order of abundance by those of the two beforsites, and the sovite. The intrusion order of these rock facies corresponds to the order of Th content.

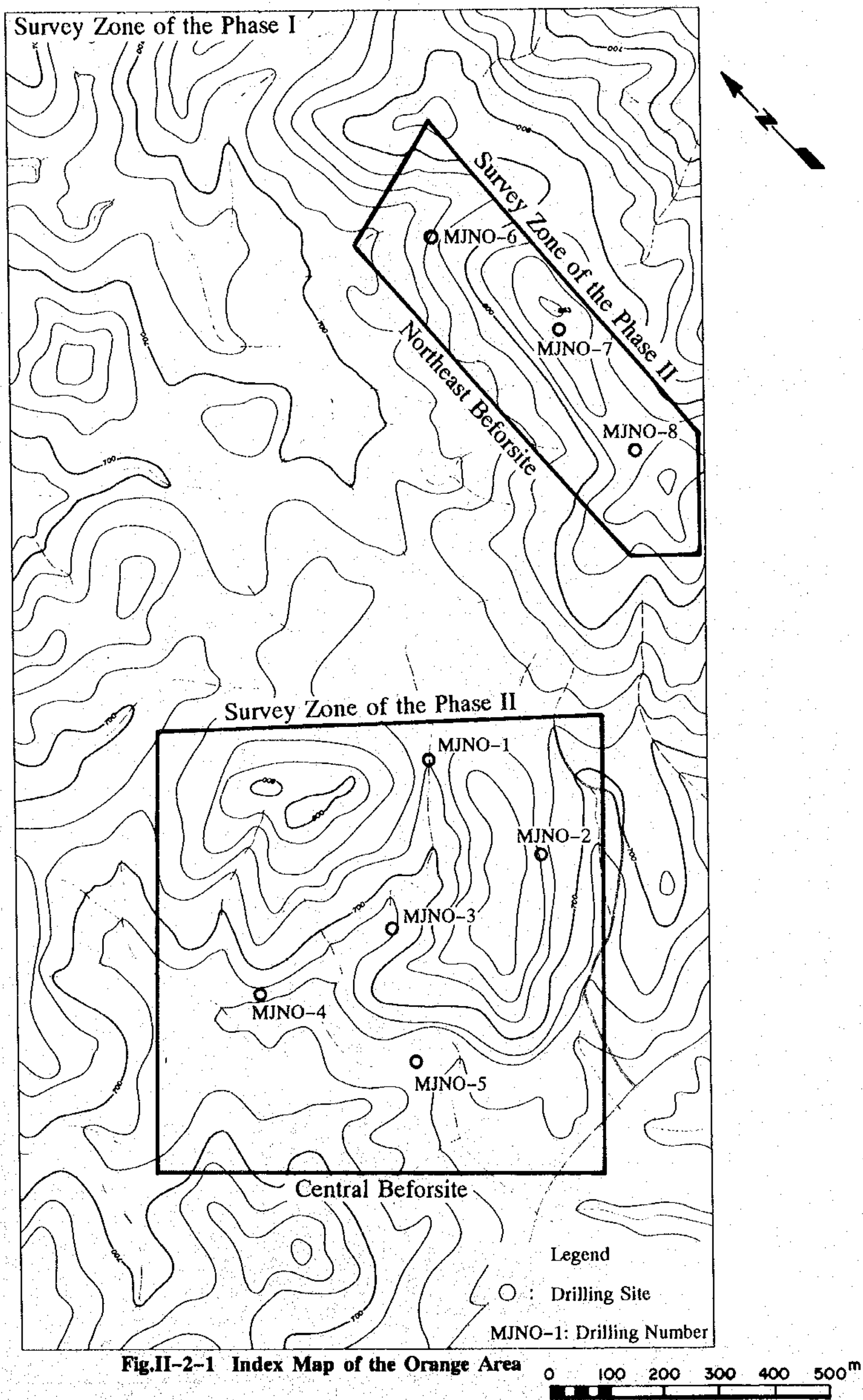


Fig.II-2-1 Index Map of the Orange Area

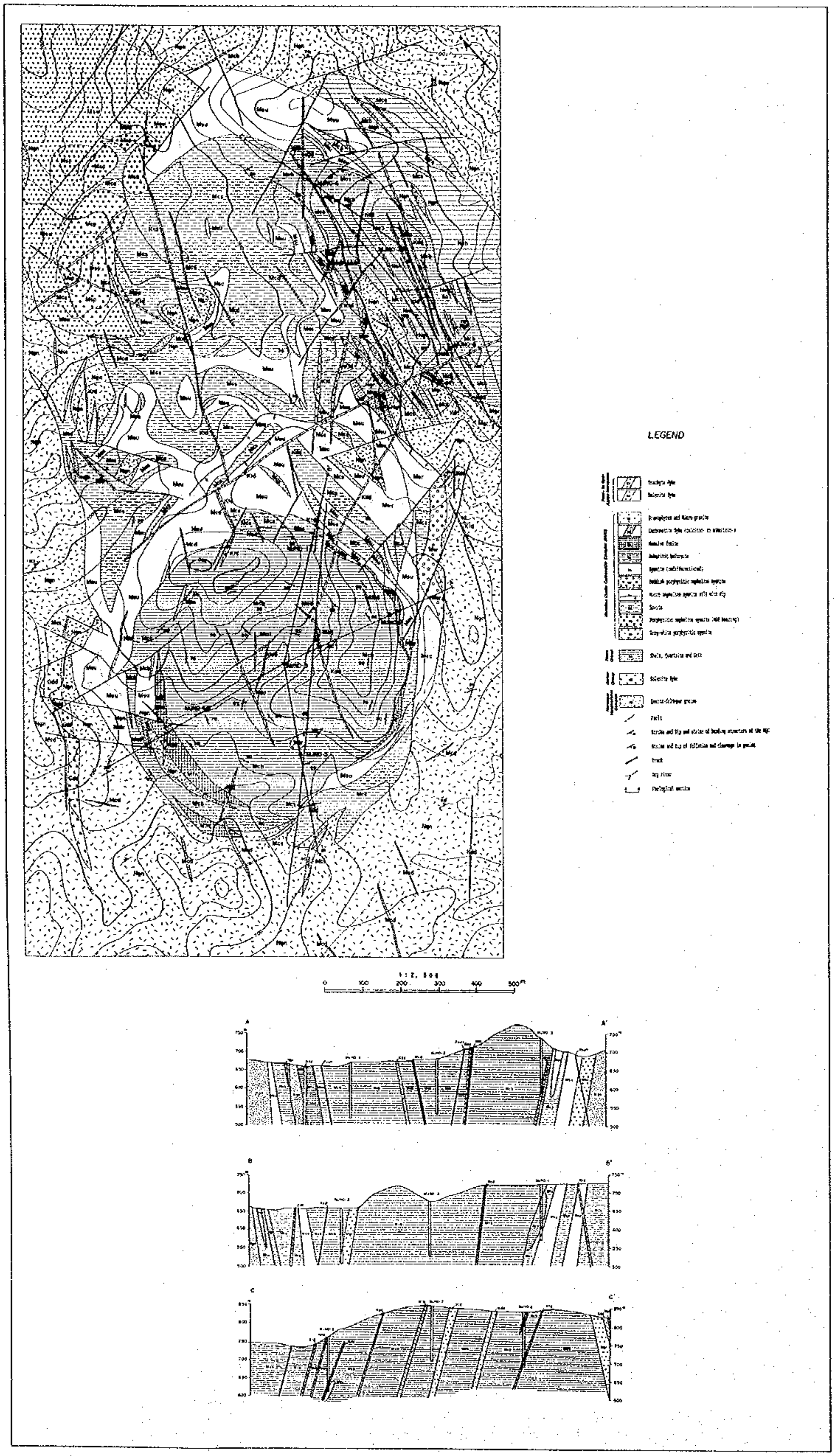


Fig.II-2-2 Geological Map of the Orange Area

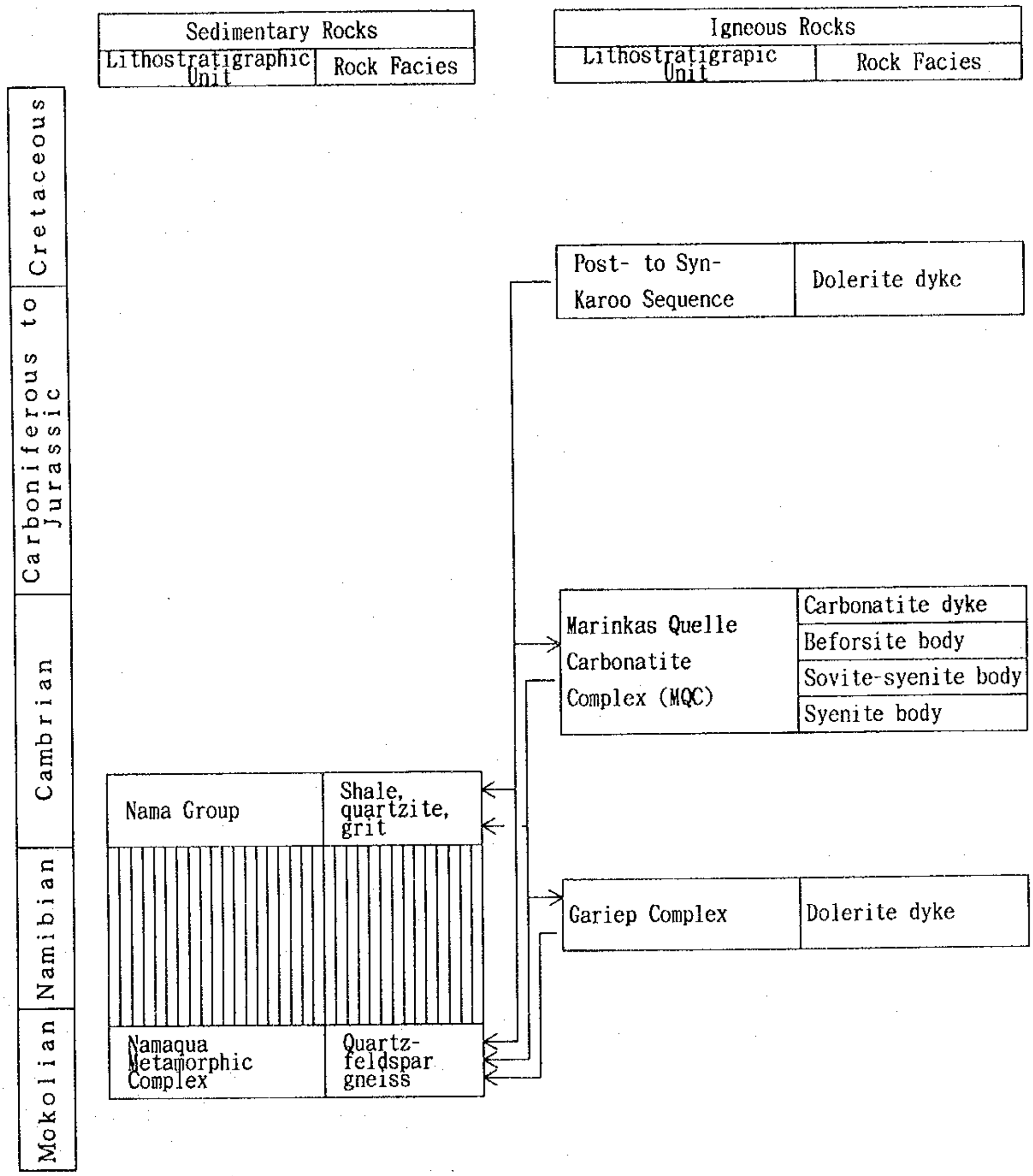


Fig.II-2-3 Lithostratigrahy of the Orange Area

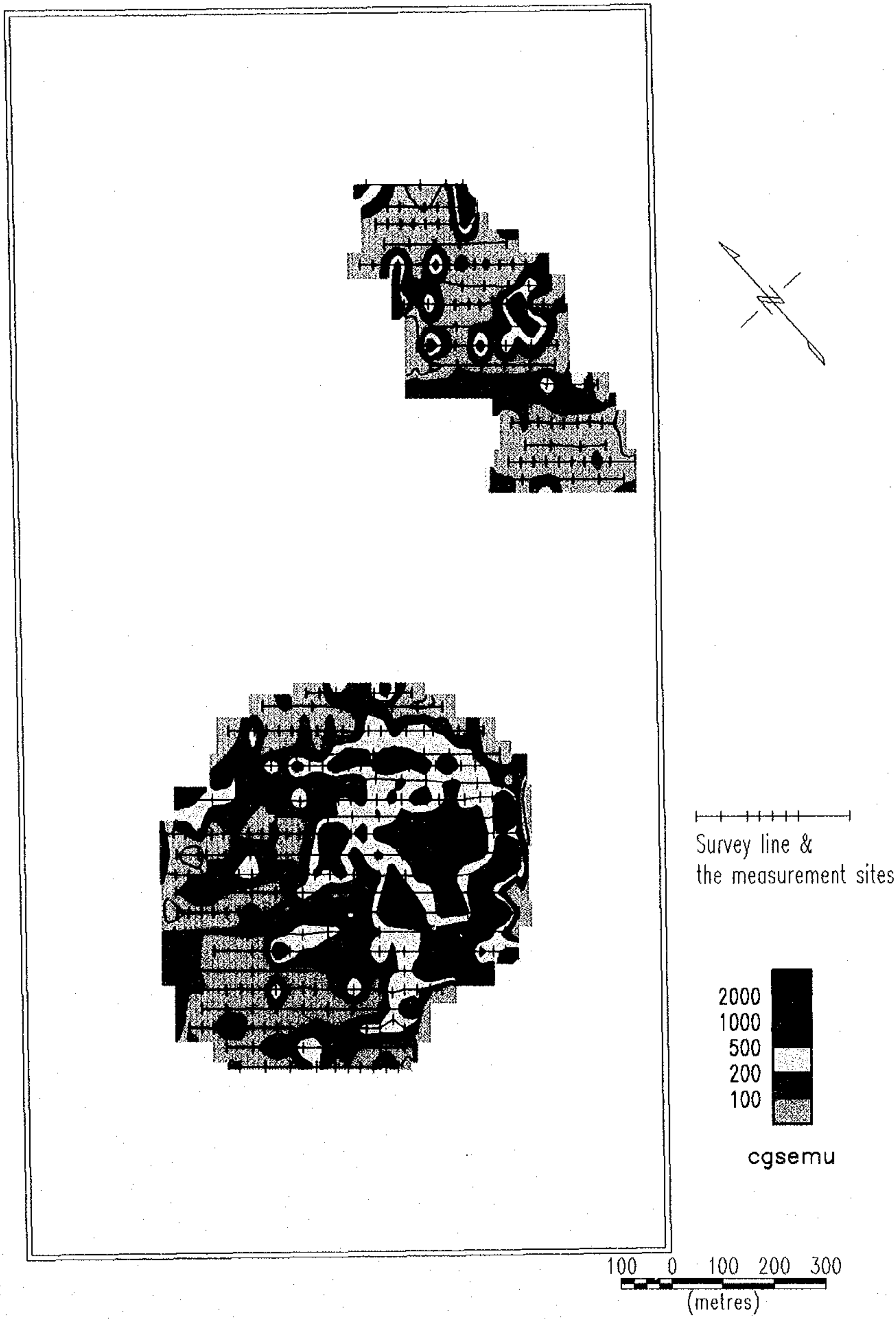


Fig.II-2-4 Contoured Map of Intensity of Magnetic Susceptibility in the Orange Area

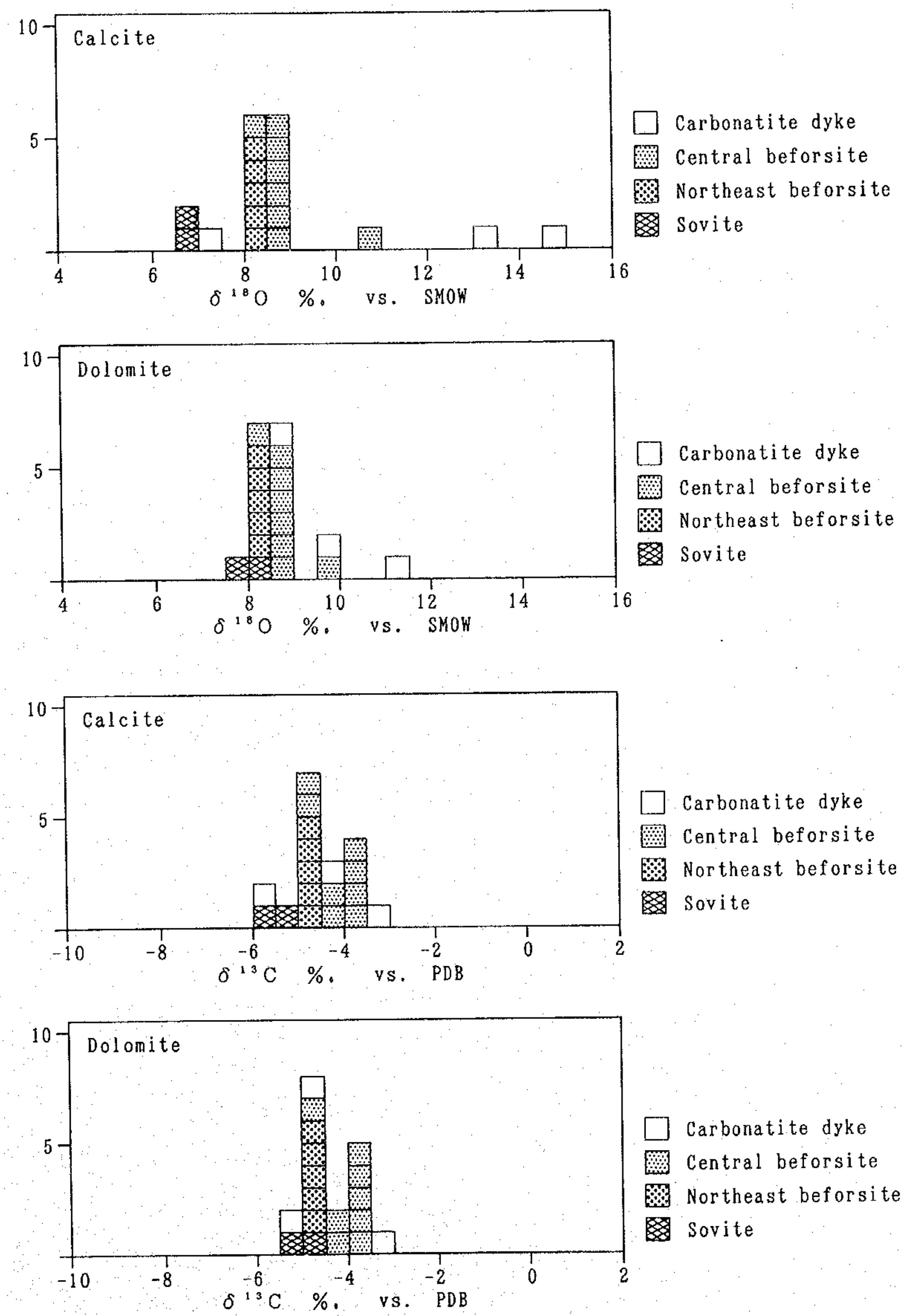


Fig.II-2-5 Histograms Showing Frequency of $\delta^{13}C$ and $\delta^{18}O$ Values

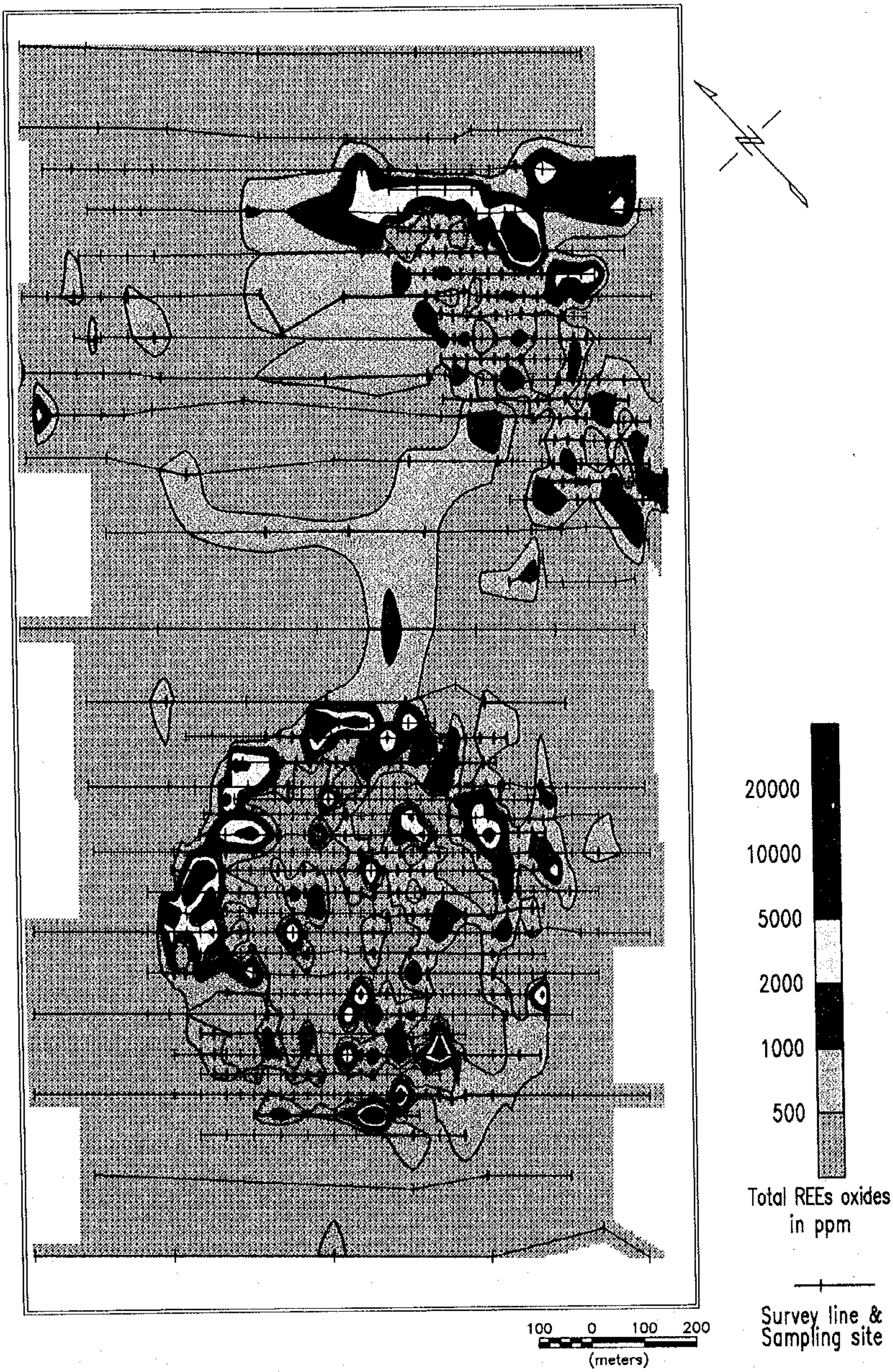


Fig.II-2-6 Contoured Map of Geochemical Distribution of the Orange Area(Total REEs Oxide)

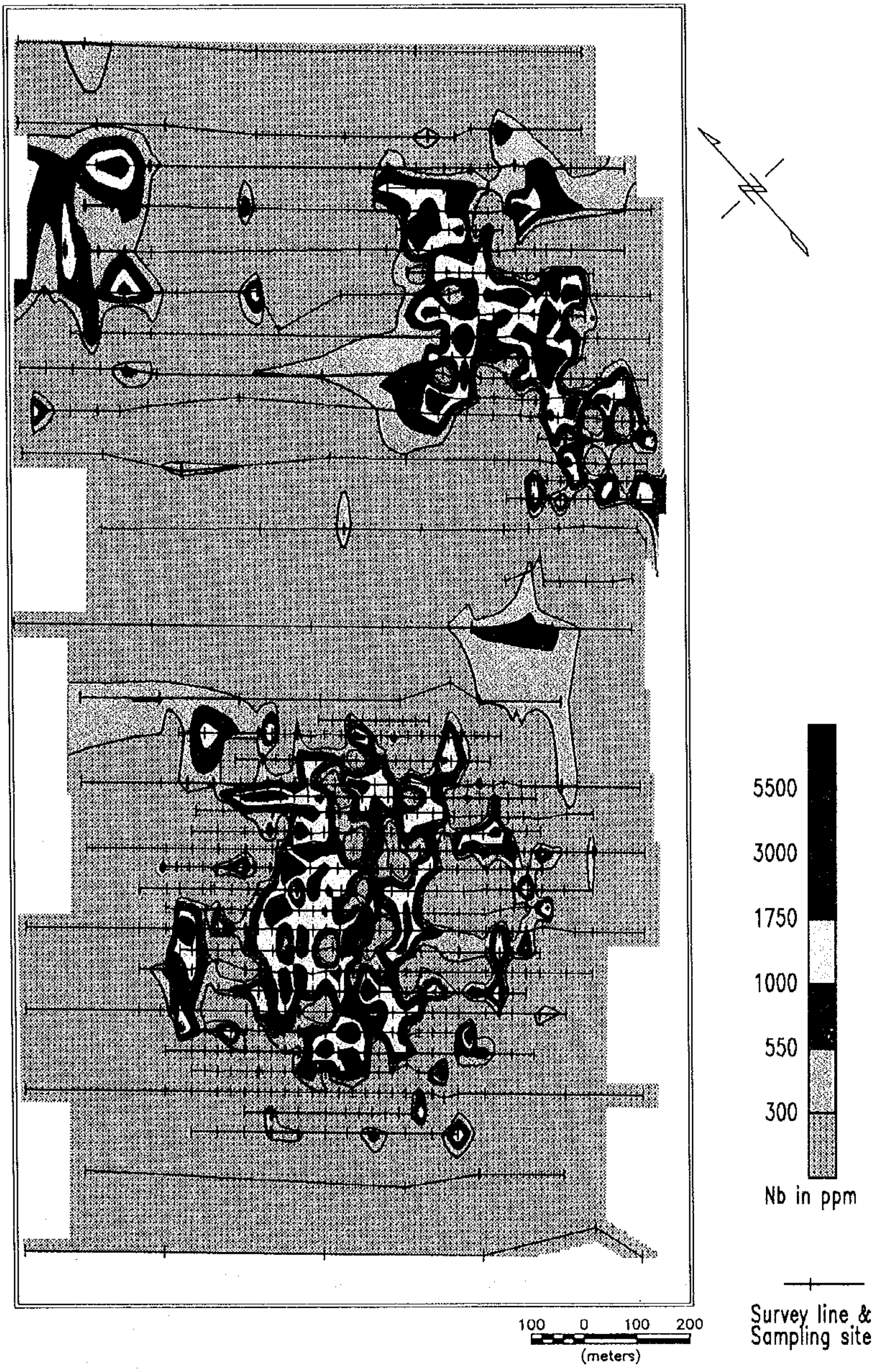


Fig.II-2-6 Contoured Map of Geochemical Distribution of the Orange Area (Nb)

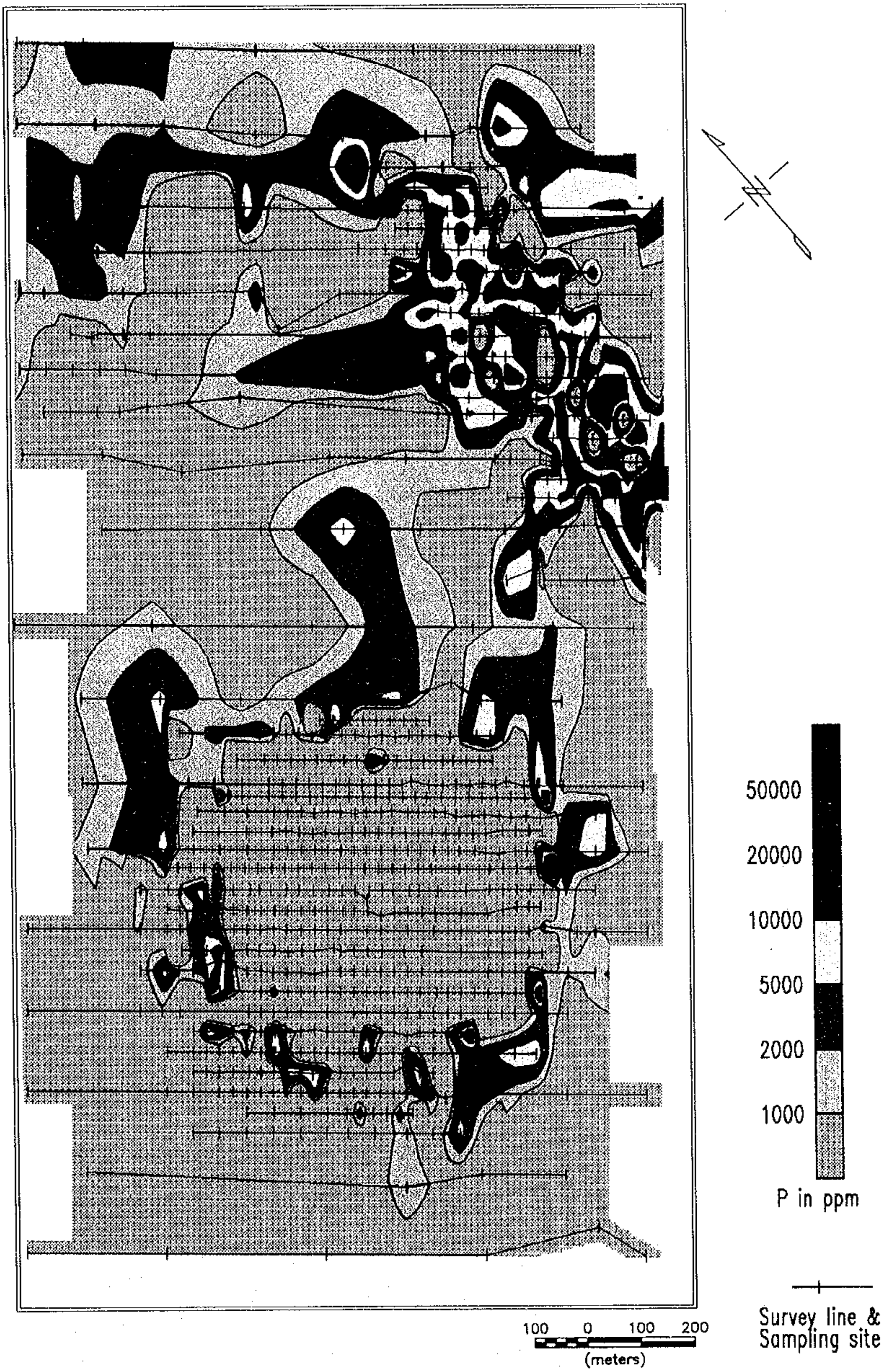


Fig.II-2-6 Contoured Map of Geochemical Distribution of the Orange Area (P)

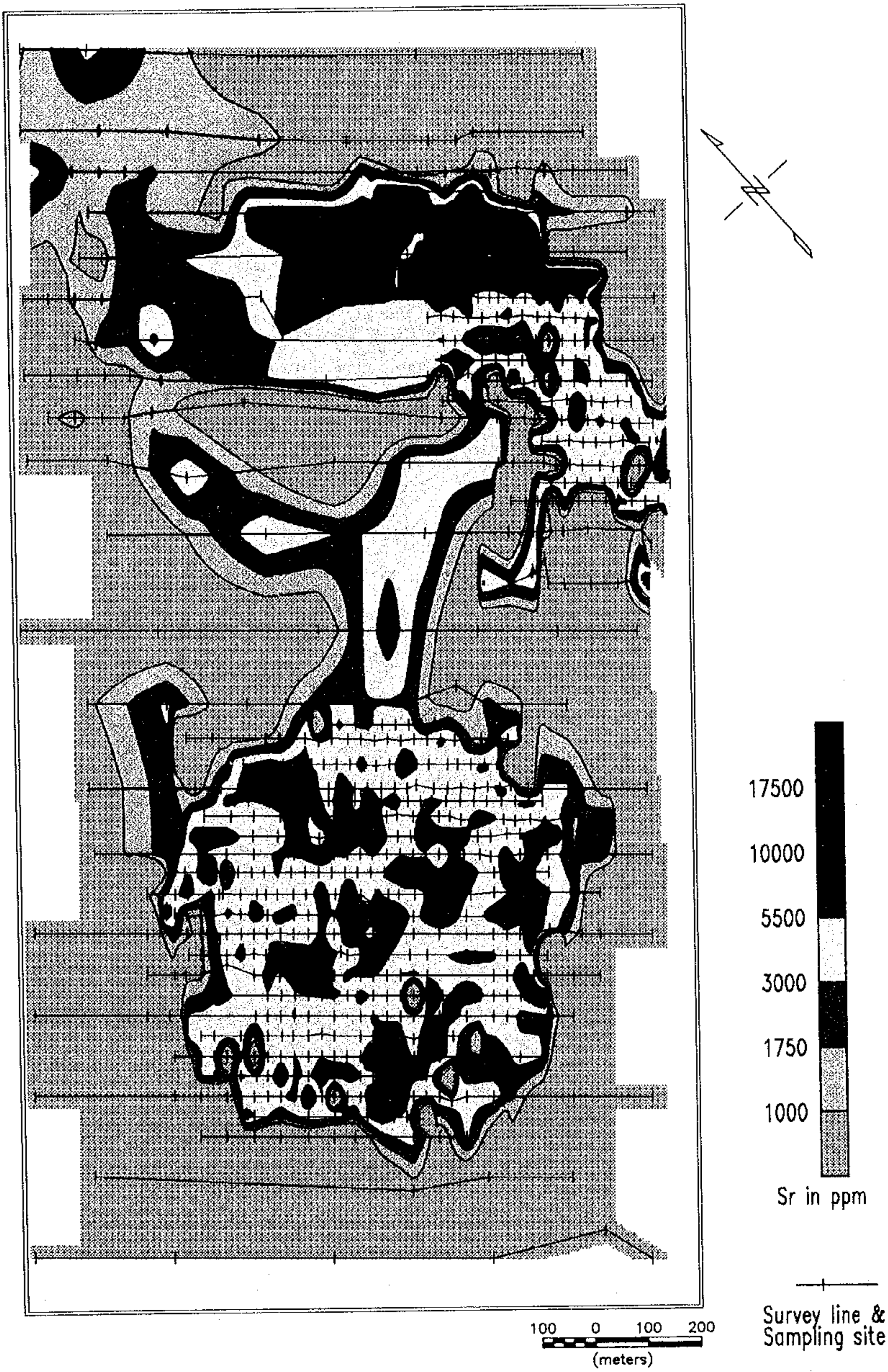


Fig.II-2-6 Contoured Map of Geochemical Distribution of the Orange Area (Sr)

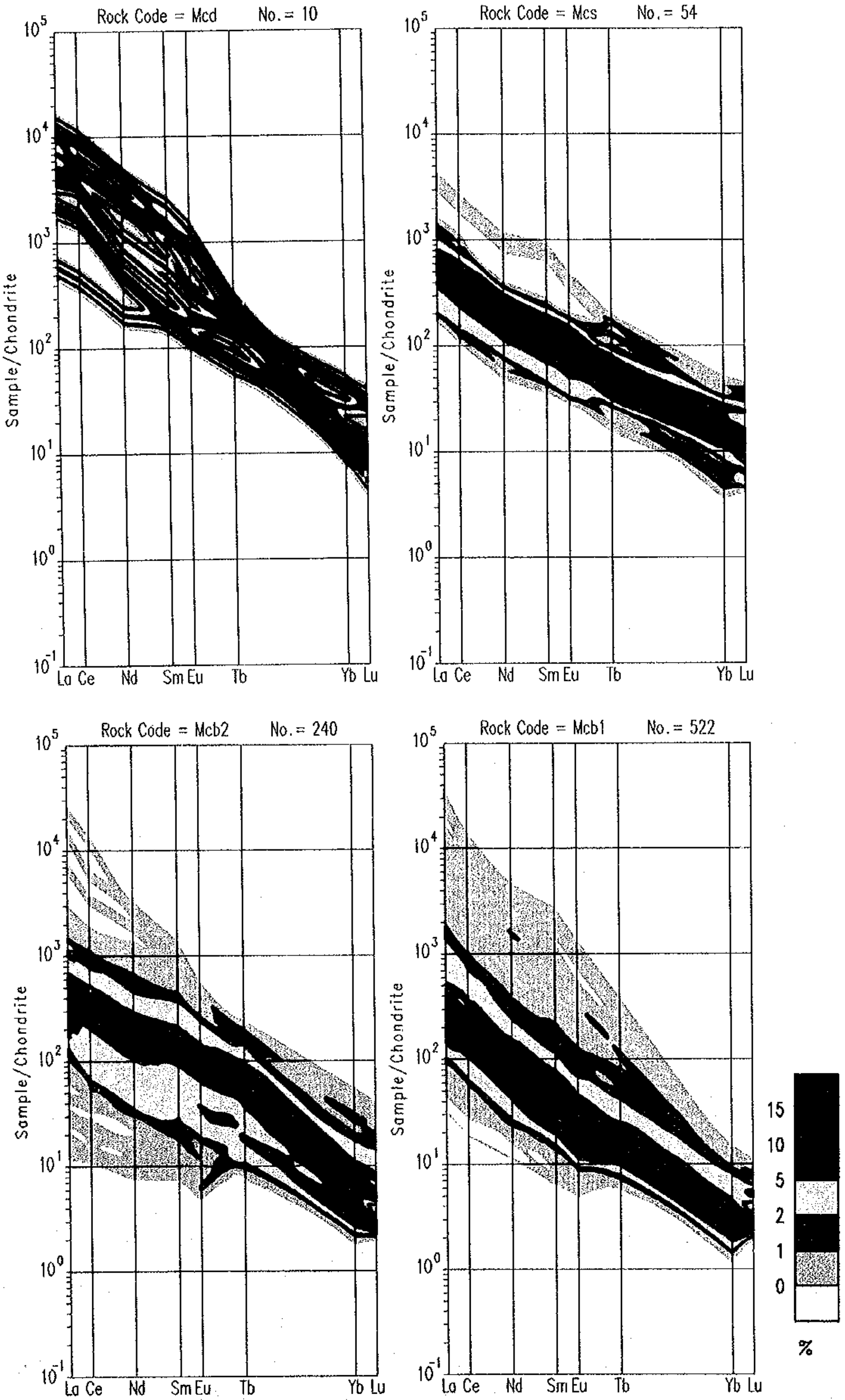


Fig.II-2-7 Rare-Earth Elements Distribution Pattern of the Orange Area (1)

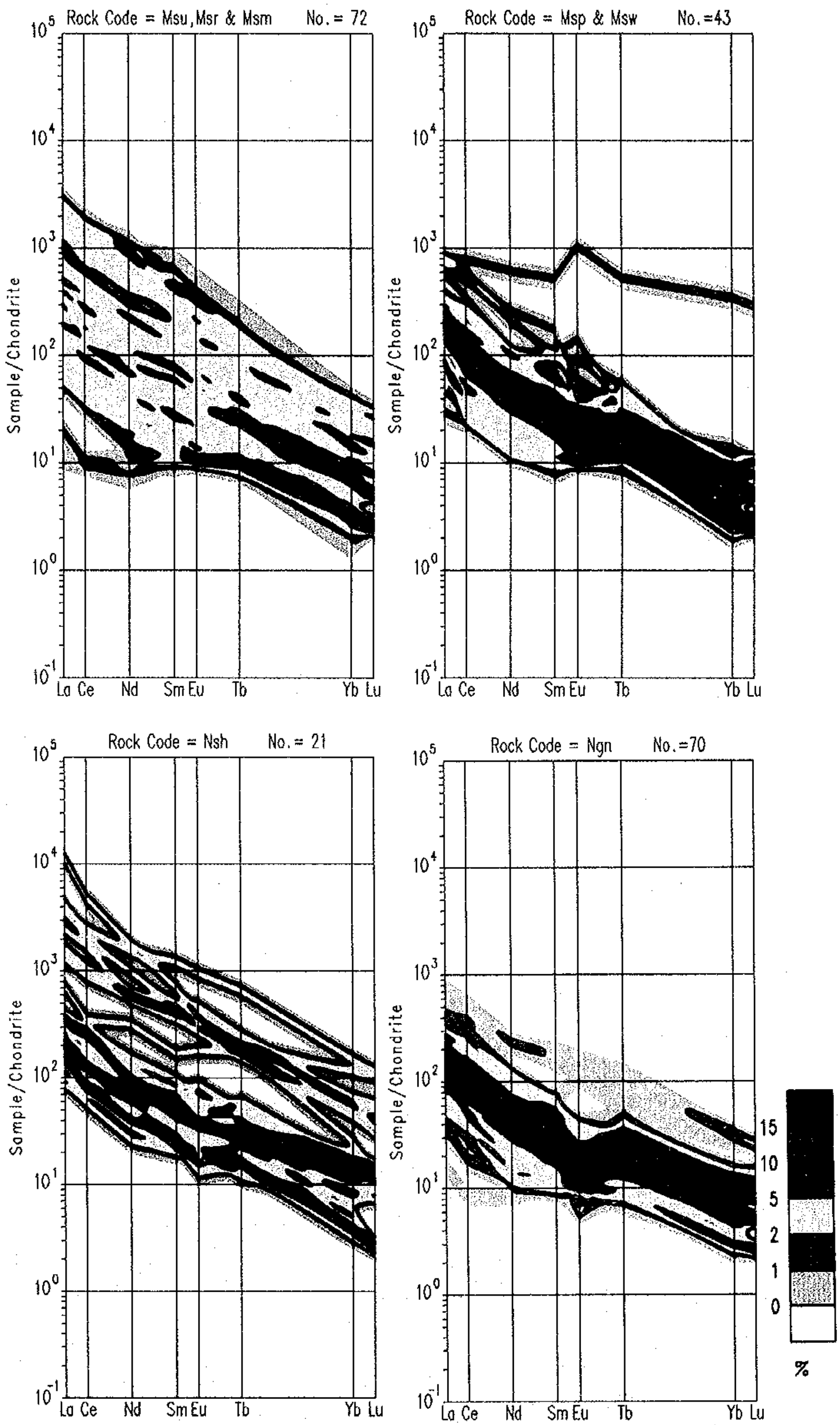


Fig.II-2-7 Rare-Earth Elements Distribution Pattern of the Orange Area (2)

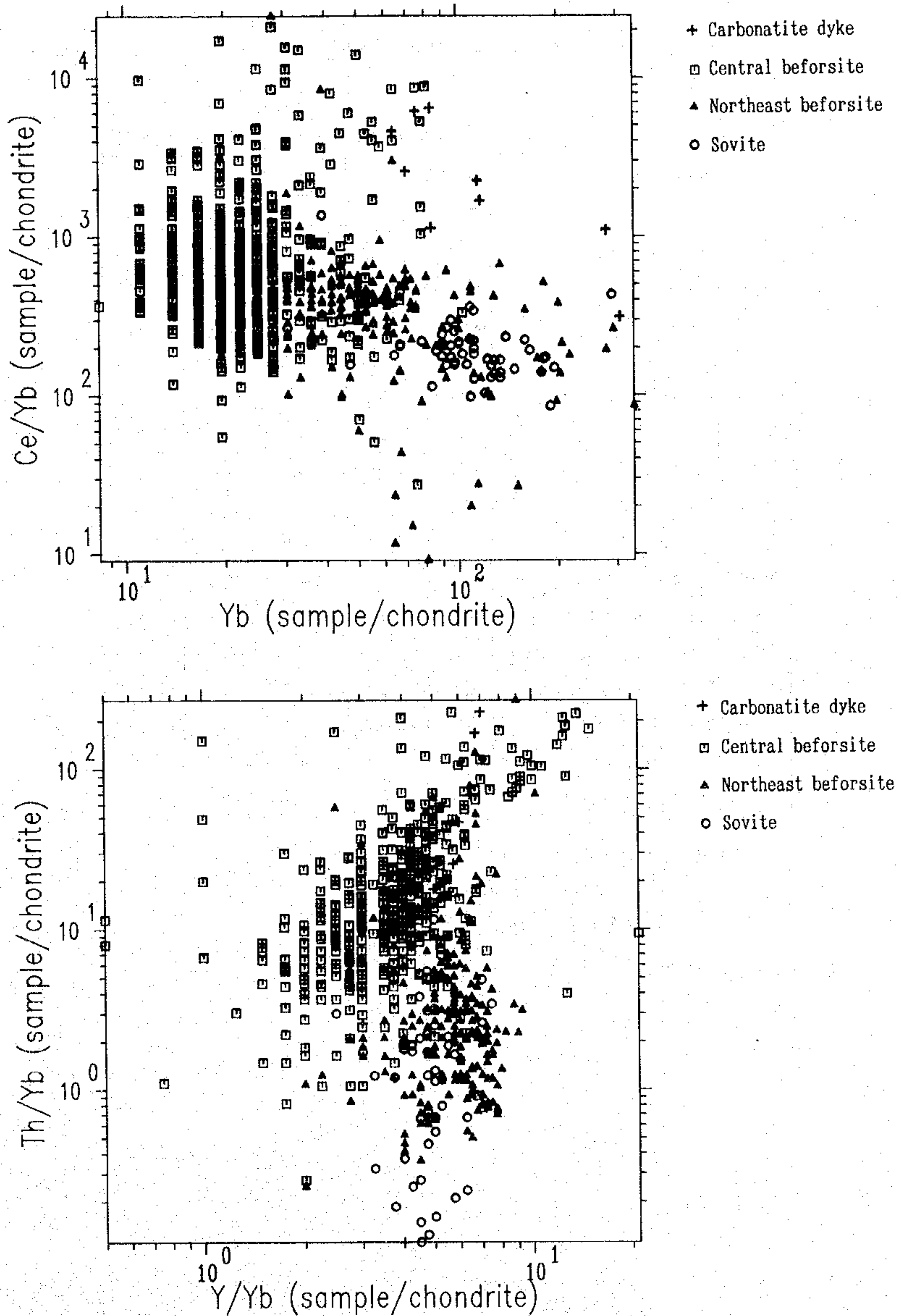


Fig.II-2-8 Y/Yb vs. Th/Yb ,and Yb vs. Ce/Yb Diagrams of the Orange Area

Table II-2-1 Oxygen and Carbon Isotopic Composition of Carbonatite from the Orange Area

Sp.No.	Rock Name	Rock Code	$\delta^{13}C$ PDB (‰)		$\delta^{18}O$ SMOW (‰)	
			Calcite	Dolomite	Calcite	Dolomite
Da415	Beforsite	Mcb1	-3.7	-3.5	8.6	8.7
E 510	Beforsite	Mcd	-3.4	-3.2	13.5	11.2
Eb523	Beforsite	Mcb1	-4.4	-4.4	8.7	8.5
Fc710	Beforsite	Mcb1	-4.1	-3.9	10.5	9.8
Kc725	Beforsite	Mcb2	-5.0	-4.9	8.0	8.1
L 715	Beforsite	Mcb2	-4.9	-4.8	8.5	8.4
La200A	Beforsite / sovite	Mcd	-5.9	-5.0	7.5	9.5
Ma225	Sovite	Mcs	-5.5	-4.7	6.5	7.7
T 1A	Ankeritic beforsite	Mcd	-4.3	-5.4	14.5	8.7
T 9A	Sovite	Mcs	-5.9	-5.4	6.5	8.3
1R-1	Beforsite	Mcb1	-4.6	-4.7	8.0	8.5
3R-1	Beforsite, sulfide rich	Mcb1	-4.6	-4.5	8.5	8.5
3R-3	Beforsite, sulfide rich	Mcb1	-4.0	-4.0	8.5	8.5
3R-5	Beforsite, sulfide rich	Mcb1	-4.0	-4.0	8.2	8.2
4R-1	Beforsite, sulfide rich	Mcb1	-3.7	-3.7	8.8	8.8
6R-1	Beforsite, apatite rich	Mcb2	-4.9	-4.9	8.3	8.3
7R-1	Beforsite, apatite rich	Mcb2	-4.7	-4.8	8.2	8.2
8R-1	Beforsite, apatite rich	Mcb2	-4.7	-4.7	8.2	8.4

Rock code Mcd: carbonatite dyke
Mcb1: Central beforsite body
MCb2: Northeast beforsite body
Mcs: sovite body

Table II-2-2 Results of Geochemical Analyses of the Orange Area

Rock code	Nos.	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm	Sc ppm	Y ppm	U ppm	Th ppm	Nb ppm	Ta ppm	Zr ppm	Mn ppm	Sr ppm	P ppm	Fe %	TR2O3 ppm
Maximum contents																					
Mcd	10	4735	9218	2905	484.4	109.0	15.3	11.0	1.3	19.6	119	26	716	848	73	113	37700	13300	5370	8.61	21657
Mfn	16	1681	3263	1330	282.9	57.5	11.5	3.5	0.5	12.3	61	21	310	539	38	1110	7464	4774	8116	8.42	8373
Mcb1	521	1338	12082	3192	563.6	107.5	21.0	3.7	0.4	39.1	130	75	666	7391	113	1130	76444	20880	25660	18.8	32716
Mcb2	241	8590	11633	2041	271.3	41.5	12.4	12.1	1.4	26.5	240	53	330	52200	26	273	15468	22060	45520	9.7	27224
Msu & Msr	72	1131	1882	870	185.1	46.9	15.8	10.5	1.2	66.2	190	210	156	5389	137	1620	8678	13214	77380	11.8	4953
Mcs	54	1338	2121	663	175.2	34.6	9.3	10.4	1.4	7.0	134	268	90	8770	67	857	10154	15640	22120	6.64	5500
Msp & Msw	43	293	749	428	117.6	87.9	30.3	84.5	11.0	10.0	1280	286	332	3170	16	700	2530	3540	87400	4.76	2763
Nsh	22	4105	4485	1222	271.8	80.3	37.3	36.5	4.3	66.1	710	42	657	1617	87	631	10974	6270	67040	12.5	12428
Ngn	70	275	526	173	45.0	14.0	7.2	8.4	1.0	66.4	190	31	141	952	31	907	10921	4462	18240	18.30	1345
Minimum contents																					
Mcd	10	215	426	143	39.2	10.3	3.8	2.3	0.2	< 0.5	40	< 1	< 1	5	< 2	< 3	5880	1130	149	1.44	1109
Mfn	16	12	30	13	3.0	< 0.5	0.6	0.9	< 0.1	< 0.5	4	< 1	5	45	< 2	< 3	121	6	< 100	1.30	88
Mcb1	521	12	18	8	1.6	< 0.5	0.4	0.3	< 0.1	< 0.5	< 1	< 1	< 1	< 2	< 2	< 3	100	788	< 100	0.40	58
Mcb2	241	5	12	6	2.0	< 0.5	0.5	0.5	< 0.1	< 0.5	6	< 1	< 1	< 2	< 2	< 3	1005	269	< 100	1.21	50
Msu & Msr	72	4	9	5	2.1	0.9	0.5	0.4	< 0.1	< 0.5	< 1	< 1	< 1	4	< 2	< 3	246	123	< 100	1.06	37
Mcs	54	79	126	42	10.0	2.9	1.1	1.1	0.2	< 0.5	17	< 1	< 1	< 2	< 2	< 3	783	1640	< 100	0.22	341
Msp & Msw	43	11	23	8	1.8	0.9	0.5	0.5	< 0.1	< 0.5	3	< 1	< 4	< 2	< 2	4	47	139	228	0.07	66
Nsh	22	31	46	13	1.6	0.8	0.5	0.4	< 0.1	< 0.5	4	< 1	< 1	22	< 2	< 3	191	57	134	0.53	121
Ngn	70	6	8	6	2.1	< 0.5	0.4	0.6	< 0.1	< 0.5	2	< 1	< 1	< 2	< 2	< 3	171	6	< 100	0.32	38
Arithetic average																					
Mcd	10	2153	4186	1304	193.7	43.85	9.82	4.92	0.59	6.86	72.8	10.50	233.2	240	11.70	19.6	12958	7869	2088	5.74	9872
Mfn	16	203	359	149	31.9	7.18	2.33	1.89	0.27	4.55	24.1	8.25	37.3	293	11.63	241.2	2468	1420	2668	4.62	966
Mcb1	521	430	575	154	24.6	4.86	1.56	0.87	0.12	5.16	11.8	4.83	31.3	926	4.58	17.5	7009	5609	1287	4.53	1479
Mcb2	241	243	401	160	32.6	7.85	3.21	1.98	0.24	3.20	35.6	2.98	17.7	1548	3.34	8.2	6918	6265	9977	3.69	1092
Msu & Msr	72	246	417	155	31.4	7.84	3.11	2.76	0.35	3.17	40.0	27.31	29.4	772	23.39	293.8	2101	2182	8483	4.08	1110
Mcs	54	227	393	132	28.1	7.96	3.27	4.06	0.52	1.22	61.2	20.07	12.0	608	8.59	105.5	2334	4931	5007	1.73	1030
Msp & Msw	43	82	143	50	10.7	4.20	1.87	3.24	0.44	1.10	47.1	37.09	23.1	547	5.12	158.9	1125	1399	3561	2.47	392
Nsh	22	470	660	233	44.8	13.23	5.86	7.25	0.90	11.99	126.2	11.95	72.8	282	10.50	117.8	3058	1641	8975	5.50	1850
Ngn	70	62	110	38	7.9	1.96	1.38	2.12	0.31	9.28	23.9	5.20	20.7	93	3.37	156.9	1136	354	1087	3.15	296
Geometric average																					
Mcd	10	1569	3151	888	136.6	31.52	8.97	4.20	0.49	4.61	68.6	5.02	85.5	93	5.40	7.7	10195	5950	1101	5.18	7351
Mfn	16	92	153	61	13.3	3.18	1.64	1.74	0.24	2.62	18.5	5.52	17.3	233	7.27	81.4	1696	705	1337	4.13	439
Mcb1	521	157	250	72	11.8	2.59	1.14	0.79	0.11	4.61	9.5	2.90	14.2	320	2.87	4.5	6420	5348	235	4.21	634
Mcb2	241	143	250	107	22.8	5.59	2.52	1.60	0.19	1.97	27.7	1.63	7.1	668	2.44	4.1	6557	5231	4946	3.44	708
Msu & Msr	72	121	200	75	15.6	4.14	1.97	1.90	0.25	1.32	21.3	11.20	17.8	404	13.86	135.0	1516	1302	2323	3.54	560
Mcs	54	201	346	119	24.6	7.16	3.01	3.79	0.47	0.83	57.1	5.69	6.3	164	3.95	22.5	1824	4445	2506	1.32	920
Msp & Msw	43	64	101	34	6.9	1.95	1.18	1.28	0.19	0.78	15.2	16.85	13.8	280	4.05	81.4	972	1107	1253	2.03	281
Nsh	22	155	257	95	18.2	5.50	2.89	3.66	0.45	5.37	51.6	5.76	19.5	124	4.81	58.0	1539	715	2574	4.18	719
Ngn	70	52	86	30	6.4	1.51	1.18	1.79	0.26	5.94	16.0	3.24	14.0	46	2.47	89.5	813	231	572	2.27	242

Beforsite (Mcb) is subdivided into the Central beforsite (Mcb1) and the Northeast beforsite (Mcb2). Other rock codes are same as Fig.II-2-2

Chapter 3 Kalkfeld area

This area was surveyed in 1993. The carbonatite complex called the Osongombo Diatreme in the survey area is located 20 km west of the town of Kalkfeld. The survey area is covered by the farms of Osongombo 80, Sud-Osongombo 83, and Okarumue 82.

3-1 Survey Method

In the 1993 phase I survey, a base map used for the field survey and geological mapping were enlarged versions of the published topographic maps from the scale of 1 to 50,000 to that of 1 to 2,500.

Geochemical rock sampling was done based on this map. Geology was checked simultaneously along the geochemical survey lines and compared with the previous geological map. Laboratory tests carried out were geochemical analyses, whole rock analyses (Appendix C-1,2), XRD and observations of rock thin sections (Appendix A-2).

3-2 Geological Survey

3-2-1 Outline of Geology

Fig.II-3-1 shows a geological map based on the field survey and after Verwoerd (1967). Fig. II-3-2 shows the lithotratigraphy of the Kalkfeld area.

The carbonatite complex, named the Osongombo Diatreme, is hosted by the marble of the Damara Sequence (Mb), and Damaran Granitoid (Gb and Gp). The carbonatite complex consists of volcanic breccia (Vb), beforsite (Br) and iron ore (Io), intruding in this order.

Light REEs (La, Ce and Nd), Th, Mn, and Fe are concentrated in the carbonatite complex. In particular, these elements are concentrated in the beforsite and the iron ore, but in the iron ore.

3-2-2 Details of Geology

Laboratory test carried out in this project are as follows:

1) Microscopic observation of thin sections and polished sections under reflected and penetrated light,
2) X-ray diffraction analyses (XRD),
3) whole rock chemical analyses,

The geology and results of laboratory tests mentioned above are described as follows;

1. Damara Sequence (Dm)

The sequence is an equi-granular marble which has grain sizes of from 3 to 5 mm in diameter. Foliation strikes approximately NE–SW direction and is commonly observed in the area. Graphite bearing marble and blue amphibole bearing marble are found in the northern area, and in the southern area, respectively. Pink material consisting mainly of potassium feldspar, is observed in the marble. Brown carbonatite veins are well developed in the marble surrounding the diatreme.

Through examination by microscope and XRD, the Sequence is subdivided into two facies of calcite marble and calcite – dolomite marble.

Fine pink material mainly consisting of potassium feldspar suggests that the marble around the diatreme was once affected by alkaline metasomatism.

2. Damaran Granitoid (Gb and Gp)

It consists of a biotite granite and pegmatitic granite sills. Brown carbonatite veins and green aegirine veins are commonly found within.

Biotite granite (Gb), which intrudes the Damara marble, develops in the southwest and the east portion of the area. The shape of the bodies is irregular.

It is composed of quartz, albite, potassium feldspar and biotite as the main rock forming minerals, and of sphene and opaque minerals as accessory minerals. Calcite and chlorite are produced as secondary minerals.

Pegmatitic granite (Gp) is sparsely distributed as a small size of sill hosted by the marble.

It is composed of quartz, albite and potassium feldspar as main minerals, and of analcime, riebeckite and sphene as accessory minerals.

3. Osongombo Diatreme (Vb, Be and Io)

The Diatreme is made up of volcanic breccia (Vb), beforsite (Be) and iron ore (Io).

(a) Volcanic breccia (Vb)

This breccia is distributed in the outer zone of the diatreme, and as a small body in the marble at the southern part of the area. The breccia fragments are mainly pink volcanic rock and granite, and the matrix is brown carbonates and iron oxide. It shows various sizes of fragments. The contact between the volcanic breccia and the beforsite is indistinct and transitional.

The pink fragments are made up of phenocrysts of potassium feldspar (5 to 1 mm in diameter), and fine crystal of albitized plagioclase and potassium feldspar (1 to 0.1 mm in diameter). Fine quartz, carbonates and opaque minerals are observed in the groundmass of the fragments. Small amounts of riebeckite and aegirine–augite are observed as mafic minerals.

(b) **Beforsite (Be)**

This is distributed in the zone surrounded by volcanic breccia in the diatreme. The surface of the beforsite is brown from the weathering of iron oxides. Banding structure becomes clear caused by differential weathering resistivity of matrices in the field. Aggregate of galena about 2 mm in diameter is found in the beforsite.

The beforsite is mainly composed of dolomite and ankerite. Calcite, kutnahorite, strontianite, barite, quartz, albite, potassium feldspar and riebeckite were identified by the microscope and XRD analysis. Barite is commonly recognized in beforsite. Magnetite, hematite, ilmenite, pyrite, marcasite, pyrrhotite, galena, sphalerite and iron hydroxide were recognized as the opaque minerals.

Normative minerals and average norms, based on whole rock chemical analysis, are magnetite (3.46%), hematite (11.97%), rutile (0.17%), apatite (4.29%), forsterite (0.28%), fayalite (0.53%), calcite (39.97%), magnesite (12.19%), siderite (6.49%) and strontianite (0.73%).

(c) **Iron ore (Io)**

The iron ore is distributed in the core of the diatreme. It is massive and the surface of the iron ore is black to dark brown.

Quartz, calcite, dolomite, ankerite, strontianite, magnetite, hematite, goethite and barite are identified.

4. Breccia of marble and granite (Br)

This unit is distributed at the northern ridge of the area. It consists of a breccia of marble and granite, and filled with brown carbonatite in the interstices of fragments.

5. Dolerite (Dd)

It is distributed in and around the diatreme. The width of the dyke is about 1 m.2.

3-3 Geochemical Survey

3-3-1 Survey Method

Rock samples were collected for this survey. 50 m by 75 m sampling grids in carbonatite area and 100 m by 150 m grids in its periphery were adopted.

Geochemical analyses of the following 19 Elements were carried out;

La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Mn, Sr, P and Fe

3-3-2 Survey Results

Fig.II-3-3 shows the geochemical analysis map. Fig.II-3-4 shows REEs Distribution Pattern. Table II-3-1 shows statistic data of geochemical analyses. Appendix C-3 shows geochemical analyses. Appendix C-4 shows frequency and cumulative frequency for geochemical analyses. Appendix C-5 shows scattering diagram of the geochemical analyses.

1. Rare-earth elements (REEs: La, Ce, Nd, Sm, Eu, Tb, Yb and Lu)

REEs are more concentrated in the carbonatite complex, compared with the peripheral rocks. In the carbonatite complex, volcanic breccia (Vb) contains 3,003 ppm at the maximum and 1,283 ppm on the average. The beforsite (Be) contains 13,600 ppm at the maximum and 2,782 ppm on the average. Iron ore (Io) contains 5,372 ppm at the maximum and 2,932 ppm on the average. The beforsite and the iron ore have higher concentration of most REEs.

Zones where concentration exceeds more than 1,000 ppm of rare-earth oxides are distributed in the volcanic breccia and the beforsite. Concentrations in excess of 2,000 ppm are distributed in the beforsite.

The beforsite in this area contains more rare-earth oxides than sovite and the two beforsites of the Orange area. Average contents in the beforsite are 2,782 ppm in the Kalkfeld area. In the Orange area, the average content is 1,665 ppm, and of the northeast beforsite is 1,252 ppm.

The beforsite of the Kalkfeld area is enriched in REEs, compared with the two beforsites of the Orange area. In particular, the middle REE (Sm, Eu and Tb) content of the beforsite of the Kalkfeld area is two or three times as high as that of the Orange area.

2. Scandium and Yttrium

Concentrations of Sc and Y in the volcanic breccia and the beforsites exceed 10 ppm. There are no other high concentration zones. Sc and Y are more concentrated here than in the Orange Area.

3. Uranium and thorium

Th shows zones with concentrations exceeding 100 ppm in the volcanic breccia, the beforsite and the iron ore. In particular, the zones of more than 1,000 ppm are sporadically distributed through the beforsite and the iron ore.

The contents are ten times as high as those of the two beforsites of the Orange area. The carbonatite complex 12 km northeast of the survey area contains 5% of ThO_2 (Verwoerd,1967).

4. Niobium and tantalum

Nb shows zone where concentration exceeds 100 ppm in the northeastern part of volcanic breccia, and the highest zone of 1,840 ppm in the west part of the volcanic breccia. But the contents are lower than those of the Orange area.

Ta shows high a concentration zone in the carbonatite and a low zone in its periphery. The content is slightly higher than that of the Orange area, but concentration grade of both areas is low.

5. Zirconium

Zr shows high concentrated zones in the volcanic breccia (Vb) and the Damaran Granitoids (Gp and Gb). Volcanic breccia (Vb) contains 176 ppm at the maximum and 55.1 ppm on the average. Granitoids (Gb and Gp) contain 56.8 and 124 ppm at the maximum, and 56.8 and 81.8 ppm on the average, respectively. There is no distinct concentration zone in the beforsite, which contains 64 ppm at the maximum and 14.8 ppm on the average. The concentration in the beforsite is the same as that in the two beforsites of the Orange area.

6. Manganese

Mn shows zones of high concentrated in the iron ore (Io) and in the beforsite (Be). The iron ore contains 40,300 ppm at the maximum, and 37,867 ppm on the average. The beforsite contains 29,900 ppm at the maximum and 13,684 ppm on the average.

A zone where concentration exceeds 5,000 ppm is situated in the inner zone of the carbonatite. In particular, zones in excess of 10,000 ppm are distributed in the beforsite and the iron ore. The average content of the Diatreme is higher than those of the two beforsites in the Orange area.

7. Strontium

Sr shows zones of high concentration in the iron ore and the beforsite. The iron ore contains 14,400 ppm at the maximum, and 5,263 ppm on the average. The beforsite contains 10,900 ppm at the maximum and 2,352 ppm on the average.

Zones exceeding 5,000 ppm are situated in the beforstic. The average content of the Diatreme is lower than those of the two beforsites in the Orange area.

8. Phosphorus

P shows the high concentrated zone in the beforsite and the volcanic breccia. The beforsite contains 37,800 ppm at the maximum and 4,672 ppm on the average. The volcanic breccia contains 9,790 ppm at the maximum and 2,455 ppm on the average. Zones in excess of 3,000 ppm are situated in the carbonatite complex and its vicinity. Slightly high content in the Damara marble is due to the carbonatite veins.

9. Iron

The Diatreme is enriched in Fe. The volcanic breccia contains 30.40 % at the maximum and 7.56 % on the average. The beforsite contains 32.50 % at the maximum and 10.86 % on the average. The iron ore contains 37.82 % at the maximum and 34.85 % on the average. Fe content is highest in the iron ore followed in order of abundance by that of the beforsite and the volcanic breccia.

3-4 Conclusions

The carbonatite complex, named the Osongombo diatreme, intrudes the marble of the Damara sequence. The complex is composed of volcanic breccia, beforsite and Iron ore, formed in this order.

Light REEs (La, Ce and Nd), Th, Mn and Fe are concentrated in the carbonatite complex. In particular, these elements are concentrated in the beforsite and the iron ore, but in the iron ore, this occupies a narrow area.

The beforsite of the Kalkfeld area is rich in normative magnetite, hematite, rutile and siderite. The two beforsites are rich in normative calcite, dolomite and strontianite. in particular, The contents are the same as the northeast beforsite and higher than the central beforsite of the Orange area. The high content of normative magnetite corresponds to the field observation of the abundance of Fe minerals such as magnetite. The carbonate of the Kalkfeld area is rich in calcite and siderite components, and the carbonate of the Orange area is rich in the dolomite component

The maximum and average contents of rare-earth oxides are 13,600 and 2,782 ppm in the beforsite, 5,372 and 2,932 ppm in the iron ore. The maximum and average content of Th are 2,290 and 356 ppm in the beforsite and 2,260 and 885 ppm in the iron ore. The maximum and average contents of Mn are 29,900 and 13,684 ppm in the beforsite and 40,300 and 37,867 ppm in the iron ore. The maximum and average contents of Fe are 32.50 and 10.86% ppm in the beforsite, and 37.82 and 34.85% in the iron ore.

The beforsite is more enriched in REEs than those of the iron ore. The iron ore is more in Th, Mn and Fe than those of the beforsite.

Compared with the two beforsites of the Orange area, The beforsite of the Kalkfeld area is more enriched in REEs than that of the Orange area. In particular, middle REEs (Sm, Eu and Tb) are more concentrated in the beforsite of the Kalkfeld are than in those of the Orange area.

Th, Ta, Mn and Fe are more concentrated in the beforsite of the Kalkfeld area compared with those of the Orange area. Nb and Sr are more concentrated in the beforsite of the Orange area, compared with that of the Kalkfeld area. U and Zr contents in the beforsite of the Kalkfeld area are same as those of the Orange area. P concentration of the beforsite of the Kalkfeld area is higher than that of the central beforsite of the Orange area, and lower than that of the northeast beforsite of the Orange area.

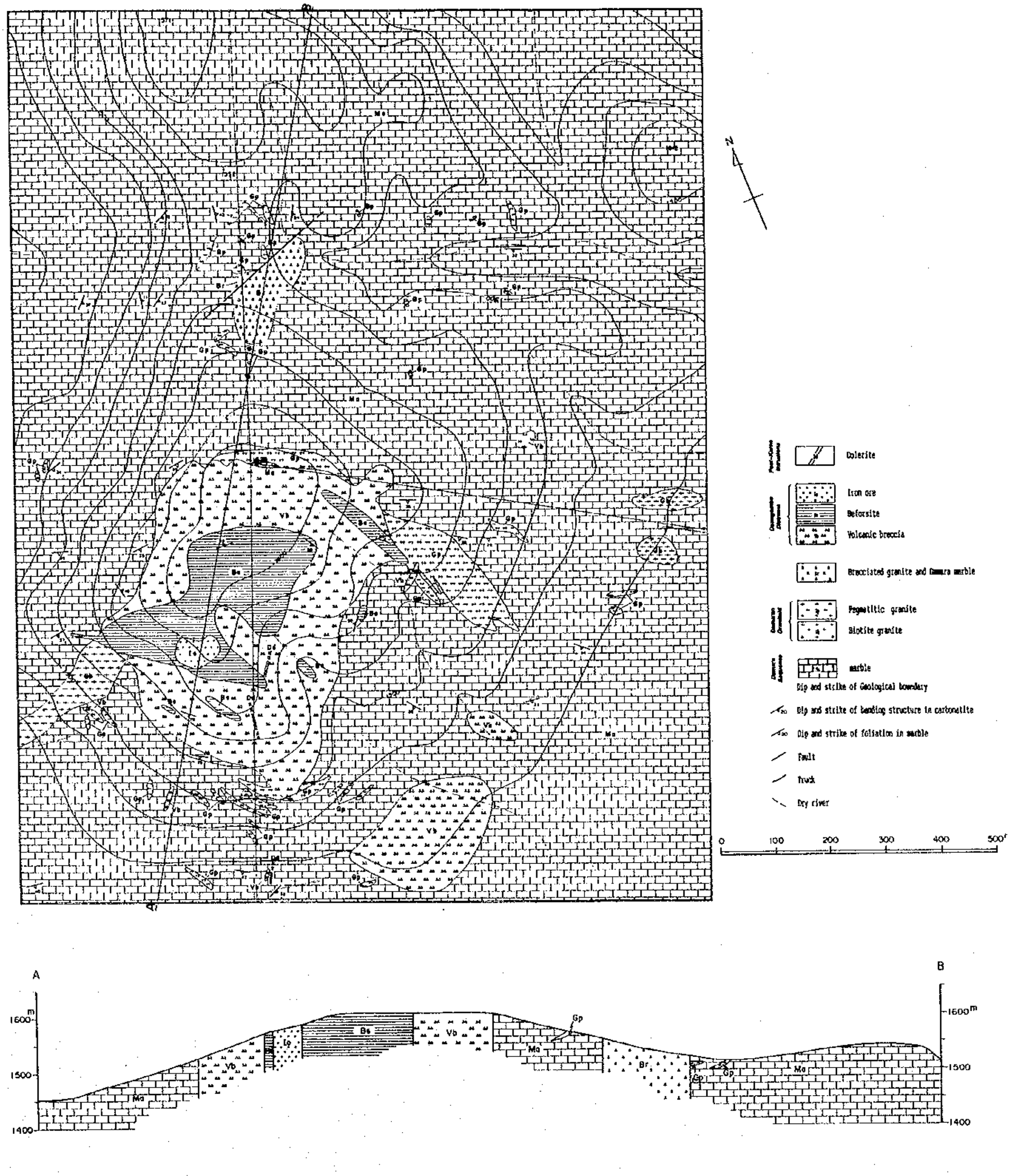


Fig.II-3-1 Geological Map of the Kalkfeld Area

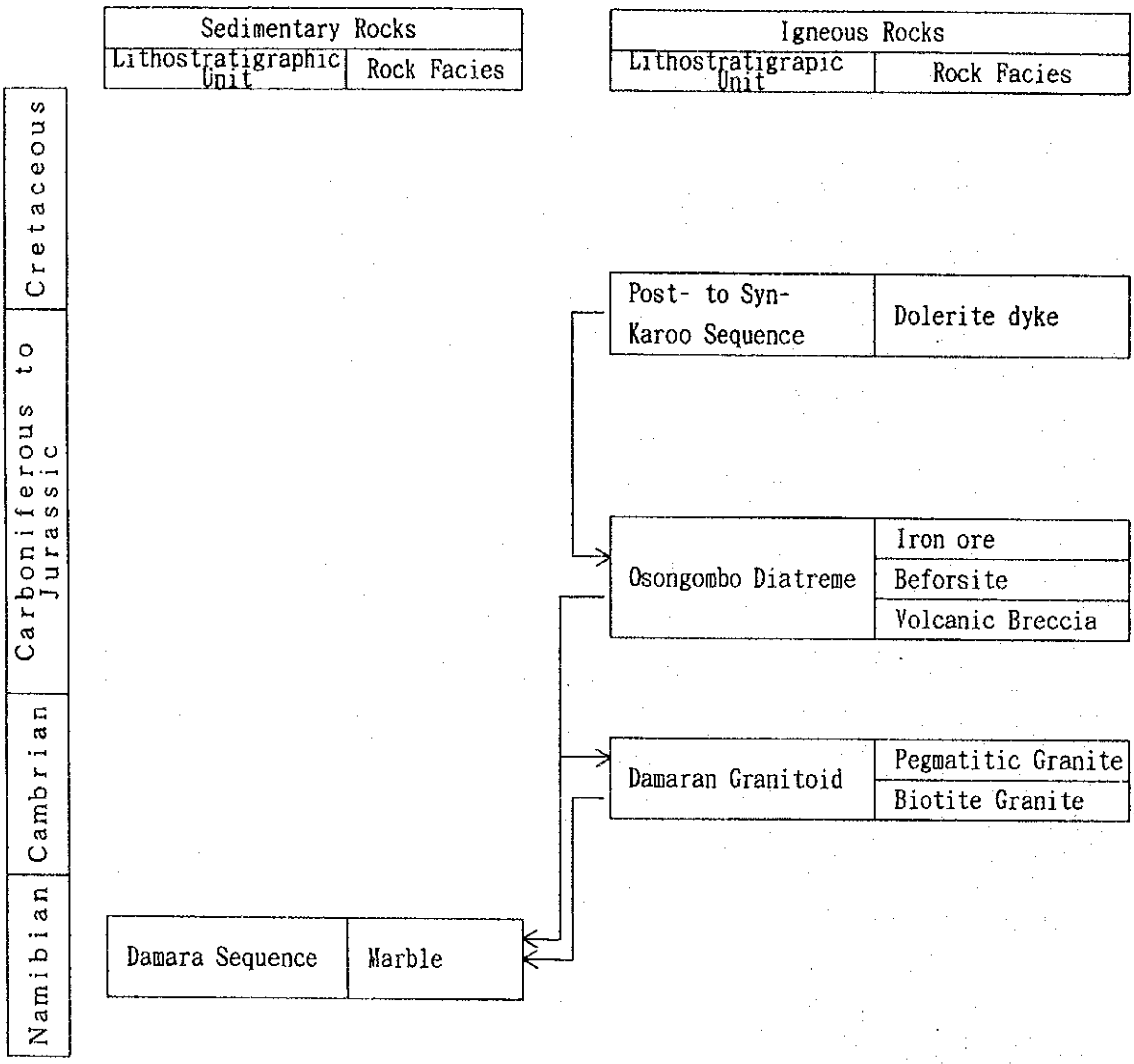


Fig.II-3-2 Lithostratigrahy of the Kalkfeld Area

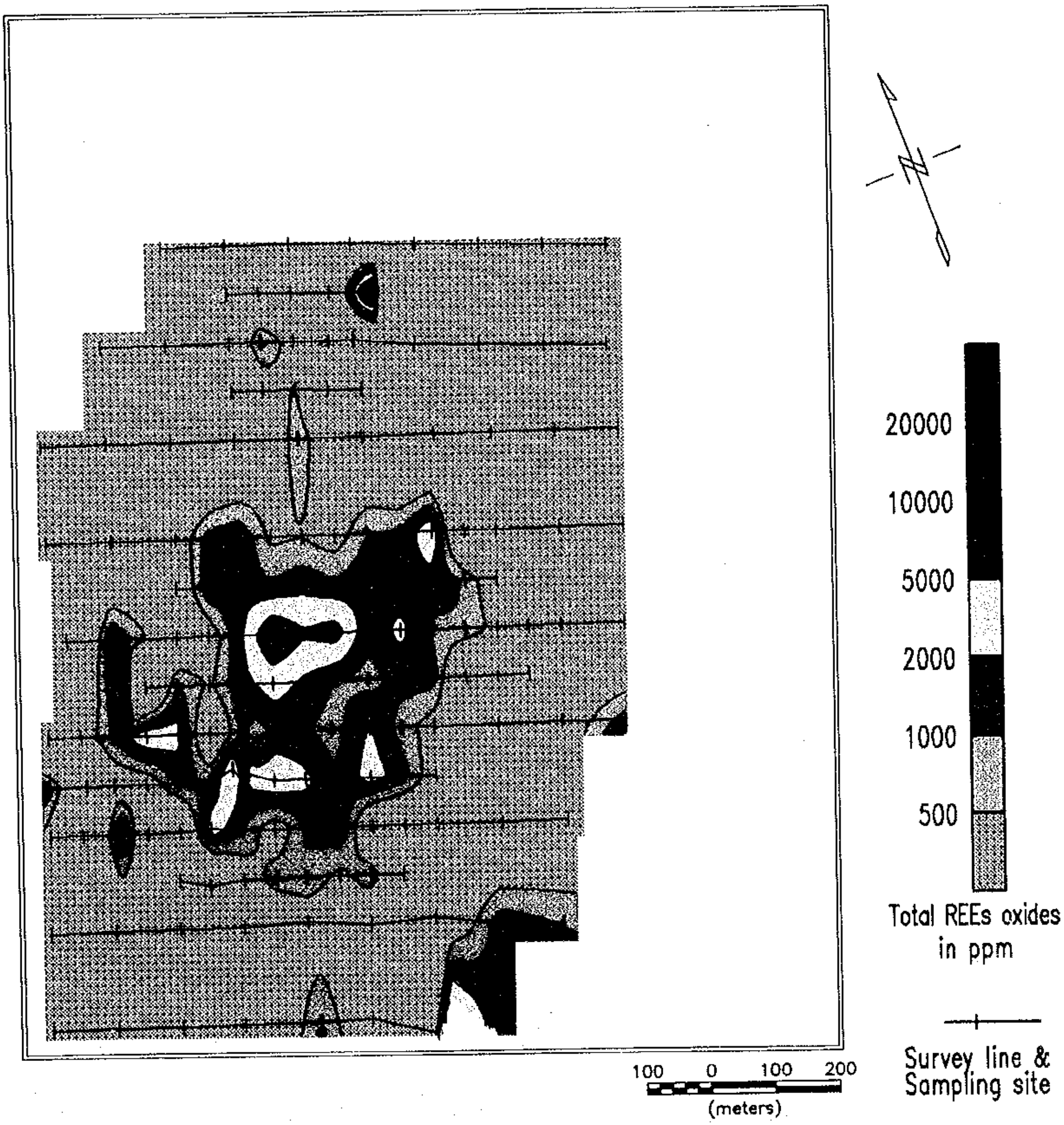


Fig.II-3-3 Contoured Map of Geochemical Distribution of the Kalkfeld Area
(Total REEs Oxide)

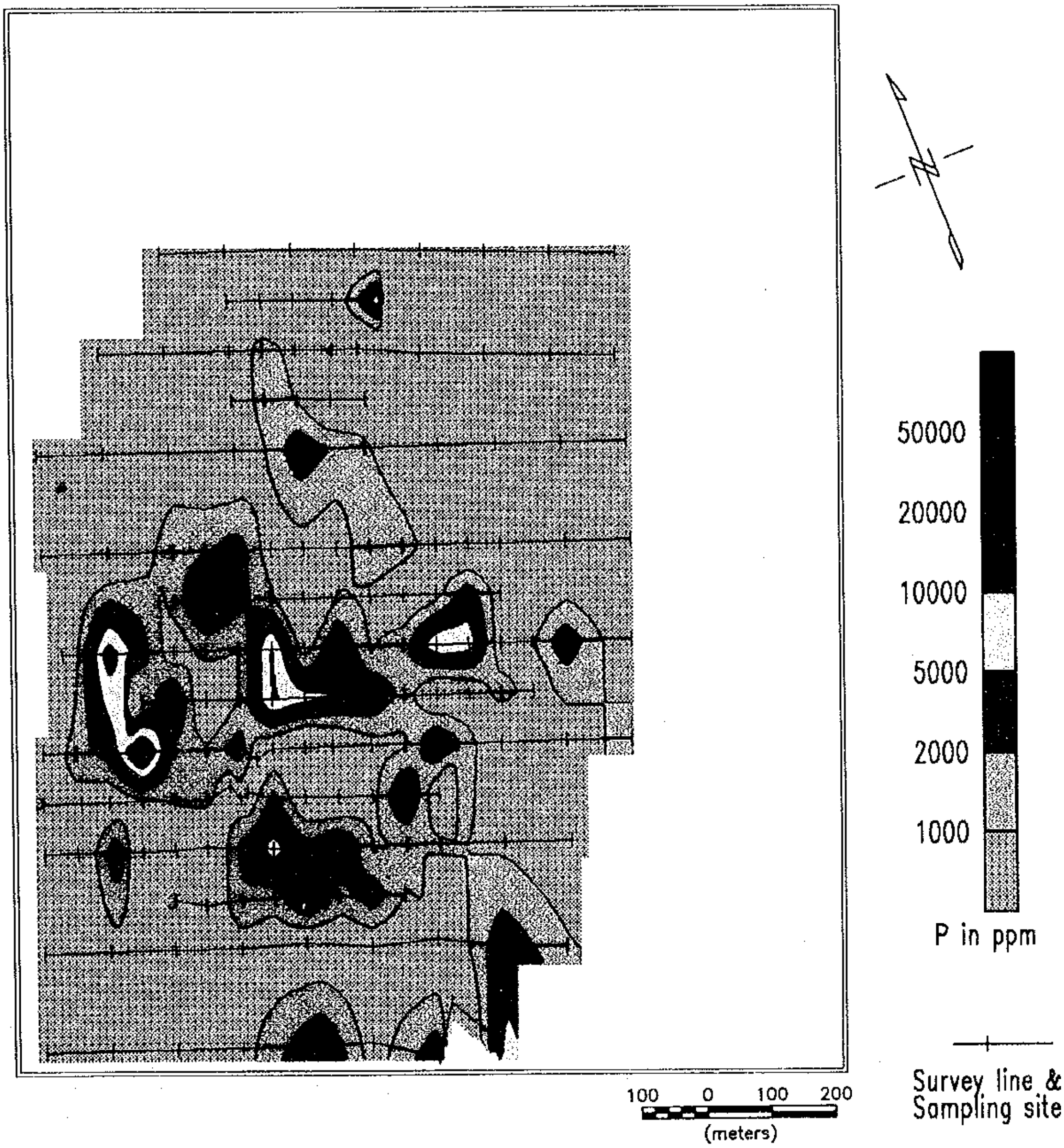


Fig.II-3-3 Contoured Map of Geochemical Distribution of the Kalkfeld Area (P)

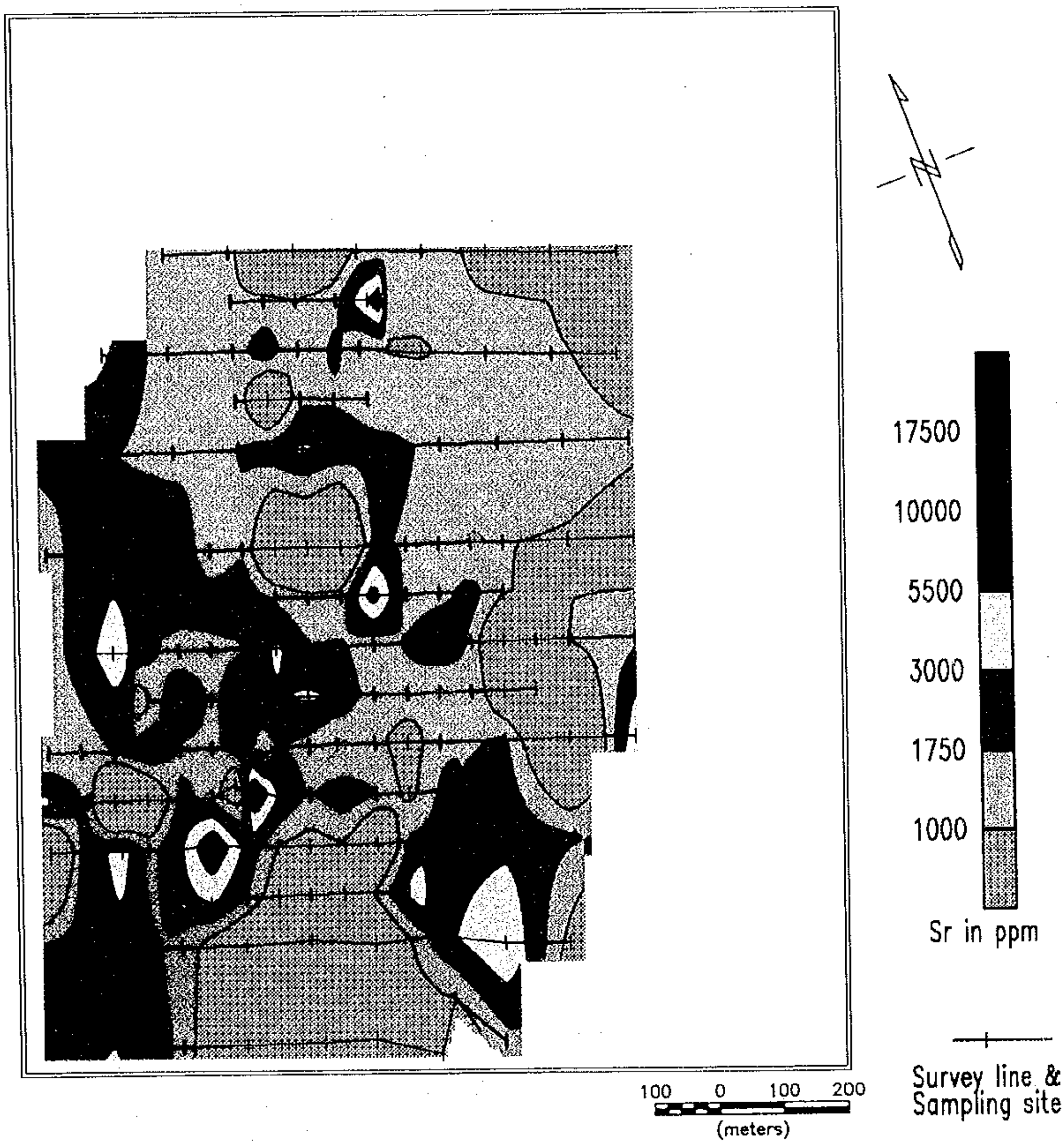


Fig.II-3-3 Contoured Map of Geochemical Distribution of the Kalkfeld Area (Sr)

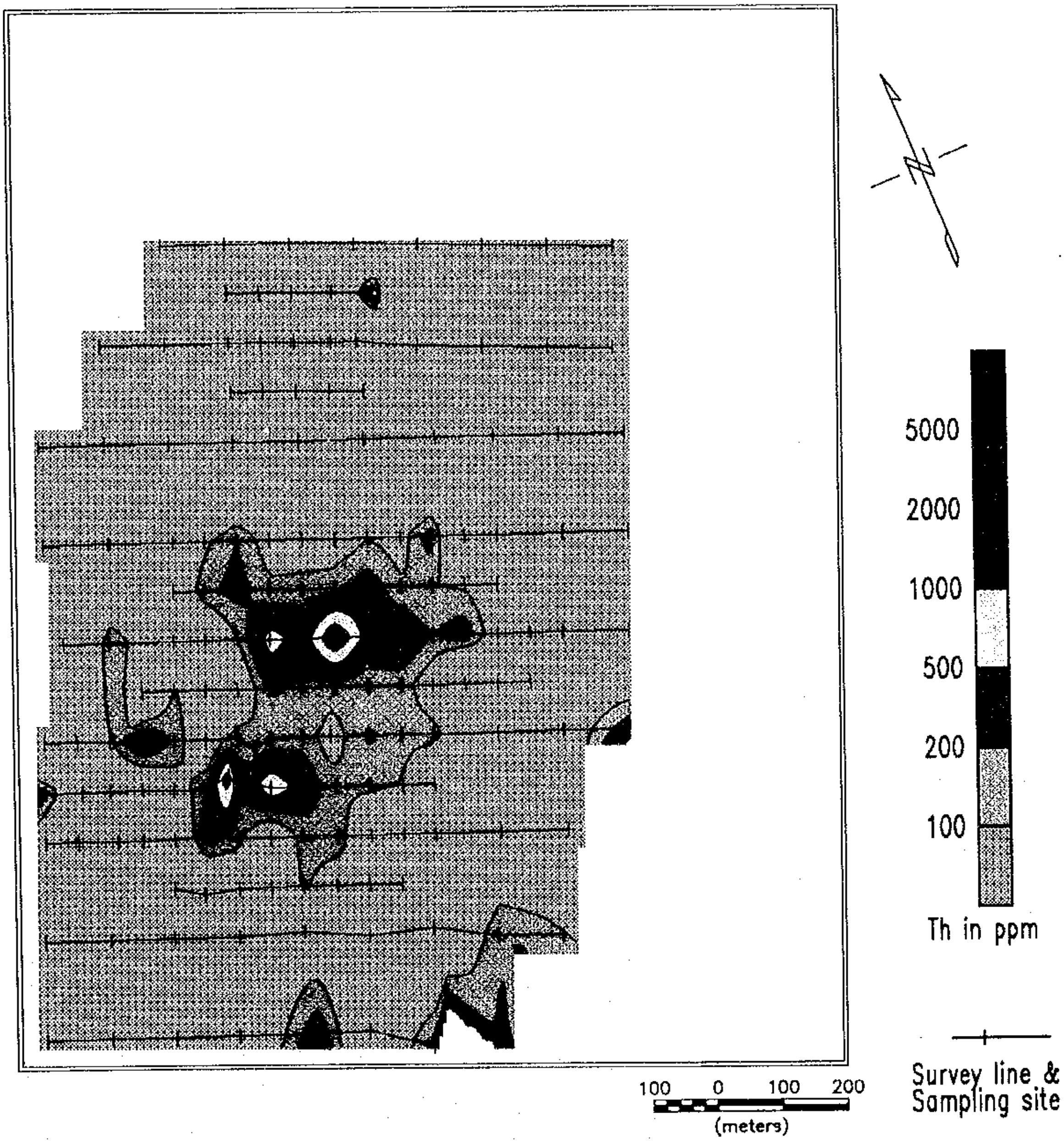


Fig.II-3-3 Contoured Map of Geochemical Distribution of the Kalkfeld Area (Th)

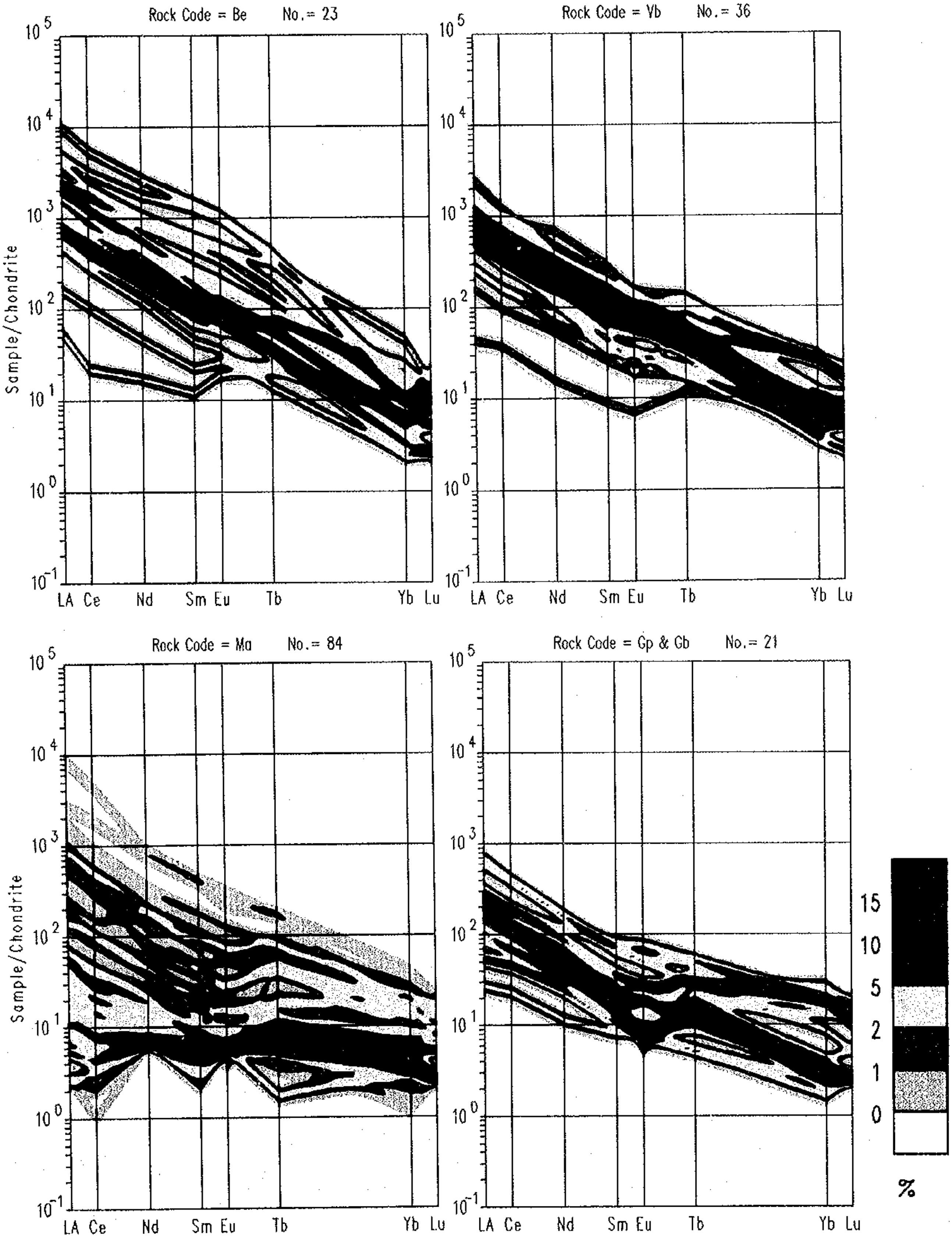


Fig.II-3-4 Rare-Earth Elements Distribution Pattern of the Kalkfeld Area

Table II-3-1 Results of Geochemical Analyses of the Kalkfeld Area

Rock Code	Nos.	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm	Sc ppm	Y ppm	U ppm	Th ppm	Nb ppm	Ta ppm	Zr ppm	Mn ppm	Sr ppm	P ppm	Fe %	TR2O3 ppm
Maximum contents																					
Io	3	899	1540	1200	300.0	70.2	29.3	6.0	0.9	4.8	76	3	2260	9	32	19	40300	14400	559	37.82	5372
Be	23	3502	5042	1834	330.0	90.0	24.0	11.0	0.8	9.1	326	17	2290	1840	28	64	29900	10900	37800	32.50	13600
Vb	36	926	1200	478	64.9	12.6	7.5	7.0	0.8	14.9	70	79	430	498	29	176	16600	8490	9790	30.40	3003
Gp	17	259	374	111	18.0	6.6	3.0	6.5	0.7	7.2	70	19	282	226	3	124	12000	1840	3490	7.69	988
Gb	4	116	187	59	7.9	2.3	1.3	4.7	0.4	3.2	11	6	45	102	< 2	95	1730	334	870	3.74	490
Ma	84	3090	4150	604	94.0	26.0	10.0	10.0	0.8	4.1	149	11	352	223	7	72	16100	5540	16300	8.55	9781
Minimum contents																					
Io	3	133	137	91	20.0	3.1	3.6	4.2	0.8	< 0.5	14	2	123	< 2	< 2	< 3	36300	442	408	31.92	537
Be	23	20	21	12	2.7	1.6	0.8	0.6	< 0.1	< 0.5	4	< 1	32	< 2	< 2	< 3	1870	879	248	4.90	96
Vb	36	16	36	11	2.0	0.6	0.7	0.8	< 0.1	< 0.5	4	< 1	16	< 2	< 2	< 3	1610	286	144	1.00	95
Gp	17	10	22	8	1.8	< 0.5	0.3	0.4	< 0.1	0.6	6	< 1	8	< 2	< 2	17	87	57	210	0.44	58
Gb	4	57	100	28	2.9	< 0.5	0.6	0.6	< 0.1	1.3	7	< 1	20	6	< 2	71	208	99	410	1.06	247
Ma	84	1	1	5	0.5	0.3	< 0.1	0.3	< 0.1	0.3	1	< 1	< 1	2	< 2	< 3	45	583	180	0.03	16
Arithetic average																					
Io	3	556	809	641	153.3	30.3	16.4	5.3	0.8	2.4	41.0	2.3	885.7	6.0	12.0	8.3	37867	5263	477	34.85	2930
Be	23	672	1069	368	64.2	18.2	5.8	2.4	0.3	4.1	47.0	3.6	356.0	145.1	8.9	14.8	13684	2352	4672	10.86	2782
Vb	36	324	490	162	23.7	6.3	3.0	2.7	0.3	5.0	20.6	7.1	146.9	125.1	5.3	55.1	6828	1852	2455	7.56	1283
Gp	17	74	127	43	6.6	2.0	1.3	2.4	0.3	3.0	18.5	4.2	55.2	57.4	2.1	56.8	1377	373	983	2.87	336
Gb	4	73	123	37	4.8	1.1	0.9	1.7	0.2	2.2	9.3	3.5	28.3	37.5	2.0	81.8	941	240	628	2.08	311
Ma	84	102	148	40	6.8	2.0	1.2	2.0	0.2	1.2	19.4	2.0	34.6	23.8	2.1	9.5	1385	1819	1010	1.08	388
Geometric average																					
Io	3	424	541	410	94.4	15.6	11.9	5.2	0.8	1.6	32.7	2.3	423.9	5.0	5.0	5.6	37827	1820	473	34.76	2025
Be	23	415	653	222	34.5	10.3	3.8	1.9	0.3	3.3	25.2	2.4	212.2	36.3	6.2	7.9	11253	1961	1742	9.71	1735
Vb	36	266	417	139	19.9	5.5	2.6	2.1	0.3	3.7	17.1	3.3	117.6	74.6	3.8	36.4	6061	1468	1613	6.73	1095
Gp	17	53	97	35	5.3	1.5	1.0	1.6	0.2	2.7	12.6	3.0	36.6	35.8	2.0	48.6	489	266	759	2.02	260
Gb	4	70	119	35	4.5	0.9	0.9	1.1	0.1	2.0	9.1	2.8	26.7	21.4	2.0	81.3	621	216	599	1.80	296
Ma	84	13	22	13	2.4	0.9	0.7	1.5	0.2	0.9	11.3	1.5	8.3	7.3	2.0	6.0	510	1637	606	0.49	86

Rock codes are same as in Fig.II-3-1.

Part III Conclusions and Recommendations

Part III Conclusions and Recommendations

Chapter 1 Conclusions

1-1 Characteristics of Mineralization and Structural Controls Related to Mineralization

Orange Area

The Marinkas Quelle Carbonatite Complex (MQC) intrudes the Namaqua Metamorphic Complex and the Nama Sequence of Cambrian age. MQC is located along the Kuboos-Bremen tectonic line, which trends NE-SW direction, and is also found at the intersection of the this tectonic line and post-Karoo faults.

The MQC is composed of syenites, sovite, beforsite and carbonatite dyke, which intrude in this order. The Th / Yb versus Y / Yb diagram indicates that Th is the lowest in the sovite followed, in order of content by the two beforsites and the carbonatite dyke. Th is concentrated in the liquid phase. Y has a similar chemical behavior to Yb of the heavy REEs and is concentrated in the solid phase. Th concentration corresponds to the intrusion order.

The main minerals of the two beforsites are dolomite and ankerite. Subordinate minerals are quartz, albite, potassium feldspar, melilite, analcime, olivine, garnet, sphene, riebeckite, phlogopite, muscovite, calcite, siderite, manganocalcite, magnesite, strontianite, apatite, barite, magnetite, hematite, pyrite, marcasite, pyrrhotite, sphalerite, galena, bastnaesite, monazite, synchysite and pyrochlore. The latter four minerals contains La, Ce, Nd and Nb.

REEs, Nb, and P have a tendency to be concentrated in the central beforsite, the northeast beforsite, and in the carbonatite dyke which emplaced in the later stage of carbonatite complex activity.

Kalkfeld Area

There are four carbonatite complexes, Osongombo, Kalkfeld, Ondurakorume and Okorusu, which are closely related in distribution and genesis to the Damarand Alkaline Province in the Damara Sequence. These are distributed along a line in order of location from southwest to northeast, and the distance between the former three complexes is approximately 15 km.

The Osongombo Diatreme is composed of volcanic breccia, beforsite, and iron ore, which intruded in this order.

The main minerals of the beforsite are dolomite and ankerite. Subordinate minerals are quartz, albite, potassium feldspar, analcime, sphene, riebeckite, aegirine, biotite, calcite, manganocalcite, siderite, strontianite, apatite, barite, zircon, hematite, and pyrochlore. rare-earth oxides, Th, Fe, and Mn have a tendency to be concentrated in the beforsite and the iron ore, which intruded in the later stage of the carbonatite activity.

necks, shallow plutonic, and deep plutonic types. The volcanic cone is regarded to be the original form of the carbonatite being least affected by erosion. The deep plutonic shape reflects strong or prolonged exposure to erosion, through which the core of the carbonatite is visible on the surface. The carbonatite of the Orange area is considered to be the shallow plutonic type. The top of the carbonatite may have eroded out.

The intrusive form and erosion level are similar to the Ondurakorume carbonatite complex located at the northeast to the Kalkfeld area (Verwoerd, 1967), which is enriched in light REEs (La, Ce and Nd), Nb and P. The geochemical tendency for concentration of REEs, Nb, P and Mn in the Orange area is considered to be similar to the Ondurakorume.

These elements are most concentrated in the two beforsites. The concentration zones of those elements are changeable on the surface, and not successive to underground. At drilling sites MJNO-1 and 2, which are situated in the outer zone of the central beforsite, the section has zone of high concentration of REEs and P at both shallow and deep sites, but these zones are not continuous.

At drilling sites of MJNO-3, 4 and 5, which are situated in the inner zone of the central beforsite, the sections have zones of high concentration of Nb at both shallow and deep sites, but the contents are not variable.

At the drilling sites, MJNO-6, 7 and 8, which are situated in the inner zone of the northeast beforsite, the sections have zones of high concentration of P and Nb at both shallow and deep sites, and the contents are not variable. There is no tendency for concentration to increase with depth. The results of the drilling survey shows no indication of distinct increase or decrease in REEs, Nb and P with depth.

The two beforsites contain rare-earth oxides with maximum values of from 2.7 to 3.2%, average contents of from 0.12 to 0.16 % at the surface, and with maximum values of from 0.4 to 2.7 %, average contents of less than 0.1 % underground. Total average contents are 0.11 to 0.15 %.

The two beforsites contain Nb with maximum values of from 0.5 to 0.6 %, average contents of from 0.08 to 0.12 % at the surface, and with maximum values of from 0.7 to 5.2 %, average contents of from 0.1 to 0.2 % underground. Total average contents are 0.09 to 0.15 %.

The northeast beforsite contains P with maximum values of 3.4 %, average contents of 0.8 % at the surface, and with maximum values of from 4.5%, average contents of from 1.2 % underground. Total average content is 1.00 %.

Kalkfeld Area

The OC of the Kalkfeld area has a diatreme form with a small exposed area of 0.3 square

1-2 Relation Between Geochemical Anomalies and Mineralization

Orange Area

REEs, Nb, Mn, Sr and P are concentrated more in the two beforsites than in other rock facies. REEs are concentrated in the outer zone of the two beforsites and reduced in the inner zone. On the other hand, Nb is concentrated in the inner zone of the two beforsites. The distribution of Nb is in distinct contrast with that of REEs. P is concentrated in the outer zone of the central beforsite, and in the northeast beforsite and its vicinity, but not concentrated in the inner zone of the central beforsite.

REEs, Nb, Mn, Sr, and P are concentrated in the sovite. Concentration of all of these contents except Sr are lower than those of the two beforsites. These elements are less concentrated in the syenites than in the two beforsites and the sovite.

The carbonatite complex is composed of syenites, sovite, two beforsites and carbonatite dykes, which intruded in this order. The geochemical survey indicated concentrations of REEs and Nb in the later stage intrusives i.e. the two beforsites and the carbonatite dyke. The MQC, especially the northeast beforsite (Mcb1), is enriched in apatite and pyrochlore. This mineralogy corresponds to the geochemical concentrations of P and Nb. The beforsite is rich in Nb and P compared with that of the Kalkfeld area.

Kalkfeld Area

REEs, Th, Mn, Fe and P are concentrated in the carbonatite complex. REEs, Th, Mn, Fe are concentrated in the beforsite. P is concentrated in the volcanic breccia.

The Osongombo Diatreme is composed of volcanic breccia, beforsite and iron ore, which intruded in this order. The geochemical survey indicates concentrations of light REEs (La, Ce and Nd), Th, Mn and Fe in the beforsite and the iron ore which were formed in the later stage of the intrusion.

The carbonatite complex contains carbonates, iron oxide minerals, and pyrochlore. This mineralogy is corresponds to the geochemical distribution of these elements.

The beforsite is rich in the middle REEs (Sm, Eu and Tb), Th, Mn and Fe, compared with those of the Orange area.

1-3 Potentialities for Ore Deposits

Orange Area

Carbonatites are divided by the intrusive forms into diatremes, cone sheets, plutonic plugs and ring dykes. The carbonatite of the Orange area is a manifest as a plutonic plug form. The exposure of the complex is about 2 km^2.

On the other hand, carbonatites are divided by erosion level into volcanic cones, volcanic km. Erosion level is shallow, since erosion indicates a volcanic neck (Verwoerd, 1967).

Compared with complexes in its vicinity, erosion of the OC is shallow, that of the Ondurakorume complex is intermediate, that of the Kalkfeld complex is deep, and that of the MQC is intermediate, based on intrusive forms and erosion levels of the carbonatite bodies.

Light REEs, Th and Mn are concentrated in the OC. In particular, these elements are concentrated in the beforsite and the iron ore formed in the later stage of OC intrusive activity. But the are of distribution of the iron ore is narrow.

The beforsite contains rare-earth oxides with a maximum of 1.36 %, an average content of 0.28 %, and the iron ore contains Nb with a maximum of 0.54 %, an average content of 0.29 %. The beforsite contains Th with a maximum of 0.23 %, an average content of 0.04 %, and the iron ore contains Th with a maximum of 0.23 %, an average content of 0.09 %. The beforsite contains Mn with a maximum of 2.99 %, an average content of 1.37 %, and the iron ore contains Mn with a maximum of 4.03 %, an average content of 3.79 %. The beforsite contains Fe with a maximum of 32.50 %, an average content of 10.86 %, and the iron ore contains Fe with a maximum of 37.82 %, at an average content of 34.85 %.

rare-earth oxides are more concentrated in the beforsite than in the iron ore, but Th, Mn and Fe are more concentrated in the iron ore than in the beforsite.

Compared with the two beforsites of the Orange area, the beforsite of the Kalkfeld area is richer in REEs, Nb and Sr than those of the of Orange area. In particular, middle REEs (Sm, Eu and Tb), are more concentrated in the beforsite of the Kalkfeld area than in those the Orange area. Th, Ta, Mn, and Fe are more concentrated in the beforsite of the Kalkfeld area than those of the Orange area. U and Zr contents in the beforsites of the Orange area are same as that of the Kalkfeld area. P is more concentrated in the northeast beforsite of the Orange area than in the central beforsite of the Orange area and the beforsite of the Kalkfeld are.

Chapter 2 Recommendations for the Future

This project is the first fundamental and systematic attempt to study to carbonatites by geochemical and drilling surveys in Namibia. This survey revealed the outline of the distribution of such valuable elements as lanthanides.

Based on the survey results of the Orange and Kalkfeld areas, recommendations for the future are summarized as follows.

The Orange and Kalkfeld areas are underlain by carbonatite complexes which contain REEs, Nb, and P as valuable elements. In particular, the beforsite of the carbonatite complex, which consists of dolomitic carbonatite, concentrates these elements. Therefore, the beforsite has a significance for exploration.

The central and northeast beforistes in the Orange area contain 0.12 % and 0.15 % of rare–earth oxides, 0.09 % and 0.15 % of Nb, respectively. The northeast beforsite contains 1.00 % of P. The beforsite in the Kalkfeld area contains 0.28 % of rare–earth oxides, 0.04 % of Th, and 10.86 % of Fe.

On the other hand, current carbonatite mines, such as Baiyun Obo, China, and Mountain Pass, USA, have rare–earth oxides of 5 to 13 % (Kamitani, 1988). Compared with these, the MQC and the OC have relatively low contents of rare–earth oxides.

The Ondurakorume carbonatite, contains 0.28 % of total rare–earth oxides, 0.24 % of Nb_2O_5, and 7 % of P_2O_5 (Verwoerd, 1967). This carbonatite is manifest as a plutonic plug and has an intermediate exposed area. The erosion level is intermediate, since erosion indicates a shallow plutonic body. The Kalkfeld carbonatite contains 0.2 to 0.8 % of Ce, 0.05 to 0.5 % of La, 0.1 to 0.25 % of Nd, and 7 to 8 % of P_2O_5. This carbonatite is manifest as a concentric ring and has a large exposed area. Erosion is deep, since erosion indicates a deep–plutonic body.

The MQC in the Orange area has an intermediate exposed area, which is a characteristic of mid–level erosion of a shallow plutonic plug. The underground concentration of the REEs is similar to the Kalkfeld carbonatite, based on the above–mentioned formation form and the drilling survey, and shows no indication of sufficient enrichment in REEs elements at depth.

Therefore, further exploration in the Orange and Kalkfeld areas should be done, following an increase in economic demand for these elements, to evaluate the ore reserves by more a detailed drilling survey.

References

References

Advertising Supplement to Mining Journal (1992): Namibia, London, 23 Oct., 16pp.

Anhaeusser, C.R and Maske, S. eds.(1985): Geological Map of Southern Africa. Geological Society of South Africa.

Bernasconi, A. (1986): The Marinkas Kwela alkaline intrusive – a porphyry molybdenum system of cambrian age in southern South West Africa / Namibia. In Anhaeusser,C.R. and Maske,S. eds., Mineral Deposits of Southern Africa. Vol.I, Geol. Soc. S. Afr, Johannesburg, S.A., 1587–1591.

Blignault, H.J. (1977): Structural–mrtamorphic imprint on part of the Namaqua mobile belt in South West Africa. Bull. Precambrian Res. Unit. Univ. Cape Town, 27, 197p.

Dendle, P.K. (1971): Kheis Project (South West Africa), Kawagganek Sub–Project. Report on Reconnaissance Investigation on the Kwagganek Prospectng Grant– No.M46/3/369, Bulletin No.1510, Falconbridge Explorations Ltd., 8pp.

Diehl, B.J.M (1990): Thorium, Yttrium, and Rare Earth Elements. Geological Survey of Namibia, Mineral Resource Series, 19pp.

Geological Survey of Namibia (1974a): Aeromagnetic Survey, Omaruru 2016CC, 1 : 50,000.

Geological Survey of Namibia (1974b): Aeromagnetic Survey, Otjiwarongo, 1 : 250,000.

Geological Survey of Namibia (1984a): Aeromagnetic Survey, Alexander Bay, 1 : 250,000.

Geological Survey of Namibia (1984b): Aeromagnetic Survey, Alexander Bay 2817AB, 1 : 50,000.

Geological Survey of South Africa (1980): Stratigraphy of South Africa. Hand Book 8, Part 1: Lithostratigraphy of the Republic of South Africa, South West Africa / Namibia and the Ripublics of Bophuthatswana, Transkei and Venda. compiled by Kent, L.E., Geological Survey of South Africa, 690pp.

Gittins, J. (1989): The Origin and Evolution Carbonatite Magmas. In Carbonatites, K. Bell ed., Unwin Hyman, 580–600.

Gold, D.P. (1966): The average and typical chemical composition of carbonatite. Miner. Soc. India. IMA Volume, 83–91.

Hamilton, D.L., Bedson, P. and Esson, J. (1989): The behavior of Trace Elements in the Evolution of Carbonatites. In Carbonatites, K. Bell ed., Unwin Hyman, 405–427.

Heath, D.C. (1973): Fish River Lead–Zinc Exploration Report for the period June 1972 to Dec. 1972, Karasburg District, South West Africa, Prospecting Grand– No.M46/3/314Rio Tinto Exploration(PTY.) Ltd., 4pp.

Ishihara, S. (1991): Carbonitoid Series and REE–Y–Zr–Ta–Nb Mineralization.Proceedings of International Conference on Rare–Earth Minerals and Minerals for Electronic Uses, Princeton of University, 527–532.

Japan Mining Engineering Center for International Cooperation (1992a): Report on the Mineral

Exploration in Namibia by Landsat Data Interpretation (in Japanese). 33pp.

Japan Mining Engineering Center for International Cooperation (1992b): Report on the Mineral Exploration in Namibia by Literature Research (in Japanese). 33pp.

Kamitani, M. (1988): Resource of rare metals - 2.Rare earth (in Japanese), Chishitu News, Geological Survey of Japan, No.405, 26-51.

Kröner, A. and Blignault, H.J. (1976): Towards a definition of some tectonic and igneous provinces in western South Africa and southern South West Africa. Trans. geol. Soc. S. Afr., 79, 232-238.

Mariano, A.N. (1989): Nature of Economic Mineralization in Carbonatites and Related Rocks. In Carbonatites, K. Bell ed., Unwin Hyman, 149-176.

Middlemost, E.A.K. (1974): Petrogenetic Model for the origin of carbonatites. Lithos 7, p275-278.

Miller, McG. and Schalk, K.E.L., eds (1980): Geological Map of Namibia. 1: 1,000,000.

Namibia Foundation (1993): Focus on Mining, Namibia Brief, No.17, Sep., 88pp.

Rio Tinto Exploration Ltd. (1973): Exploration report for the period June 1972 to December 1972. By D.C. Heath. Unpublished internal report.

Sakamaki, Y. and Kamitani, H. (1988a): Rare Metal Resources, Rare Earth(1), Geological News, No. 404, 17-29.

Sakamaki, Y. and Kamitani, H. (1988b): Rare Metal Resources, Rare Earth(2), Geological News, No. 405, 26-51.

Schommarz, R.E. (1988): Preliminary Report on the Marinkas Quelle Carbonatite Complex. Unpublished report., Geological Survey of Namibia, 9pp.

Smithies, R.H. (1990): Geological Report Anorogenic Alkaline Complex and Associated Hydrothermal Systems on the Farm Kanabeam. GENMIN Mineral Resources, Open file No.M46/3/1802, Geological Survey of Namibia, 11pp.

Söhnge,P.G. and De Villiers, J. (1948): The Kuboos Pluton and its associated line of intrusives. Trans. Geol. Soc. S. Afr., 51, 1-31.

Stacey, J.S. and Kramers, J.D. (1975): Approxima of terrestrial lead isotope evolution by a two-stage model. Earth Planet. Sci. Letters, 26, 207-221.

Suwa K. (1981): Petrology of Carbonatite (in Japanese). Mining Geology, 31, 457-465.

Takenouchi, S. (1973a): Carbonatite Ore Deposits(I) (in Japanese). Mining Geology, 23, 367-382.

Takenouchi, S. (1973b): Carbonatite Ore Deposits(II) (in Japanese). Mining Geology, 23, 437-451.

Takenouchi, S. (1981): Carbonatite deposits (in Japanese). Mining Geology, 31, 415-420.

Verwoerd W.J. (1965): Note on the Economic Geology of south West African Carbonatite Occurrences.Geological Survey of Namibia, Open File Report EG076, 2pp.

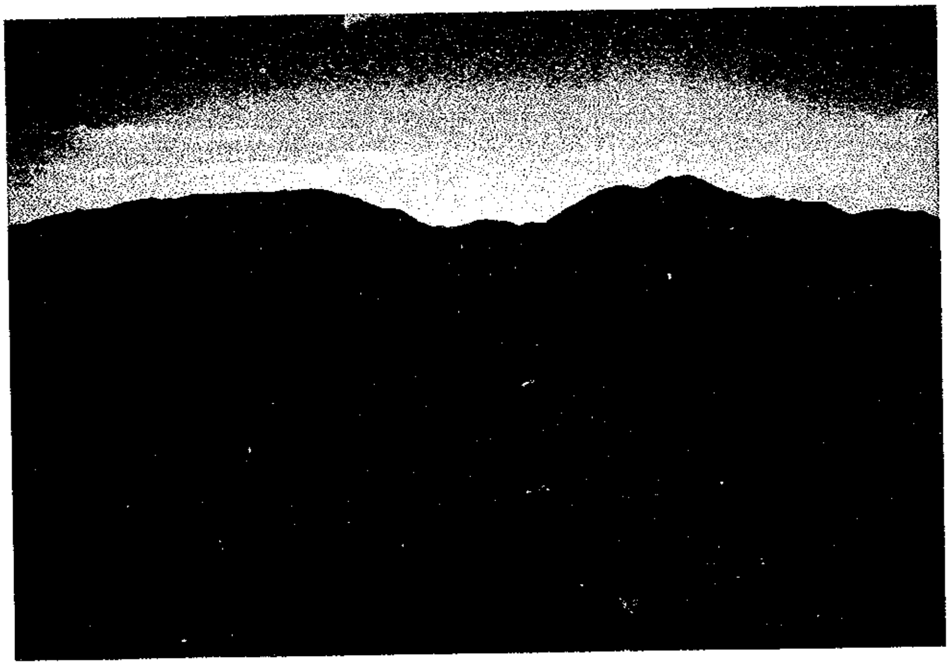
Verwoerd, W.J. (1967): The Carbonatites of the South Africa and South West Africa. Geological Survey of South Africa, Handbook 6, 452pp.

Verwoerd, W.J. (1986): Mineral Deposits Associated with Carbonatites and Alkaline Rocks. In Mineral Deposits of Southern Africa, Vol.II, C.R. Anhaeusser and S. Maske eds., Geological Society of South Africa, 2173-2191.

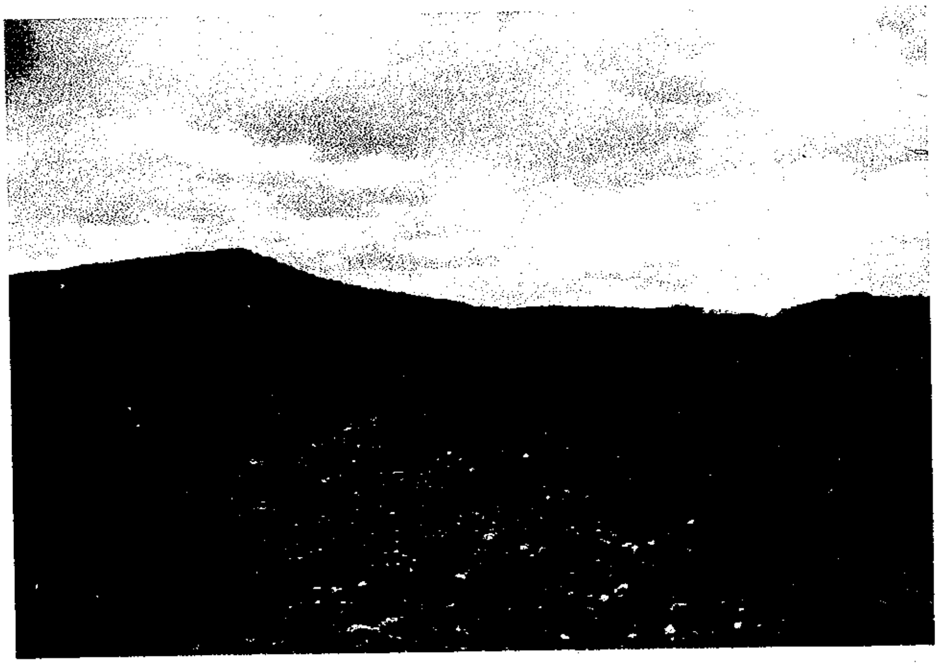
Appendices

A–1 Photographs of Survey Area

A-1 Photographs of the Survey Area



Overlooking of the Orange Area



Overlooking of the Kalkfeld Area

A-1 Photographs of Survey Areas

A–2 Photomicrographs

Abbreviation

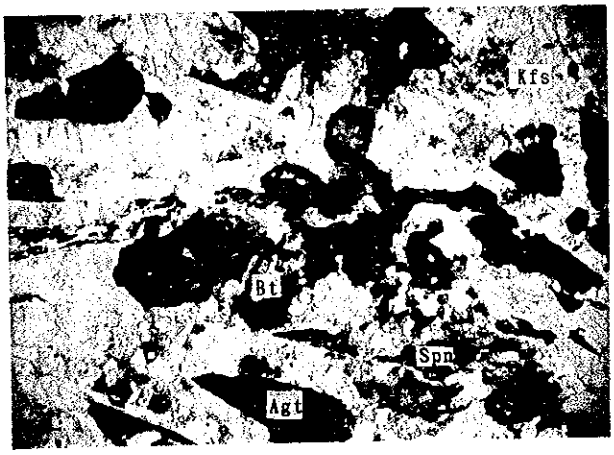
Minerals

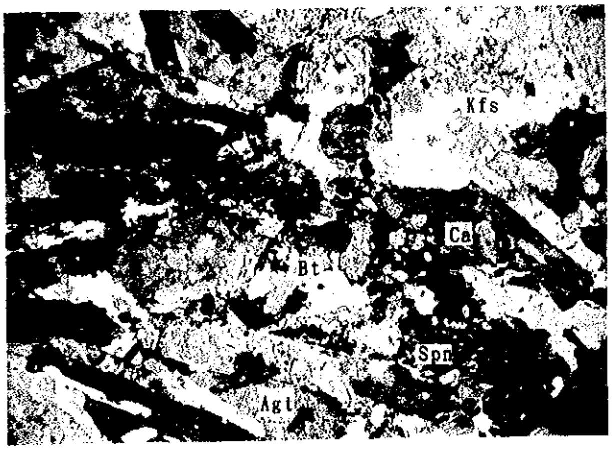
Qtz:	quartz
Pl:	plagioclase
Kfs:	orthoclase
Spn:	sphene
Agt:	aegirine
Cpx:	clinopyroxene
Bt:	biotite
Phl:	phlogopite
Rbk:	riebeckite
Cal:	calcite
Dol:	dolomite
Ap:	apatite
Pyro:	pyrochlore
Po:	pyrrhotite

Open nicol 0.7mm

Cross nicol 0.7mm

Sample No. A 90
Formation Namaqua Metamorphic Complex
Rock name Gneiss
Locality The Orange Area

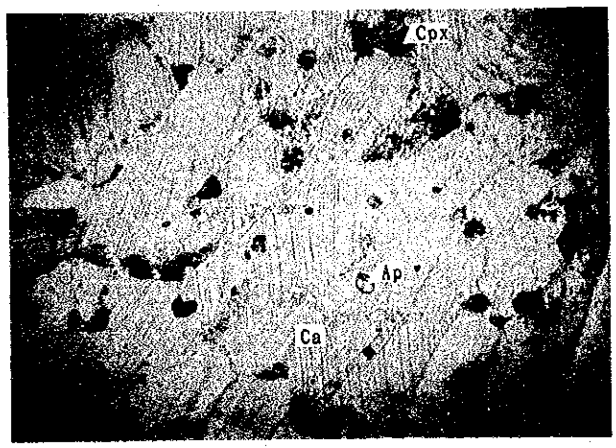




Open nicol 0.7mm

Cross nicol 0.7mm

Sample No. I 80
Formation Marinkas Quelle Carbonatite Complex
Rock name Syenite
Locality The Orange Area



Open nicol 0.7mm

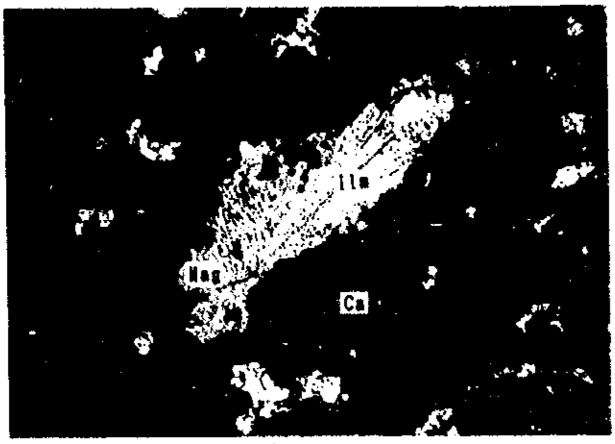
Cross nicol 0.7mm

Sample No. R 20
Formation Damara Sequence
Rock name Calcite Marble
Locality The Kalkfeld Area

A–2 Photomicrographs (1)

Open nicol 0.5mm

Sample No. E 50
Formation Marinkas Quelle Carbonatite Complex
Rock name Beforiste
Locality The Orange Area

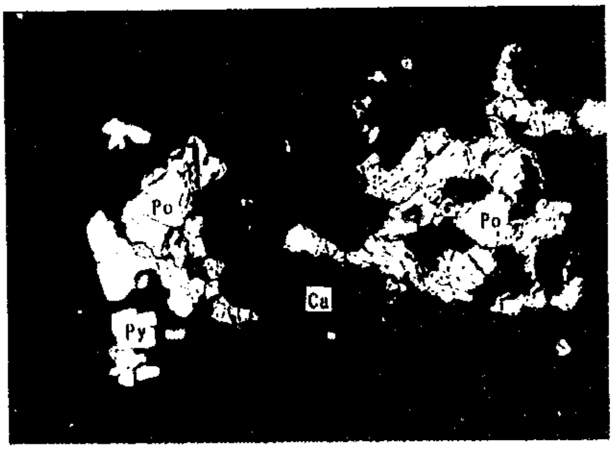


Open nicol 0.5mm

Sample No. Ea 51(No.2)
Formation Marinkas Quelle Carbonatite Complex
Rock name Beforiste
Locality The Orange Area

Open nicol 0.5mm

Sample No. N 12
Formation Marinkas Quelle Carbonatite Complex
Rock name Leuco syenite
Locality The Orange Area

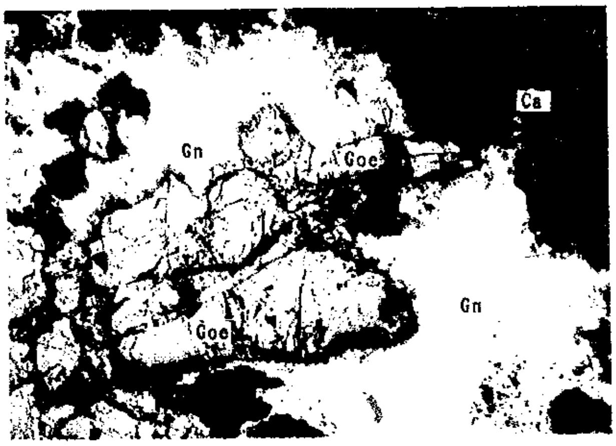


Open nicol 0.5mm

Sample No. Na 12
Formation Marinkas Quelle Carbonatite Complex
Rock name Porphyritic Syenite
Locality The Orange Area

Open nicol 0.5mm

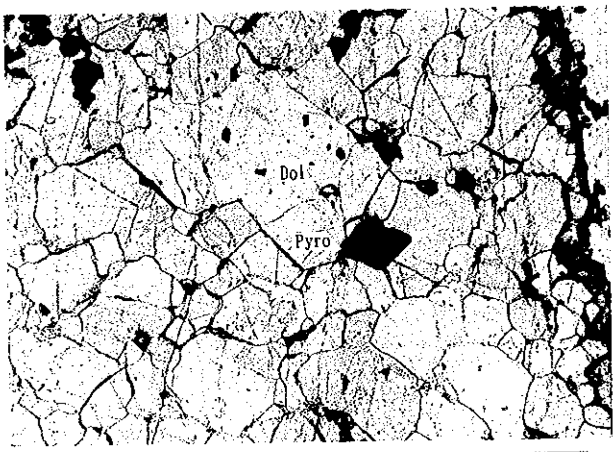
Sample No. Sa40
Formation Osongomo Diatreme
Rock name Beforsite
Locality The Kalkfeld Area



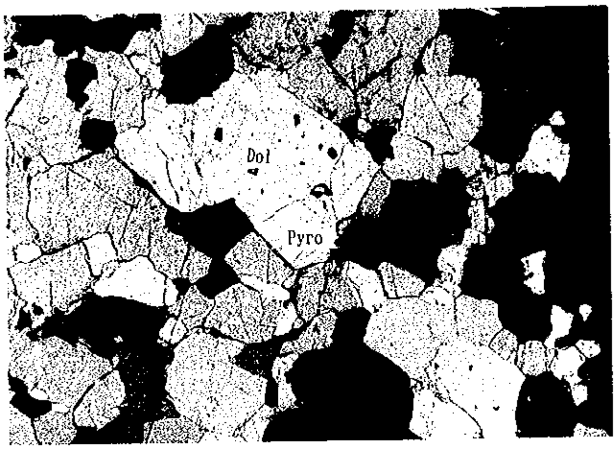
Open nicol 0.5mm

Sample No. U 45
Formation Osongomo Diatreme
Rock name Beforsite
Locality The Kalkfeld Area

A–2 Photomicrographs (2)

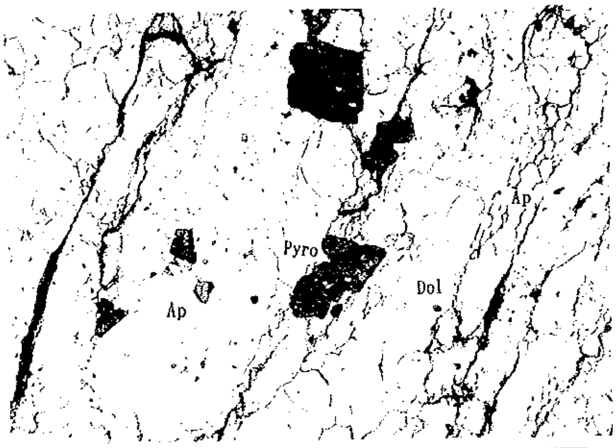


Open nicol 0.7mm

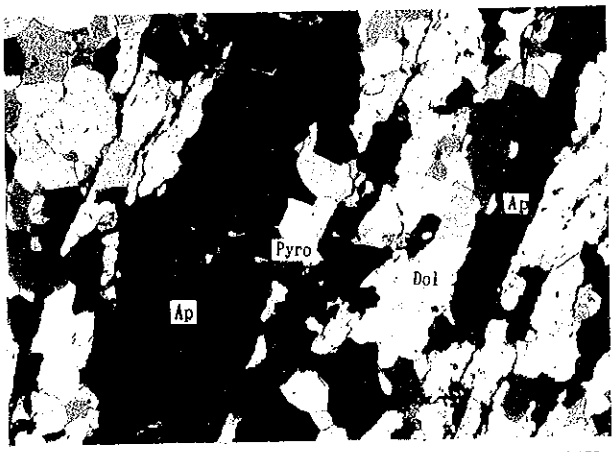


Cross nicol 0.7mm

Sample No. Da415
Formation Central beforsite body of the Marinkas Quelle Carbomatite Complex
Rock name pyroclore bearing beforsite
Locality The Orange Area

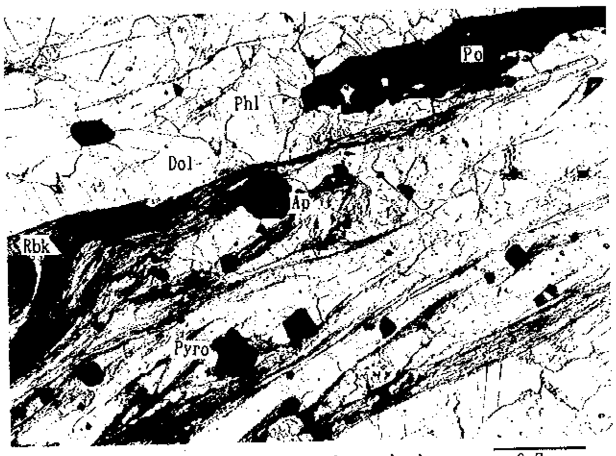


Open nicol 0.7mm

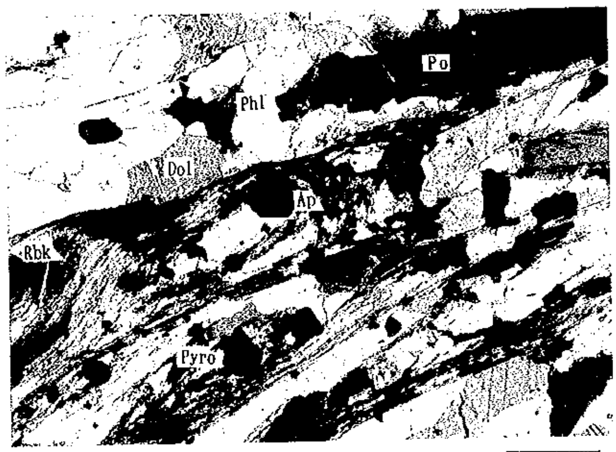


Cross nicol 0.7mm

Sample No. Lc415
Formation Northeast beforsite body of the Marinkas Quelle Carbonatite Complex
Rock name pyroclore bearing beforsite
Locality The Orange Area



Open nicol 0.7mm

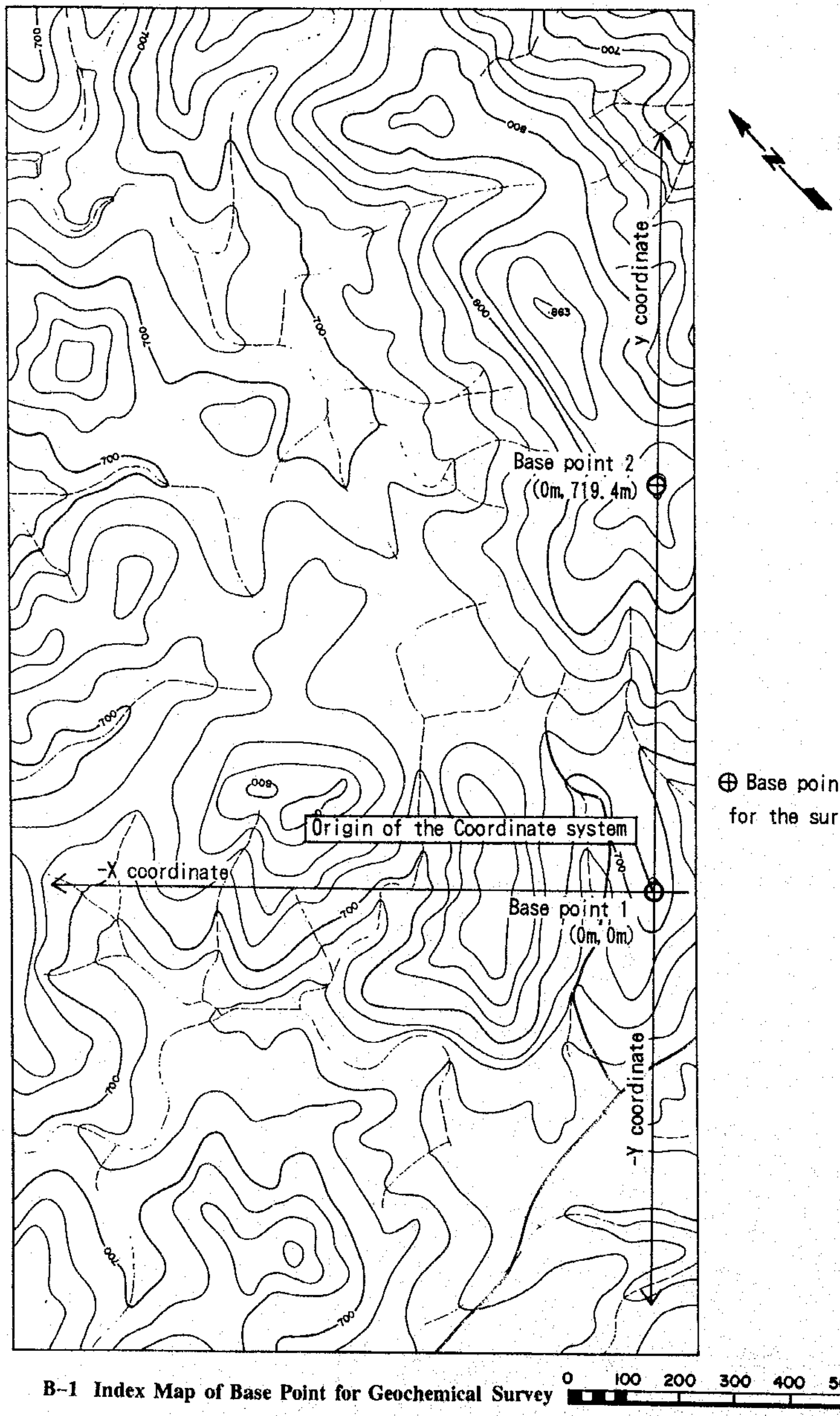


Cross nicol 0.7mm

Sample No. 6T-2 (MJNO-2 117.0m)
Formation Northeast beforsite body of the Marinkas Quelle Carbonatite Complex
Rock name pyroclore bearing beforsite
Locality The Orange Area

A-2 Photomicrographs (3)

B–1 Index Map and List of Samples from the Orange Area



⊕ Base point
for the surveying

B-1 Index Map of Base Point for Geochemical Survey

Abbreviation in the list

Minerals

- Qtz: quartz
- Fd: feldspar
- Ne: nepheline
- Hbl: Hornbende
- Agt: aegirine
- Aug: augite
- Px: pyroxene group mineral
- Phl: phlogopite
- Bt: biotite
- Cal: calcite / calcitic
- Dol: dolomite / dolomitic
- Ank: ankerite / ankeritic
- Ap: apatite
- Mag: magnetite
- Hem: hematite
- Gln: galena

Structure

- Bre.: Brecciated / breccia

Rock code

- Ktd: trachyte dyke (Post- to Syn- Karoo sequence)
- Kdd: dolerite dyke (Post- to Syn- Karoo sequence)
- Mgr: granophyre and micro granite (MQC)
- Mcd: carbonatite dyke (MQC)
- Mfn: massive fenite (MQC)
- Mcb: beforsite (MQC)
- Mcb1: Central beforsite (MQC)
- Mcb2: Northeast beforsite (MQC)
- Msu: syenite (undifferentiated) (MQC)
- Msr: reddish porphyritic nepheline syenite (MQC)
- Msm: micro nepheline syenite sill (MQC)
- Mcs: sovite (MQC)
- Msp: porphyritic nepheline syenite (REE bearing) (MQC)
- Msw: grey-white porphyritic syenite (MQC)
- Nsh: shale, quartzite, and grit (Nama group)
- Ngn: quartz-feldspar gneiss (Namaqua metamorphic complex)

B-1 List of Samples from the Orange Area (1)

No.	Sample No.	X m	Y m	Depth m	Rock Name	Rock Code	Analytical methods Year	REE	WR	TS	PS	PO	XR	EA	IA	PA
	Surface															
1	A 100	-1162.5	-750.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
2	A 300	-900.0	-750.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
3	A 500	-600.0	-750.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
4	A 700	-300.0	-750.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
5	A 900	0.0	-750.0	-	Gneiss, Qtz-Fd	Ngn	93	○		○			○			
6	B 200	-1050.0	-600.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
7	B 400	-750.0	-600.0	-	Beforsite, Ank	Mcd	93	○					○			
8	B 500	-600.0	-600.0	-	Beforsite vein, Hbl?	Mcd	93	○								
9	B 600	-450.0	-625.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
10	B 700	-309.0	-600.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
11	B 800	-152.0	-600.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
12	Ba310	-850.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
13	Ba320	-800.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
14	Ba400	-750.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
15	Ba410	-700.0	-525.0	-	Syenite-albitite?	Mfn	93	○								
16	Ba420	-650.0	-525.0	-	Syenite-albitite?	Mfn	93	○								
17	Ba500	-600.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
18	Ba510	-560.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
19	Ba520	-510.0	-525.0	-	Sovite, Hbl	Mcs	93	○								
20	Ba600	-450.0	-525.0	-	Sovite	Mcs	93	○								
21	Ba610	-400.0	-525.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
22	Ba620	-350.0	-525.0	-	Sovite, Hbl-Agt	Mcs	93	○								
23	Bb400	-749.5	-487.5	-	Beforsite	Mcbl	94	○	○							
24	Bb410	-699.7	-487.5	-	Syenite, fenitised	Msu	94	○								
25	Bb420	-650.0	-487.5	-	Beforsite	Mcbl	94	○								
26	Bb500	-598.5	-487.5	-	Beforsite	Mcbl	94	○	○							
27	Bb510	-562.0	-487.5	-	Beforsite	Mcbl	94	○								
28	Bb515	-537.3	-487.5	-	Beforsite, Ank	Mcbl	94	○	○							
29	Bb520	-512.6	-487.5	-	Beforsite	Mcbl	94	○								
30	Bb525	-487.6	-487.5	-	Beforsite, Ank	Mcbl	94	○								
31	Bb600	-462.6	-487.5	-	Beforsite, Ank	Mcbl	94	○	○							
32	Bb605	-437.6	-487.5	-	Syenite	Msu	94	○								
33	C 100	-1162.5	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
34	C 300	-900.0	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
35	C 310	-850.0	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
36	C 320	-800.0	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
37	C 325	-775.0	-450.0	-	Beforsite, Ank	Mcbl	94	○								
38	C 400	-750.0	-450.0	-	Beforsite	Mcbl	93	○								
39	C 405	-725.0	-450.0	-	Beforsite, Ank	Mcbl	94	○								
40	C 410	-700.0	-450.0	-	Beforsite	Mcbl	93	○								
41	C 415	-675.0	-450.0	-	Syenite	Msu	94	○								
42	C 420	-650.0	-450.0	-	Dolerite	Kdd	94	○	○							
43	C 425	-625.0	-450.0	-	Beforsite	Mcbl	94	○								
44	C 500	-600.0	-450.0	-	Syenite, porphyritic	Mfn	93	○								
45	C 505	-575.0	-450.0	-	Beforsite	Mcbl	94	○								
46	C 510	-550.0	-450.0	-	Beforsite, Phl	Mcbl	93	○								
47	C 515	-525.0	-450.0	-	Beforsite	Mcbl	94	○								
48	C 520	-500.0	-450.0	-	Beforsite	Mcbl	93	○								
49	C 525	-475.0	-450.0	-	Beforsite	Mcbl	94	○								
50	C 600	-450.0	-450.0	-	Sovite, Hbl-Agt	Mcs	93	○								
51	C 605	-425.0	-450.0	-	Sovite, Px-Phl	Mcs	94	○								
52	C 610	-400.0	-450.0	-	Sovite, Hbl-Agt	Mcs	93	○								
53	C 620	-350.0	-450.0	-	Sovite, Hbl-Agt	Mcs	93	○								
54	C 700	-300.0	-450.0	-	Sovite, Hbl-Agt	Mcs	93	○								
55	C 800	-150.0	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
56	C 900	0.0	-450.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
57	Ca300	-900.0	-375.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
58	Ca310	-850.0	-375.0	-	Beforsite	Mcbl	93	○								
59	Ca315	-825.0	-375.0	-	Beforsite, Hbl-Agt-Phl-Ank	Mcbl	94	○								
60	Ca320	-800.0	-375.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
61	Ca325	-775.0	-375.0	-	Beforsite, Hbl-Agt-Phl-Ank	Mcbl	94	○								
62	Ca400	-750.0	-375.0	-	Syenite, porphyritic, banded	Mfn	93	○		○			○			
63	Ca405	-725.0	-375.0	-	Beforsite, Hbl-Phl	Mcbl	94	○								
64	Ca410	-700.0	-375.0	-	Beforsite, Phl-Agt-Hbl-Dol, vei	Mcbl	93	○		○			○			
65	Ca415	-675.0	-375.0	-	Beforsite	Mcbl	94	○								
66	Ca420	-650.0	-375.0	-	Beforsite	Mcbl	93	○								
67	Ca425	-625.0	-375.0	-	Beforsite	Mcbl	94	○								
68	Ca500	-600.0	-375.0	-	Beforsite	Mcbl	93	○					○			
69	Ca505	-576.6	-376.0	-	Beforsite	Mcbl	94	○								
70	Ca510	-550.0	-376.0	-	Beforsite	Mcbl	93	○								
71	Ca515	-526.6	-375.0	-	Beforsite	Mcbl	94	○								
72	Ca520	-499.7	-376.5	-	Beforsite	Mcbl	93	○								
73	Ca525	-476.4	-375.0	-	Beforsite	Mcbl	94	○								
74	Ca600	-448.0	-375.0	-	Beforsite	Mcbl	93	○								
75	Ca605	-400.0	-375.0	-	Beforsite	Mcbl	94	○								
76	Ca620	-350.0	-375.0	-	Syenite, porphyritic	Msu	93	○		○			○			
77	Ca700	-300.0	-375.0	-	Syenite - albitite ?	Msu	93	○								
78	Ca710	-250.0	-375.0	-	Sovite, Agt-Phl-Hbl	Mcs	93	○								

B-1 List of Samples from the Orange Area (2)

No.	Sample No.	X m	Y m	Depth m	Rock Name	Rock Code	Analytical methods Year	REE	WR	TS	PS	PO	XR	EA	IA	PA
79	Ca720	-210.0	-375.0	-	Sovite, Agt-Phl-Hbl	Mcs	93	○								
80	Cb310	-850.0	-337.5	-	Beforsite	Mcbl	94	○								
81	Cb315	-825.0	-337.5	-	Beforsite, Phl-Px	Mcbl	94	○	○							
82	Cb325	-775.0	-337.5	-	Beforsite, Ank	Mcbl	94	○								
83	Cb400	-747.0	-335.5	-	Fenite, Agt-Phl	Mfn	94	○								
84	Cb405	-725.0	-337.5	-	Beforsite, Phl-Px	Mcbl	94	○								
85	Cb410	-698.0	-337.5	-	Beforsite	Mcbl	94	○								
86	Cb415	-678.0	-337.5	-	Beforsite	Mcbl	94	○	○							
87	Cb420	-650.0	-337.5	-	Beforsite	Mcbl	94	○								
88	Cb425	-625.0	-332.5	-	Beforsite	Mcbl	94	○								
89	Cb500	-600.0	-337.5	-	Beforsite	Mcbl	94	○	○							
90	Cb510	-550.0	-337.5	-	Beforsite	Mcbl	94	○								
91	Cb515	-525.0	-337.5	-	Beforsite, Phl-Agt	Mcbl	94	○	○							
92	Cb520	-500.0	-337.5	-	Beforsite	Mcbl	94	○								
93	Cb525	-475.0	-337.5	-	Beforsite	Mcbl	94	○								
94	Cb600	-450.0	-342.5	-	Beforsite	Mcbl	94	○	○							
95	Cb605	-425.0	-337.5	-	Beforsite, Ank	Mcbl	94	○								
96	Cb610	-400.0	-337.5	-	Beforsite	Mcbl	94	○								
97	Cb615	-375.0	-337.5	-	Beforsite, Ank	Mcbl	94	○	○							
98	Cb620	-350.0	-337.5	-	Syenite, Agt-Hbl, fenitised	Msu	94	○								
99	Cc310	-850.0	-412.5	-	Gneiss, Qtz-Fd, fenitised	Ngn	94	○								
100	Cc315	-825.0	-412.5	-	Beforsite, Px-Hbl	Mcbl	94	○	○							
101	Cc320	-800.0	-413.5	-	Beforsite	Mcbl	94	○								
102	Cc325	-775.0	-412.5	-	Beforsite, Ank	Mcbl	94	○								
103	Cc400	-746.0	-412.5	-	Beforsite	Mcbl	94	○	○							
104	Cc405	-725.0	-412.5	-	Beforsite, Hbl-Agt-Phl	Mcbl	94	○								
105	Cc410	-700.0	-412.5	-	Fenite	Mfn	94	○								
106	Cc415	-675.0	-412.5	-	Beforsite	Mcbl	94	○	○							
107	Cc420	-650.0	-412.5	-	Beforsite, Ap	Mcbl	94	○								
108	Cc425	-627.0	-415.5	-	Beforsite, Phl	Mcbl	94	○								
109	Cc500	-601.0	-409.5	-	Beforsite	Mcbl	94	○	○							
110	Cc505	-575.0	-412.5	-	Beforsite, Agt-Phl	Mcbl	94	○								
111	Cc510	-550.0	-412.5	-	Beforsite	Mcbl	94	○			○		○			
112	Cc515	-525.0	-412.5	-	Beforsite	Mcbl	94	○	○							
113	Cc520	-500.0	-412.5	-	Beforsite	Mcbl	94	○								
114	Cc525	-475.0	-412.5	-	Syenite, Agt-phl	Msu	94	○								
115	Cc600	-448.0	-394.5	-	Beforsite	Mcbl	94	○	○							
116	Cc605	-425.0	-412.5	-	Beforsite, Ank	Mcbl	94	○								
117	Cc610	-400.0	-412.5	-	Beforsite	Mcbl	94	○								
118	D 100	-1162.5	-300.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
119	D 200	-1067.7	-300.0	-	Beforsite vein, Phl-Agt-Hbl	Mcd	93	○		○			○			
120	D 220	-950.0	-300.0	-	Gneiss, Qtz-Fd	Ngn	93	○								
121	D 300	-909.0	-300.0	-	Syenite - albitite	Msu	93	○								
122	D 305	-875.0	-300.0	-	Beforsite	Mcbl	94	○								
123	D 310	-850.0	-300.0	-	Beforsite	Mcd	93	○					○			
124	D 400	-747.0	-300.0	-	Beforsite	Mcbl	93	○								
125	D 405	-725.0	-300.0	-	Beforsite	Mcbl	94	○								
126	D 410	-700.0	-300.0	-	Beforsite	Mcbl	93	○								
127	D 415	-675.0	-300.0	-	Beforsite	Mcbl	94	○								
128	D 420	-650.0	-300.0	-	Beforsite	Mcbl	93	○								
129	D 500	-600.0	-300.0	-	Beforsite	Mcbl	93	○								
130	D 505	-525.0	-300.0	-	Beforsite	Mcbl	94	○								
131	D 510	-550.0	-300.0	-	Beforsite	Mcbl	93	○								
132	D 515	-525.0	-300.0	-	Beforsite, Ank	Mcbl	94	○								
133	D 520	-500.0	-300.0	-	Beforsite	Mcbl	93	○								
134	D 525	-475.0	-300.0	-	Beforsite, Ank	Mcbl	94	○								
135	D 600	-450.0	-300.0	-	Beforsite	Mcbl	93	○								
136	D 605	-425.0	-300.0	-	Beforsite, Ank	Mcbl	94	○								
137	D 610	-400.0	-300.0	-	Beforsite	Mcbl	93	○								
138	D 615	-375.0	-300.0	-	Beforsite, Ank	Mcbl	94	○								
139	D 620	-350.0	-300.0	-	Beforsite	Mcbl	93	○								
140	D 700	-300.0	-300.0	-	Beforsite	Mcbl	93	○								
141	D 705	-275.0	-300.0	-	Beforsite, Ank	Mcbl	94	○								
142	D 710	-250.0	-300.0	-	Sovite, Phl-Hbl, banded	Mcs	93	○								
143	D 720	-200.0	-300.0	-	Sovite, Px-Hbl	Mcs	93	○								
144	D 800	-150.0	-300.0	-	Gneiss, Qtz-Fd, fenitised	Ngn	93	○								
145	Da220	-950.0	-225.0	-	Syenite - albitite	Msu	93	○								
146	Da300	-900.0	-225.0	-	Gneiss, Qtz-Fd, fenitised	Ngn	93	○	○	○			○			
147	Da305	-878.0	-225.0	-	Fenite, Agt	Mfn	94	○								
148	Da310	-850.0	-225.0	-	Syenite, bre.	Msu	93	○								
149	Da320	-800.0	-205.0	-	Beforsite, banded	Mcbl	93	○	○	○			○			
150	Da400	-750.0	-225.0	-	Beforsite, Agt	Mcbl	93	○								
151	Da405	-724.9	-225.0	-	Beforsite	Mcbl	94	○								
152	Da410	-702.1	-227.2	-	Beforsite	Mcbl	93	○								
153	Da415	-675.0	-227.0	-	Beforsite, Ap	Mcbl	94	○			○		○	○	○	
154	Da420	-649.5	-226.7	-	Beforsite	Mcbl	93	○								
155	Da425	-625.0	-230.0	-	Beforsite	Mcbl	94	○								
156	Da500	-600.0	-225.0	-	Beforsite	Mcbl	93	○				○				
157	Da505	-575.0	-225.0	-	Beforsite, Ank	Mcbl	94	○								