REPORT
ON
THE MINERAL EXPLORATION
IN
THE ORANGE AND KALKFELD AREAS, THE REPUBLIC OF NAMIBIA

PHASE II

MARCH, 1995

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

PREFACE

In response to the request of the Government of the Republic of Namibia, the Japanese Government decided to conduct Mineral Exploration in the Orange and Kalkfeld Areas Project and entrusted the survey to the Japan International Cooperation Agency (JICA) and the Metal Mining Agency of Japan (MMAJ).

The JICA and MMAJ sent to the Republic of Namibia a survey team headed by Mr. Yukuo Kinryu from 13 August to 2 November, 1994. This fiscal year is the second phase of this mineral exploration which was started in 1993.

The team exchanged views with the officials concerned in the Government of the Republic of Namibia and conducted a field survey in the Orange and Kalkfeld areas. After they returned to Japan, further studies were made and the present report was prepared.

We hope that this report will serve towards the development of the Project and contribute to the promotion of friendly relations between our two countries.

We wish to express our deep appreciation to the officials concerned in the Government of the Republic of Namibia for their close cooperation extended to the team.

February 1995

Kimio FUJITA
President
Japan International Cooperation Agency

Takashi ISHIKAWA
President
Metal Mining Agency of Japan

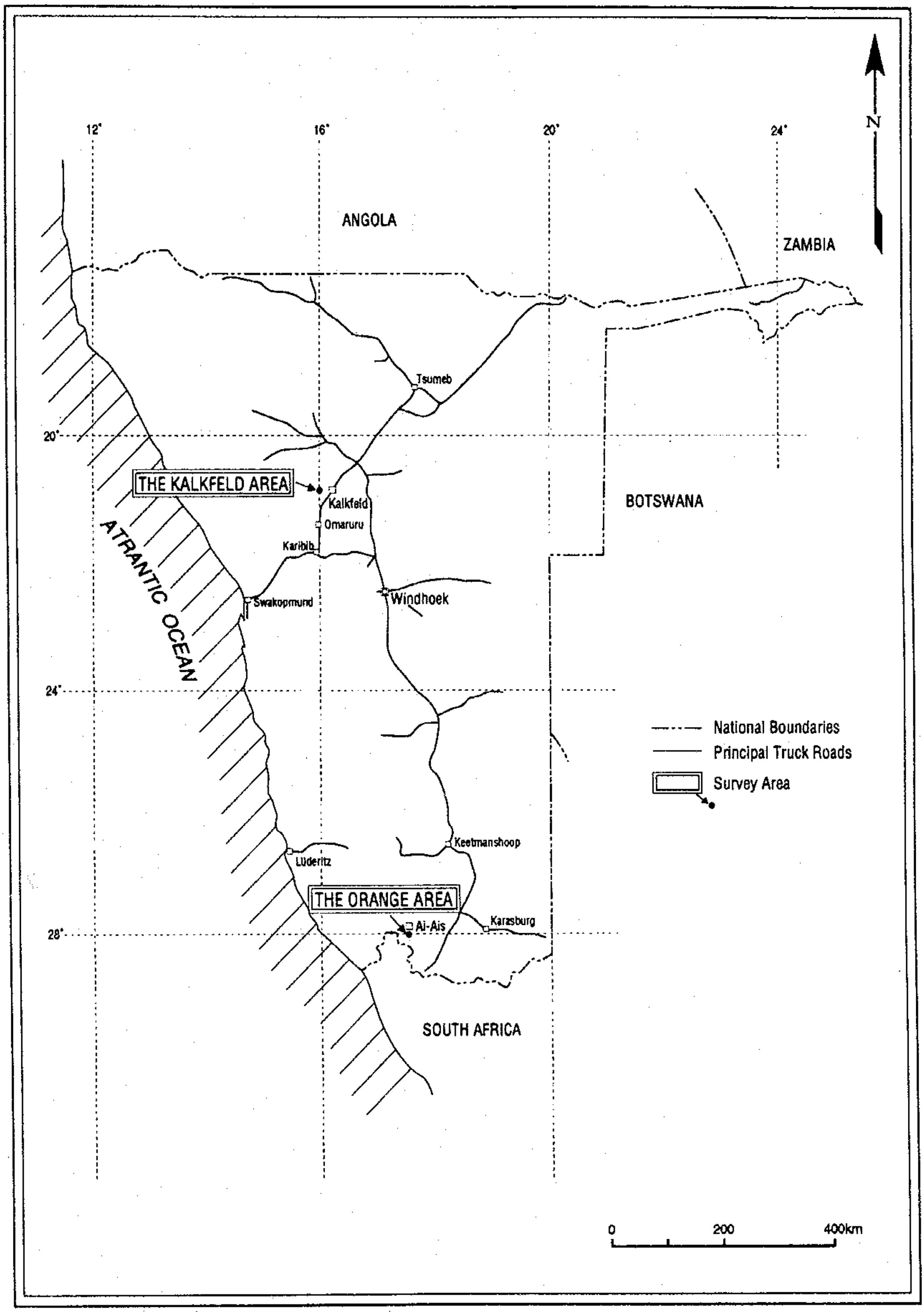

Fig. I-1-1 Location Map of the Survey Areas

Summary

This survey was carried out to clarify the geology and related mineralization, and to explore for new ore deposits in the Orange and Kalkfeld areas, the Republic of Namibia.

In 1993, the Phase I Survey, based on the literature research and geochemical survey, was conducted and revealed high potential zones of mineralization. In 1994, the Phase II Survey, based on the geochemical and drilling survey, was conducted in the central and northeast beforsite bodies in the Orange area, which were extracted by the Phase I Survey. The results by these surveys in the Orange area are as follows:

The Orange area is underlain by Namaqua Metamorphic Complex of Precambrian age and Nama Group of Cambrian age. These basement rocks are intruded by a carbonatite complex which is called Marinkas Quelle Carbonatite Complex (MQC).

The MQC is located along Kuboos-Bremen tectonic line which trends northeast to southwest and is also formed at the intersection of the Kuboos-Bremen tectonic line and post-Karoo faults. The MQC manifests plutonic plug in shape. The erosion level is intermediate, because the MQC exposed through erosion indicates shallow plutonic type. Therefore the MQC continues deeply compared with other carbonatite complexes.

The MQC has four main intrusive bodies. The Syenite body, the sovite - syenite body, the central beforsite body and northeast beforsite intrude in this order.

The major minerals of the carbonatites are calcite, dolomite and ankerite. There are a variety of subordinate minerals in the carbonatites such as strontianite, apatite, barite, magnetite, shalerite, galena, bastnaesite, monazite, synchysite and pyrochlore. The latter four minerals contain a large quantity of light rare-earth elements (LREEs) and Nb. Geochemical survey indicates the concentration of LREEs, Nb, and P in the MQC. Particularly LREEs concentrate in each outer zone of two isolated beforsite bodies. Nb concentrates in each inner zone of two beforsites. P concentrates in northeast beforiste body. As compared with the carbonatite complex in the Klakfeld area, Nb and P are dominant in the MQC in the Orange area.

Drilling survey shows geochemical elements concentrate underground as on the surface. But these elements have no tendency to increase underground. Both beforsites contain total rare-earth oxides less than 0.1 %, Nb of 0.1 to 0.2 %. the northeast beforsite contains P of 0.8 to 1.2 %.

This survey is the first fundamental approach to the Namibian carbonatite by geochemical and drilling survey. This survey revealed the outline of the distribution of precious elements as lanthanoids.

But, current mined carbonatites have rare-earth oxides in 5 to 13%. As compared with this contents, the MQC has no high contents of these oxides. Also the MQC has smaller contents of

rare-earth oxides, P, and Nb than other carbonaitites explorated in Namibia.

Therefore further exploration should be done after the economical demand for these elements to evaluate the ore reserve by more detailed drilling survey.

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Part I General Remarks

Chapter 1 Introduction

1-1 Background and Purpose of the Survey

This survey is two-years project from 1993 to 1994 in the Orange and Kalkfeld areas. This year, 1994, is the second year (phase II) of this project. The potential of resource of rare-earth elements and Nb in the carbonatite complexes of both areas is judged to be significant. And more detailed survey and discovery of new deposits are expected by Namibia. Therefore, the Government of the Republic of Namibia requested to conduct the Technical Cooperation for a Mineral Exploration to the Government of Japan. The Government of Japan corresponded the request and conducted the literature search, geological survey, geochemical survey. Through these survey, survey team were dispatched and carried out the basic survey in order to explore new deposits.

1-2 Conclusions and Recommendations for the Phase II Survey

1-2-1 Conclusions of the Phase I Survey

The survey area are divided into two areas, which are the Orange area and the Kalkfeld area as shown Fig.I-1-1 and Appendix A-1. In the 1993 phase I survey, literature research and geochemical survey were conducted in both areas. Based on this survey, in the 1994 phase II survey, more detailed geochemical survey and drilling survey were concentrated in the two beforsite bodies of the Orange area by the following reasons;

1) Orange Area

The area is underlain by the Namaqua Metamorphic Complex of Precambrian age and the Nama Sequence of Cambrian age. Marinkas Quelle Carbonatite Complex (MQC) intrudes these basement rocks. The Namaqua Metamorphic Complex comprises gneiss. The Nama Sequence comprises slate, shale and quartzite. The MQC comprises beforsite, sovite, syenite, and so on. This carbonatite complex shows plutonic plug in shape. Major minerals of carbonatite are of calcite, dolomite and ankerite. Subordinated minerals are of siderite, manganocalcite, apatite, phlogopite, riebeckite, barite, magnetite, hematite, pyrite, pyrrhotite, bastnaesite, monazite, synchysite, and pyrochlore. Last four minerals contain La, Ce, Nd, and Nb. Geochemical survey indicates the concentration of La, Ce, Nd, Nb, and P in carbonatite complex. Particularly two isolated beforsite bodies and its periphery concentrate La, Ce, Nd and Nb. One of two beforsite bodies concentrates phosphorous. Compared with carbonatite in the Klakfeld area, Nb and P are dominant.

2) Kalkfeld Area

The area is underlain by the Damara Sequence of Precambrian age. The Damara Granitoids and the Osongombo Diatreme of Cambrian age intrude this basement rocks. The damara Sequence comprises marble. The Osongombo Carbonatite Diatreme (OC) comprises volcanic breccia, beforsite, and iron ore. This carbonatite shows diatreme in shape. Major minerals of carbonatite are of dolomite and ankerite. Subordinated minerals are of manganocalcite, calcite, strontianite, apatite, geothite, hematite, and pyrochlore. Iron ore and pyrochlore contain Th and Nb. Geochemical survey indicates the concentration of La, Ce, Nd, Th, Mn, Sr, and P in this diatreme. Particularly, the beforsite body concentrates La, Ce, Nd, Nb and P. Iron ore concentrates Th, Mn and Sr. Compared with carbonatite in the Orange area, Th, Mn and Sr are dominant.

1-2-2 Recommendations for the Phase II Survey

Based on the survey results above mentioned, the methods of the survey of the phase II are proposed as follows;

1) Orange Area

Two beforsite bodies of the MQC concentrate rare earth elements, but the distribution pattern is seemed to be not homogeneous because of the difference of texture and mineral assemblage in beforsite. Therefore, to clarify the horizontal distribution of rare earth elements in beforsite, It is suggested to conduct more detailed lithologic survey and geochemical survey. Furthermore, drilling survey should be done to clarify the spatial distribution pattern of rare earth elements.

2) Kalkfeld Area

Compared with the Orange area, the concentration of rare earth elements and the distribution area of beforsite are not dominant in the Kalkfeld area. Therefore, the advanced step should be planned after the interpretation of the results of phase II survey in the Orange area.

1-3 Outline of the Phase II Survey

1-3-1 Survey Area

Location of the survey area is shown in Fig.I-1-2. The outline of the work in this year is as follows.

1-3-2 Survey Objectives

It was clarified that two beforsite bodies concentrate rare earth elements, niobium, phosphorus by the phase I survey in 1993. To follow up this result and clarify more detailed distribution of these elements, geochemical survey and drilling survey were conducted. Geochemical survey handled rock sampling and catched the superficial and horizontal geochemical anomalies by several laboratory tests. Drilling survey revealed the underground geology and dispersion of geochemical anomalies.

The Outline of this survey is shown in Table I-1-1.

1-3-3 Members of the Survey

The following members were organized for this project.

Planning and Negotiation

Japanese Representative	Namibian Representative
Mr.Takahisa Yamamoto (Metal Mining Agency of Japan)	Mr.Josephat Vatanavi Mazeingo (Acting Permanent Secretary, Ministry of Mines and Energy)
Mr.Naofumi Hashimoto (Ministry of Foreign Affairs, Japan)	Dr.Brian G. Hoal (Director, Geological Survey of Namibia)
Mr.Yoichi Iida (Ministry of International Trade and Industry, Japan)	Dr.Gabriele I.C. Schneider (Chief Geologist, Geological Survey of Namibia)
Mr.Satoshi Shiokawa (Metal Mining Agency of Japan)	
Mr.Koh Naito (Japan International Cooperation Agency)	
Mr.Yoichi Okuizumi (Metal Mining Agency of Japan)	

Field Survey:

Japanese Members	Namibian Member
Mr.Yukuo Kinryu (Dowa Engineering Co.,Ltd.)	Dr.Gabriele I.C. Schneider (Chief Geologist, Geological Survey of Namibia)
Mr.Hirohide Konno (Dowa Engineering Co.,Ltd.)	
Mr.Keiichi Ikeda (Dowa Engineering Co.,Ltd.)	

Field Supervisors:

Mr. Kenichi Takahashi	(Japan International Cooperation Agency)
Mr. Haruhisa Morozumi	(Metal Mining Agency of Japan)
Mr. Yoichi Okuizumi	(Metal Mining Agency of Japan)

1-3-4 Terms of the Survey

The survey was carried as follows.

Geochemical Survey:	13 August to 21 September, 1994
Drilling Survey:	13 August to 2 November, 1994

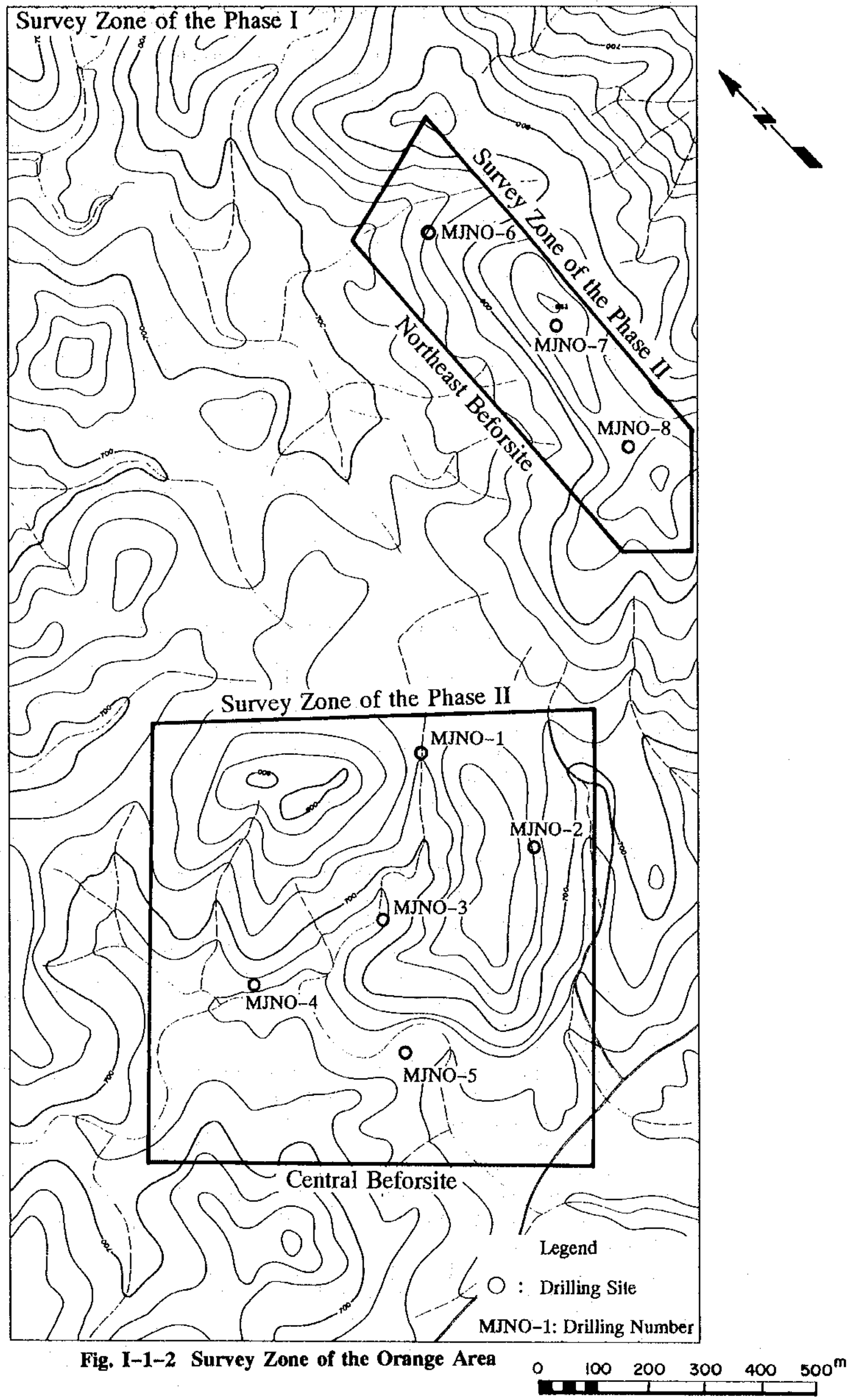


Fig. I-1-2 Survey Zone of the Orange Area

Table I-1-1 The Outline of the Survey (1)

Items	Contents		
Geochemical Survey	Survey Area		Nos. of Samples
Central Beforsite	0.8 km^2		450 samples
Northeast Beforsite	0.2 km^2		
Drilling Survey	Drilling No.	Depth	Inclination
Central Beforsite	MJNO-1	150m	-90°
	MJNO-2	150m	-90°
	MJNO-3	150m	-90°
	MJNO-4	150m	-90°
	MJNO-5	150m	-90°
Northeast Beforsite	MJNO-6	150m	-90°
	MJNO-7	150m	-90°
	MJNO-8	150m	-90°

Table I-1-1 The Outline of the Survey (2)

Laboratory Items and Analytical Elements	Contents
Geochemical Survey	
(1) Obsevation of Polished Thin Section	10 samples
(2) X-ray Diffraction Examination	5 samples
(3) Oxygen and Carbon Isotope Analysis	10 samples
(4) EPMA Analysis	5 samples
(5) Geochemical Analysis (La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Fe, Mn, Sr, P:19 elements)	450 samples
(6) Whole Rock Analysis (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, CaO Na_2O, MgO, K_2O, P_2O_5, LOI:12 elements)	100 samples
(7) Age Determination by Pb-Pb Method	1 samples
Drilling Survey	
(1) Obsevation of Polished Thin Section	10 samples
(2) X-ray Diffraction Examination	5 samples
(3) Oxygen and Carbon Isotope Analysis	8 samples
(4) EPMA Analyses	5 samples
(5) Geochemical Analysis (La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Fe, Mn, Sr, P:19 elements)	240 samples
(6) Whole Rock Analysis (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, CaO Na_2O, MgO, K_2O, P_2O_5, LOI:12 elements)	60 samples

Chapter 2 Physical Features of the Survey Area

2-1 Location and Transportation

The Orange Area is situated in Karasburg state, southern part of Namibia. The access form Windhoek, the capital of Namibia, by vehicle is as follows.

	679 km		64 km	base camp site	36 km
Windhoek ——	(Route B1) ——		(Route C10) —	Ai-Ais ———	(unpaved road)
	7 hours		1 hour		40 mins.

	20 km	
Kanabium Farm —	(unpaved road) —	Orangre area
	40 mins.	

2-2 Topography and River System

Namibia land covers 820,000 square kilometres. Namibia has twice wider areas than that of Japan, and is in contact with Angola, Zambia, South Africa and Botswana.
The topography is divided into the forest zone of northern part, the savannah zone of inland plateau, and the desert zone along the Atlantic Ocean. The forest zone and the desert zone are flat in topography. Inland plateau is hilly or mountainous. The Orange area is situated at the boundary between the savannah zone and the desert zone.

The topography of the Orange area reflects its lithology. The parts underlain by basement metamorphic rocks shows steep mountainous shape.The parts underlain by intrusive granitic rocks show gentle mountainous shape. The parts intruded by carbonatite form peaks of mountains because of relatively low weathering.

River system in the Orange area is not big. In the rainy season, river water flows, but in the dry season, the rivers dry up.

2-3 Climate and Vegetation

The climate of the survey area is hemi-arid to subtropical. The temperature is the highest in January and February, ranging 17 to 31 degrees centigrade, and is the lowest in July, ranging 6 to 18 degrees centigrade.

Capital Windhoek shows 13 °C on the average in July and 23 °C on the average in December. Annual rainfall is 600 mm/year in the forest zone, 20 mm/year in the desert zone, and 350 mm/year in the inland plateau on the average. Rainfall is many in summer, October to April, few in winter.

Vegetation is variable. The forest zone is overgrown with broad-leaved tree. The inland plateau is pasture with stunted acacia and Welwitschia. The desert zone is covered by scattered shrub, lichen and scrub.

Chapter 3 General Geology

3-1 Geology around the Survey Area

The regional geological map after Blignault and Kroner(1974) is shown in Fig.I-3-1. Carbonate complexes in the area belong to the group of alkaline intrusive rocks, which is situated along the NE-SW direction of the Kuboos-Bremen line (Kroner and Blignault,1976). The group of the alkaline rocks intrude in the Namaqua Metamorphic Complex, the Gariep group, and the Nama Sequence. Pb – Sr age of Marinkas Kwela(Quelle) syenite shows 505.88 ± 18.68 Ma (Smithies,1990).

Marinkas Quelle Carbonatite Complex, situated in the survey area, was described primary by Bilgnault (1971), and the detailed geological map was made up by Schommarz (1988).

3-2 Mineralization around the Survey Area

Verwoerd (1965,1967), Dendle (1971), Hearth (1973), Schommarz (1988) surveyed carbonatites and alkaline complex for base metals, rare metals, and radioactive elements around the Orange area.

Lead-silver veins hosted by alkaline complexes were mined at the small scale(Blignault,1979; Rio Tint,1973; Smithies,1990). No large-scale mine has been operated around the survey area.

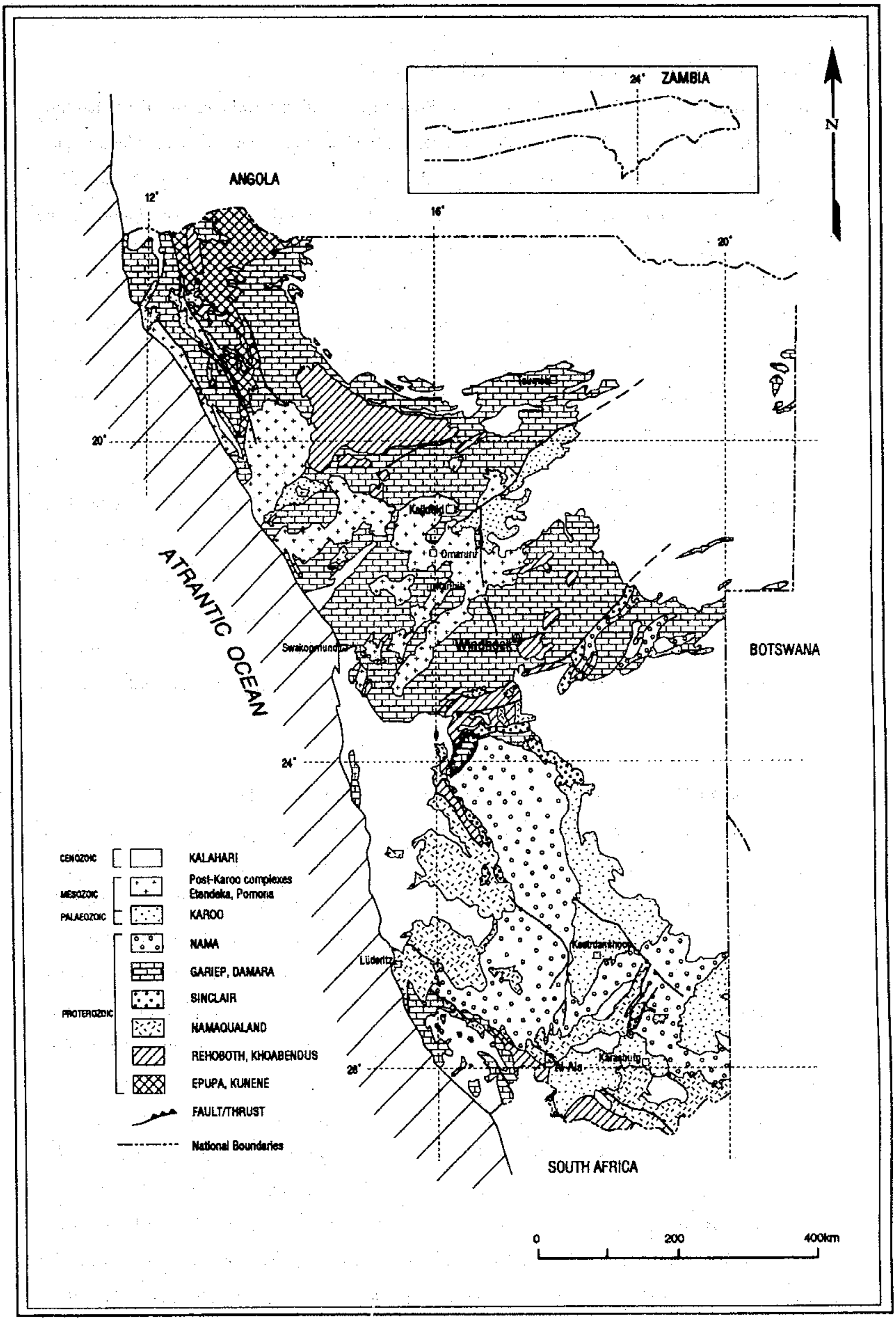


Fig. I-3-1 Index Map of Namibia

Chapter 4 Considerations of the Survey Results

4-1 Characteristics of Mineralization and Structural Controls Related to Mineralization

The Marinkas Quelle Carbonatite Complex (MQC) intrudes the Namaqua Metamorphic Complex and the Nama Sequence of Cambrian age. The 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.

4-2 Relation Between Geochemical Anomalies and Mineralization

19 elements of La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Fe, Mn, Sr, and Fe are analysed for the geochemical survey.

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 rich 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 surveyed in the Phase I.

4-3 Potentialities for Ore Deposits

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 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, 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 REEs 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.

Chapter 5 Conclusions and Recommendations

5-1 Conclusions

The Orange area is underlain by the Namaqua Metamorphic Complex of Precambrian age and the Nama Sequence of Cambrian age. These basement rocks host the carbonatite complex called the Marinkas Quelle Carbonatite Complex (MQC).

The MQC is located along the Kuboos-Bremen tectonic line which trends northeast to southwest and is also found at the intersection of the Kuboos-Bremen tectonic line and post-Karoo faults.

The MQC is manifest as in plutonic plug from it modes of intrusion. The erosion level is shallow to intermediate, since the MQC exposed through erosion indicates a shallow plutonic type. Therefore the MQC continues at depth in comparison with other carbonatite complexes.

The MQC has four main intrusive bodies, a syenite body, a sovite-syenite body, a central beforsite body and a northeast beforsite, intruded in this order. $\delta^{13}C$ and $\delta^{18}O$ also increase in this intrusion order.

The major minerals of the carbonatite are calcite, dolomite and ankerite. Subordinate minerals are strontianite, apatite, barite, magnetite, sphalerite, galena, bastnaesite, monazite, synchysite and pyrochlore. The latter four minerals contain La, Ce, Nd and Nb.

The geochemical survey indicated the concentrations of La, Ce, Nd, Nb and P in the MQC. In particular light REEs (La, Ce and Nd) are concentrated in the outer zones of the two isolated beforsite bodies. Nb is concentrated in the inner zones of the two beforsites. P is concentrated in northeast beforsite body.

The drilling survey showed that geochemical elements are concentrated underground as on the surface. But these elements have no tendency to increase underground.
Both beforsites contain 0.1 % of rare-earth oxides, 0.1 % of Nb. The northeast beforsite contains 1.0 % of P. In comparison to the carbonatite complex in the Klakfeld area, Nb and P are dominant in the MQC in the Orange area.

5-2 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 area, recommendations for the future are summarized as follows.

The Orange area is 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.

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

The MQC in the Orange area has an intermediate exposed area, which is a characteristic of mid-level erosion of a shallow plutonic plug, and shows no indication of sufficient enrichment in REEs at depth. Therefore, further exploration in the Orange area should be done, following an increase in economic demand for these elements, to evaluate the ore reserves by more a detailed drilling survey.

Part II Surveys Details

Part II Surveys Details

Chapter 1 Geochemical Survey

1-1 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 a 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 analysis, whole rock chemical analysis, x-ray diffraction analysis (XRD) and observation of rock thin sections.

In the 1994 phase II survey, geochemical and drilling surveys were conducted in the central and northeast beforsites which were determined to contain concentrations of rare-earth elements and other valuable elements in the phase I survey in 1993. Fig.I-1-2 shows the geochemical survey zones and drilling sites. Laboratory tests (Fig.II-1-4) carried out were observation of rock polished thin sections (Table II-1-1 and Appendix A-2), whole rock chemical analysis and norm analysis (Appendix B-1 and 2), geochemical analysis (Fig. II-1-7 and Appendix B-1 and 3), XRD (Table II-1-2), EPMA (Table II-1-3), oxygen and carbon isotope analysis (Fig.II-1-5, Table II-1-4) and age determination by Pb-Pb method (Table II-1-5).

1-2 Geology

1-2-1 Regional Geology

The regional geological map around the Orange area, after Blignault and Kroner (1974) is shown in Fig.II-1-1. Carbonatite complexes in the area belong to the group of alkaline intrusive which are arranged in the NE-SW direction of the Kuboos-Bremen tectonic line (Kroner and Blignault, 1976). The group of the alkaline intrusive intrudes in the Namaqua Metamorphic Complex, the Gariep Group and the Nama Sequence. The Rb-Sr age of the Marinkas Quelle syenite ranges 505.88±18.68 Ma (Smithies, 1990).

The Marinkas Quelle Carbonatite Complex (MQC) was described initially by Blignault (1971), and a detailed geological map was made by Schommartz (1988).

1-2-2 Details of Geology

Fig.II-1-2 shows a geological map based on the field survey and after Schommarz (1988). Fig.II-1-3 shows the lithostratigraphy of the Orange area. Table II-1-6 shows mineral assemblage of the MQC.

This area is underlain by the Namaqua Metamorphic Complex, the Gariep Group, the

Nama Sequence, the Marinkas Quelle Carbonatite Complex (MQC) and syn– to post Karoo Intrusions.

1. Namaqua Metamorphic Complex (Ngn)

This complex is a host rock of the MQC, and widely extends outside the area. It mainly consist of quartz–feldspar gneiss. Structural trend of foliation strikes NW–SE in direction and dips to south. Brecciated structure is commonly observed at the contact zone with the MQC. Fractures and surroundings of fragments in the brecciated zone are filled up by dark green to bluish–green amphibole, aegirine, aegirine–augite, phlogopite, carbonate minerals and apatite. Brown carbonatite veins also fulfill interstitially in the brecciated zone. The contact zone with the MQC is fenitized, and replaced by alkaline feldspars and carbonate minerals.

A large quantity of alkaline feldspars formed by fenitization and alkaline metasomatism are identified by the microscopic observation and through XRD analyses. The identified minerals is quartz, albitized plagioclase and potassium feldspar as the predominant components, aegirine–augite, gedrite, hornblende, riebeckite, biotite and phlogopite as subordinate minerals. Garnet, sphene, zircon, apatite, calcite, fluorite and opaque minerals are associated as accessory minerals. Cancrinites is identified in part of northern contact zone with the MQC.

2. Gariep Group (Gdd)

It consists of dolerite of the Gannakouriep dyke intruding in the Namaqua Metamorphic Complex. The dolerite is situated in the southwest of the area, and is intruded by the carbonatite dyke (Mcd).

3. Nama Sequence (Nsh)

It is situated in the eastern margin of the MQC and occasionally found in the northeastern part of the MQC as xenoliths. It consists of black shale, quartzite, grit and arkose. Brecciated structure is common. Breccia ranges in size from 10 cm to several metres. Dark green to bluish–green mineral veinlet fills the interstices of fragments. Brown carbonatite veins are observed in the brecciated zone. Weak bedding planes are observed in the black shale. Quartzite is light greenish–grey to white. A grading structure is observed in some of quartzite blocks. Grit and arkose is greyish white to light green , and includes large amount of quartz and feldspar grains. This sequence seems entirely brecciated and the distribution of each facies is not concordant with the occurrence estimated by strikes and dips of bedding planes. Therefore, the lithostratigraphy of each facies is not well known.

4. Marinkas Quelle Carbonatite Complex (MQC)

The MQC exhibits an elliptical shape elongated in a NE-SW direction and occurs as a pluton which intrudes the Namaqua Metamorphic Complex and the Nama Sequence.

The MQC is subdivided broadly into four bodies, i.e. a syenite body (Msw and Msp), sovite-syenite body (Mcs, Msu, Msrm and Msm), a beforsite body (Mcb1) and a northeast befrsite body (Mcb2) .

(a) Syenite body (Msw and Msp)

The body is situated in the north of the area in a half moon shape. It consists of white to grey porphyritic syenite (Msw) and porphyritic nepheline syenite (Msp). The later is expected the significant concentration of heveay rare-earth elements (Schommarz, 1988).

The white to grey porphyritic syenite (Msw) is creamy white to grey, partly greenish grey. Brecciated structure is common. The various size of Fragments of gneiss and black shale includes as xenolith in the body. The syenite composed of white feldspar wherein the grain size is around 5 mm in diameter, and contains a characteristically small amount of mafic minerals. Brown carbonatite veins fill interstitially in the split of breccied fragments.

The predominant minerals are composed of albitized plagioclase, albite, potassium feldspar, nepheline, cancrenite, analcime, and aegirine-augite, and subordinate minerals are of quartz, sphene, hornblende, riebeckite, biotite, phlogopite, muscovite, calcite, opaque minerals, zircon, and apatite. Epidote, sercite and chlorite contain as hydrothermal alteration product.

The porphyritic nepheline syenite (Msp) is creamy white to light greyish-green, partly pinkish in colour. It commonly contains white to light yellow feldspar and aegerine-augite phenocryst whose grain sizes range from 1 to 5 mm in diameter, and phenocrysts of biotite whose grain size is 0.1 to 1 mm in diameter. Aggregate of alkali-feldspar around 5 cm in diameter occurs at some outcrops. Brecciated structure and calcitic carbonatite dykes within a few tens cm in width are commonly observed in the body.

The predominant minerals are composed of albitized plagioclase, potassium feldspar, nepheline, cancrenite, analcime, and aegirine-augite, and subordinate minerals are of sphene, biotite, phlogopite, calcite, opaque minerals, and apatite. Epidote, sercite, chlorite, and goethite contain as hydrothermal alteration product.

(b) Sovite-syenite body (Mcs, Msu, Msr and Msm)

This body exhibits a ring structure in the north-central portion of the area, and is partly deformed to ellipsoid. It consists of sovite (Mcs), porphyritic syenite (Msr), undifferentiated syenite (Msu), and fine-grained syenite sill (Msm).

Sovite (Mcs) is widely distributed in the area, especially in the north-central portion. At the portion, a basin–like landscape is formed by the difference in resistivity for erosion between dolomite–dominated beforsite and gneiss around the basin, and calcite–dominated sovite. Phlogopite aggregates at the contact zone with the beforsite bodies (Mcb1 and Mcb2), and foliates concordant with the contact plane.

Calcite about several millimetres in diameter is a principal component of sovite. It composed subordinately of quartz, albite, potassium feldspar, nepheline, cancrinite, sodalite, analcime, riebeckite, aergirine–augite, phlogopite, dolomite, magnetite, and apatite. Chlorite and goethite contain as hydrothermal alteration and weathering products. Barite, barytocarcite, kutnohorite, and magnesite from a float of iron ore in the basin are identified by the XRD analysis.

$\delta^{13}C$ values of calcite and dolomite range from –5.5 to –5.9 ‰ and from –4.7 to –5.4 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite range +6.5 ‰ and from +7.7 to +8.3 ‰, respectively. Dolomite is slightly enrich in ^{13}C and ^{18}O compared to dolomite.

Reddish porphyritic syenite (Msr) is distributed at the east of the contact zone with the Namaqua Metamorphic Complex. It characteristically contains phenocryst of pink feldspar.

It is composed predominantly of albite and potassium feldspar, and subordinately of nepheline, cancrenite, kalsilite, analcime, aegirine–augite, garnet, sphene, biotite, calcite, opaque mineral and apatite.

Undifferentiated syenite (Msu) is widely distributed within the Complex. It shows a creamy white, greenish–grey, grey to light grey, and includes a variety of grain size of component minerals. It shows a brecciated structure at the contact zone with the beforsite bodies, and green veinlets fill the interstices of the fragments.

It is composed predominantly of albite, potassium feldspar, and biotite / phlogopite, and subordinately of nepheline, kalsilite, cancrenite, analcime, aegirine–augite, garnet, sphene, riebeckite, biotite, phlogopite, muscovite, calcite, opaque minerals such as magnetite and pyrite, rutile, and apatite. Epidote, allenite, sercite, chlorite, calcite, and goethite contain as hydrothermal alteration and weathering products. Pseudomorph of olivine is replaced by serpentine and talc.

The fine–grained syenite sill (Msm) intruding the central portion of the complex has a width of about 1 metre.

(c) Beforsite body (Mcb, Mfn and Mgr)

The ankeritic beforsite (Mcb) is subdivided into the central beforsite (Mcb1) and the northeast beforsite (Mcb2).

The central beforsite (Mcb1) exhibits a ring structure. The surface of the outcrops present dark brown to brown due to weathering, and shows a distinct difference in colour of surface compared to the surrounding rocks, such as sovite, gneiss and syenite. Banding structure with steep dips is developed in the body, and strike of that is concordant with the ring-shaped body. Aggregates of phlogopite and of goethite are observed in part of this body. Euhedral quartz lacking of prism fills in open-fracture about 2 mm in width are observed at the western portion of the body.

It is composed predominantly of dolomite and phlogopite, and subordinately of quartz, potassium feldspar, melilite, analcime, olivine, garnet, sphene, muscovite, calcite, siderite, opaque minerals such as magnetite, hematite, pyrite, and pyrrhotite, perovskite, apatite, and pyrochlore.

Euhedral pyrochlore about 0.1mm in diameter is found out in the body. Pyrochlore contains from 48.8 to 50.3 weight % of Niobium, and from 0.50 to 0.56 weight % of Cerium. The atomic ratio of Na : Ca is approximately 1 : 1. Chemical formula of pyrochlore on the average is determined as $(Na_{0.97},Ca_{0.92},Sr_{0.06},Ce_{0.01})_{1.96}(Nb_{1.94},Ta_{0.00},Zr_{0.00},Ti_{0.05},Si_{0.00})_{2.00}O_{5.67}F_{1.59}$ assuming $A_2B_2O_6F$. It contains excess fluorine more than that of the ideal formula.

$\delta^{13}C$ values of calcite and dolomite range from −3.7 to −4.1 ‰, and from −3.5 to −3.9 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite range form +8.6 ‰ to +10.5 5 ‰, and from +8.5 to +9.8 ‰, respectively. Dolomite is slightly enriched in ^{13}C, and slightly diminished in ^{18}O compared to calcite.

The northeast beforsite (Mcb2) has a rounded shape elongated to the N−S direction. It is hosted by gneiss of the Namaqua Metamorphic Complex, shale and quartzite of the Nama Sequence, and syenites and sovite of the MQC. All, except sovite, are strongly brecciated, and interstitially filled with carbonatite veins and dykes. The surface of the body shows a dark brown to light brown due to weathering. The banding structure parallel with the shape of the body become clear on surface caused by different resistivity for weathering. Apatite is contained characteristically along the banding structure with a light green in colour and about 5 millimetres wide.

It is composed predominantly of dolomite and apatite, and subordinately of quartz, albite, potassium feldspar, garnet, sphene, riebeckite, phlogopite, muscovite, calcite, opaque minerals such as magnetite, hematite, pyrite, pyrrhotite, and pyrochlore.

Pyrochlore is frequently observed under microscope, and analysed by EPMA. Pyrochlore contains from 45.8 to 50.2 weight % of Niobium, and from 0.17 to 0.41 weight % of Cerium. The atomic ratio of Na : Ca is approximately 1 : 1. Chemical formula of pyrochlore on the average is determined as $(Na_{0.98},Ca_{1.00},Sr_{0.04},Ce_{0.01})_{2.03}(Nb_{1.90},Ta_{0.00},Zr_{0.00},Ti_{0.08},Si_{0.01})_{2.00}O_{5.68}F_{1.63}$ assuming $A_2B_2O_6F$. It contains excess fluorine more than that of the ideal formula.

$\delta^{13}C$ values of calcite and dolomite range from −4.9 to −5.0 δ and from −4.8 to −4.9 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite range form +8.0 to +8.5 and from +8.1 to +8.4 ‰, respectively. Dolomite is enriched in ^{13}C and diminished in $\delta^{18}O$ compare to dolomite.

Fenite (Mfn) is formed at the margin of the central beforsite(Mcb1).

It is composed predominantly of albitized plagioclase, potassium feldspar and aegirine, and subordinately of sphene, riebeckite, phlogopite, calcite, magnetite, apatite, and sericite.

Granophyre and micro-granite (Mgr) is found in the centre of the central beforsite (Mcb1) and at the southern margin of the northeast beforsite (Mcb2). It is white to light grey in colour, and exhibits a holocrystalline texture.

It is composed mainly of quartz, albite and potassium feldspar, and of small amount of aegirine, calcite, pyrite, and marcasite and apatite.

Normative minerals and average norms, calculated from whole rock chemical compositons of the central beforsite, are magnetite (1.52%), hematite (2.10%), rutile (0.01%), apatite (0.45%), forsterite (0.08%), fayalite (0.30%), calcite (57.30%), magnesite (31.41%), siderite (4.49%), and strontianite (1.11%). Those of the northeast beforsite are magnetite (0.66%), hematite (1.01%), rutile (0.05%), apatite (4.39%), forsterite (0.14%), fayalite (0.71%), calcite (54.67%), magnesite (29.07%), siderite (5.61%), and strontianite (1.46%). The central beforsite is enriched in magnetite, hematite, calcite, and dolomite, while the northeast beforsite is enriched in apatite and strontianite. Contents of forsterite, fayalite and siderite in both beforsites are similar according to the statistic τ-test.

The Pb-Pb age of galena from the central beforsite, based on the model age method after Stacy and Kramers (1975), is estimated 329 Ma with 38.286 ± 0.0548 (2σ of $^{208}Pb/^{204}Pb$, 15.648 ± 0.0141 (2σ) of $^{207}Pb/^{204}Pb$, and 18.139 ± 0.0021 (2σ) of $^{206}Pb/^{204}Pb$.

(d) Carbonatite dyke (Mcd)

The carbonatite dyke (Mcd) intrudes most of the rock facies in the area. It is made up of both ankeritic carbonatite (beforsite) and calcite carbonatite (sovite). The surface of both rock facies is brown due to weathering.

It is composed predominantly of calcite or dolomite – ankerite, and subordinately of albite, potassium feldspar, manganocalcite, siderite, strontianite, bastnaesite, hematite, apatite, and monazite (?). Goethite is commonly observed as a weathering product.

The chemical formula of bastnaesite on the average from the beforsite dyke is determined as $(La_{0.12},Ce_{0.41},Nd_{0.21},Pr_{0.08},Ca_{0.14},Fe_{0.02},Sr_{0.02})_{1.00}(CO_3)_{0.94}(F_{0.48},Cl_{0.00},OH_{0.49})_{0.97}$.

$\delta^{13}C$ values of calcite and dolomite range from -3.4 to -5.9 ‰ and from -3.2 to -5.4 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite range from +7.5 to +14.5 ‰ and from +8.1 to +11.2 ‰, respectively. Dolomite and calcite have a variety of ranges of $\delta^{13}C$ and $\delta^{18}O$ compared with those of the sovite body (Mcs) and the beforsite bodies (Mcb1 and Mcb2).

5. Syn- to post-Karoo Intursions (Kdd and Ktd)

The Intrusions are made up of dolerite (Kdd) and trachyte (Ktd). Both have a relatively narrow width of around 2 metres. The dykes intrude all the rock facies. Most of these dykes strike in NE-SW or NW-SE directions. The strikes of the dykes are concordant with those of the banding structures in the northeast beforsite (Mcb2).

The main minerals of the dolerite are plagioclase, clinopyroxene, hornblende and biotite. Subordinate minerals are sericite, chlorite, calcite, perovskite and opaque minerals under the microscope. The main minerals of trachyte dyke are quartz, albite, potassium feldspar, nepheline, aegirine-augite and biotite. Subordinate minerals are fluorite, sericite, chlorite, calcite and pyrite.

1-3 Geochemical Survey

1-3-1 Survey Method

The geochemical survey was carried out during 1993 and 1994. Rock samples are collected for this survey. In 1993, 50 m by 75 m sampling grids were adopted in the MQC area. 100 m by 150 m grids were adopted in other rock facies. In 1994, the geochemical survey concentrated on the central beforsite and northeast beforsite. 25 m by 25 m grids were adopted in the two beforsites. These grids bridge the grids of the survey in 1993.
The geochemical analysis were carried out for the following 19 elements;
La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Mn, Sr, P and Fe

1-3-2 Survey Results

Fig.II-1-8 shows the geochemical analysis map. Fig.II-10 shows rare-earth elements distribution pattern. Table II-1-7 shows analytical accuracies and detection limits. Table II-1-8 shows the geochemical statistic data. Appendix B-3 shows the geochemical analyses. Appendix B-4 shows frequency and cumulative Frequency for geochemical analyses. Appendix B-5 shows scattering diagram of the geochemical analyses.

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

REEs have similar chemical behaviors. Rare-earth oxides, assuming R_2O_3, are concentrated in the sovite (Mcs), the central beforsite (Mcb1), the northeast beforsite (Mcb2), and the carbonatite dyke (Mcd) in the MQC and the contents of REEs show the tendency to increase in this order. In the sovite, the maximum value of R_2O_3 is 5,500 ppm, and the mean value is 1,029 ppm. In the central beforsite, the maximum is 32,716 ppm, and the mean is 1,665 ppm. In the northeast beforsite, the maximum content is 27,224 ppm, and the mean is 1,252 ppm. In the carbonatite dykes, the maximum content is 21,657 ppm and the mean is 9,871 ppm.

In the central beforsite body (Mcb1), REEs distribution shows that R_2O_3 more than 1,000 ppm concentrates at the rim of this body, rather than at the core. In places, R_2O_3 exceed 10,000 ppm. Some portions of the fenitized syenite (Mfn) and gneiss (Ngn) have concentrations of over 1,000 ppm. These portions are situated in the intrusive boundary between beforsite and syenite or gneiss, in which beforsite networks are dominant.

The Northeast beofrsite (Mcb2) has portions where the concentration exceeds 1,000 ppm in outer zone of this body, rather than the inner zone. In place the concentration exceeds 10,000 ppm.

The Nama Sequence has a few point of concentration, in which beforsite networks have REEs. The porphyritic nepheline syenite (Msp) has 2,763 ppm at maximum. But the contents in this syenite are not so high compared with the two beforsites.

Through XRD analysis, Ce-Nd-La-bearing bastnaesite and monazite were identified. Contents of light REEs (La, Cd, and Nd) are coinciding between the two of the beforsites. But middle to heavy REEs (Eu, Tb, Yb and Lu) are concentrated more in the northeast beforsite (Mcb2) than in the central beforsite (Mcd1).

2. Scandium and yttrium

Zones where concentrations zone exceed 100 ppm of these elements are distributed in the northern part of the area, which is underlain by the Nama sequence. On the other hand, low value zones are found in the MQC area.

3. Uranium and thorium

Th maximum content of Th is 716 ppm in the carbonatite dyke (Mcd). There are several zones in the survey area where concentrations of these elements are comparable to those in the Kalkfeld area. The outer zones of the central beforsite have relatively high portions of these elements.

4. Niobium and tantalum

Niobium are concentrated in the MQC, especially both of the central befofsite and the northeast beforsite. In the central beforsite, Nb concentrates more than 1,000 ppm in the inner zone, and shows a distinctive distribution compared to that of R_2O_3 which has a tendency to concentrate in the outer zone of the body. The northeast beforsite also has values in excess of 1,000 ppm in the inner zone. According to the result of XRD and EPMA analyses, one of the most important Nb-bearing minerals is pyrochlore in the area.

Ta is concentrated weakly in the two beforsites (Mcb1 and Mcb2), the syenites (Msu and Msr), the fenite (Mfn) and the carbonatite dyke (Mcd), but highly concentrated zones are not distinct.

5. Zirconium

Beforsite bodies (Mcb1 and Mcb2) are characteristically lack of Zr content less than 100 ppm compared with surrounding silicate-dominant rocks. No significant concentration is not distributed in the area.

6. Manganese

Zones where concentration of Mn exceeds 5,000 ppm are distributed in the central and northeast beforsite bodies. The variation of content within the bodies is limited to compare with that of other rock facies. There is no difference of Mn contents between two of the beforsite bodies.

7. Strontium

Sr is highly concentrated in the carbonatite dyke, the central beforsite, the northeast beforsite and the sovite, and is concordant with their distributions. In the central and northeast beforsite bodies, the concentration of Sr distinctively reach up to 22,060 ppm. Through XRD analysis, strontianite is identified in the highly Sr concentrated zones.

8. Phosphorus

Concentration of P over 5,000 ppm is observed in the northeast beforsite. In contrast, the central beforsite body has no concentration of P, and the marginal zone of the body composed peripheral gneiss and syenite shows relatively high concentrations. Apatite is the commonly observed as phosphorus mineral, and monazite is identified through XRD analyses.

9. Iron

The two beforsite bodies and the carbonatite dyke are enriched in Fe. These rock facies have mean values of form 3.73 to 5.74%. The peripheral rocks of the beforsites have aegirine and / or aegirine-augite which lead to an increase in Fe contents. The central beforsite is enriched in Fe rather than the northeast beforsite.

1-4 Considerations

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 REE 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 northeast 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.

Chemical formula of Bastnaesite on the average from beforsite dyke is determined as $(La_{0.12},Ce_{0.41},Nd_{0.21},Pr_{0.08},Ca_{0.14},Fe_{0.02},Sr_{0.02})_{1.00}(CO_3)_{0.94}(F_{0.48},OH_{0.49})_{0.97}$, and is enriched in Ce, Nd and La. Pyrochlore has a composition of $(Na_{0.98},Ca_{0.96},Sr_{0.05},Ce_{0.01})_{2.00}(Nb_{1.92},Ti_{0.07},Si_{0.01})_{2.00}O_{5.68}F_{1.68}$ on the average. The atomic ratio of Na:Ca is approximately 1:1. Pyrochlores on the surface has the same composition as that of underground.

$\delta^{13}C$ and $\delta^{18}O$ 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 $\delta^{13}C$ and $\delta^{18}O$.

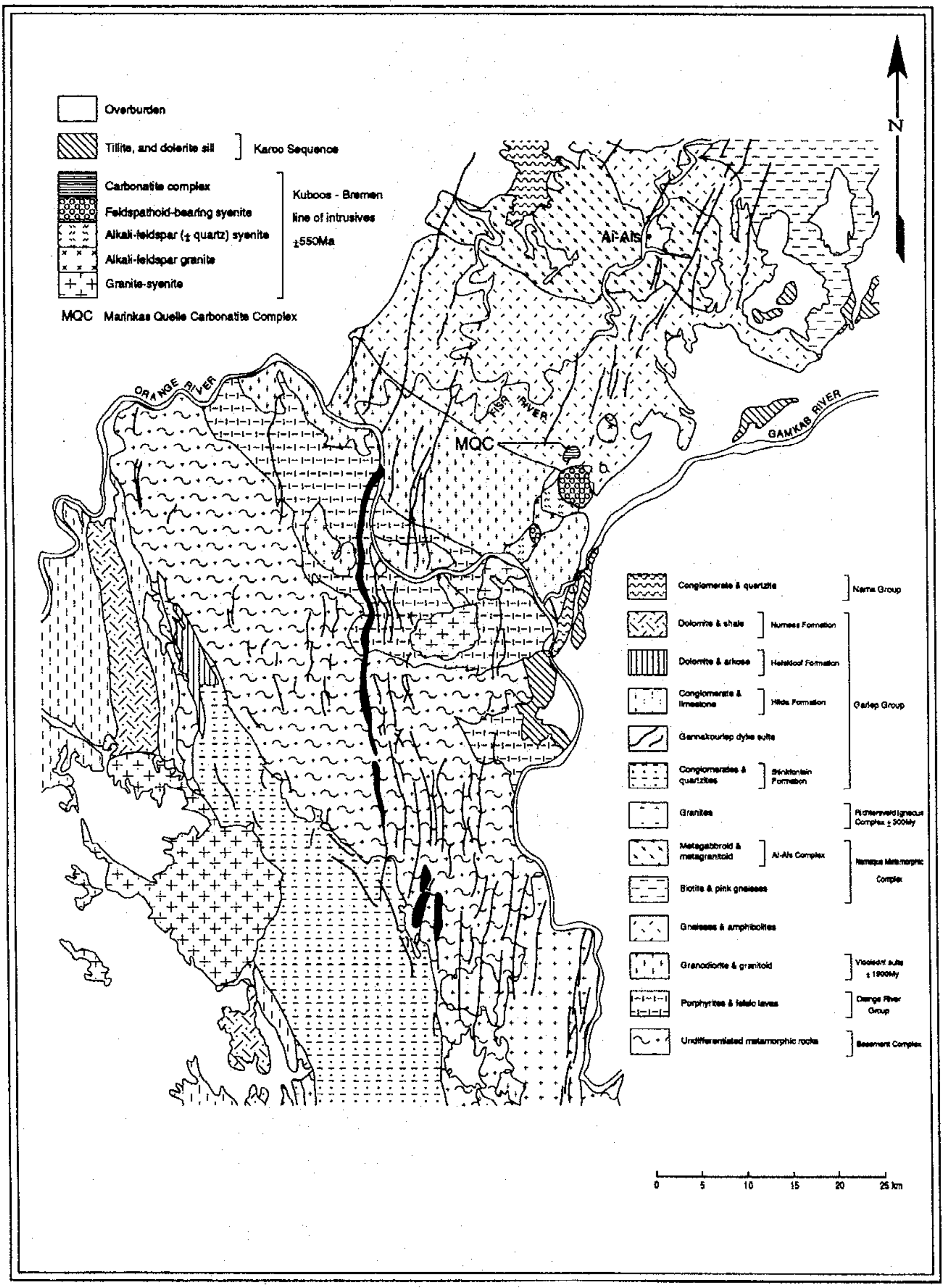


Fig. II-1-1 Regional Geological Map of the Orange Area and Vicinity

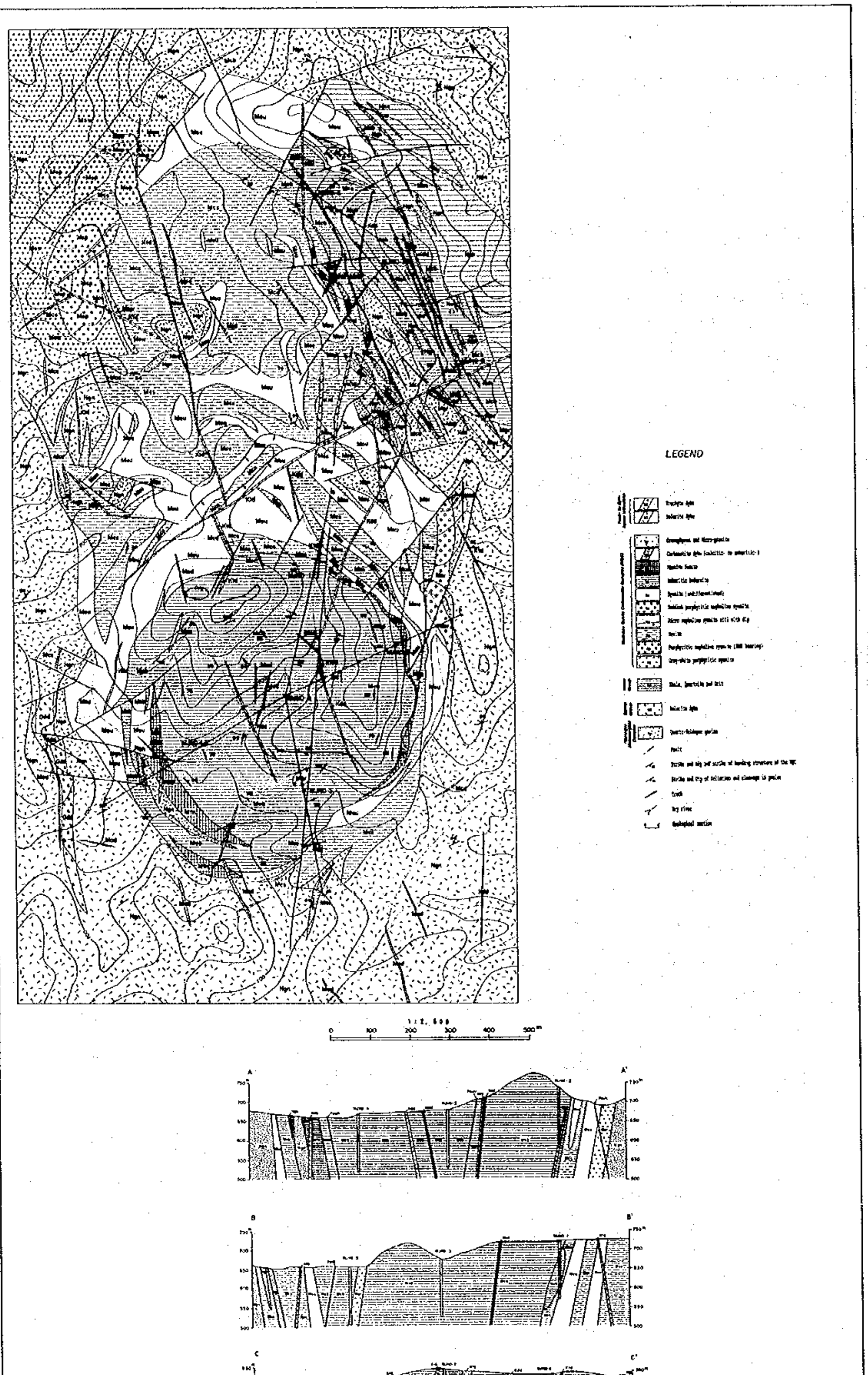


Fig. II-1-2 Geological Map of the Orange Area

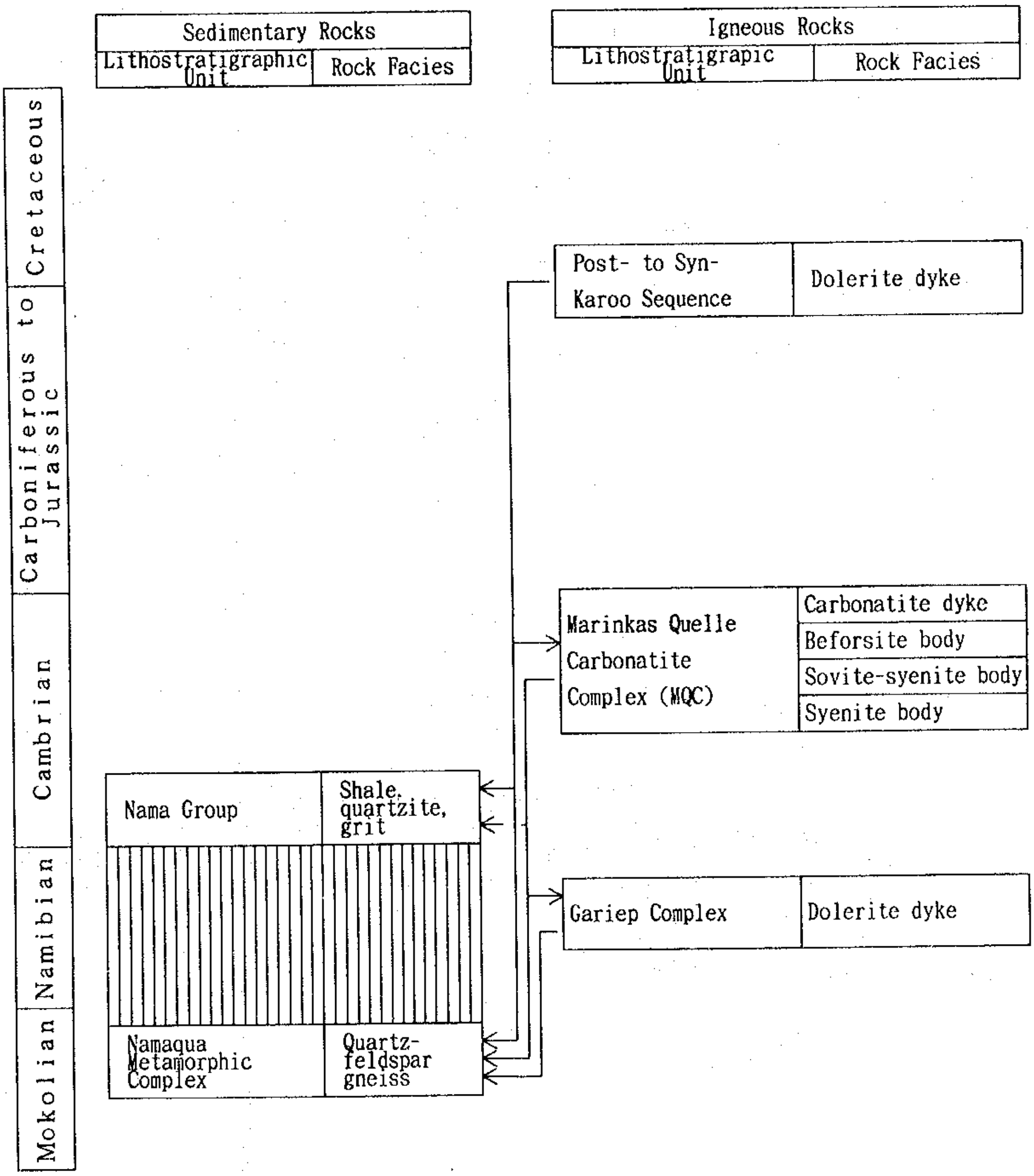


Fig. II-1-3 Lithostratigraphy of the Orange Area

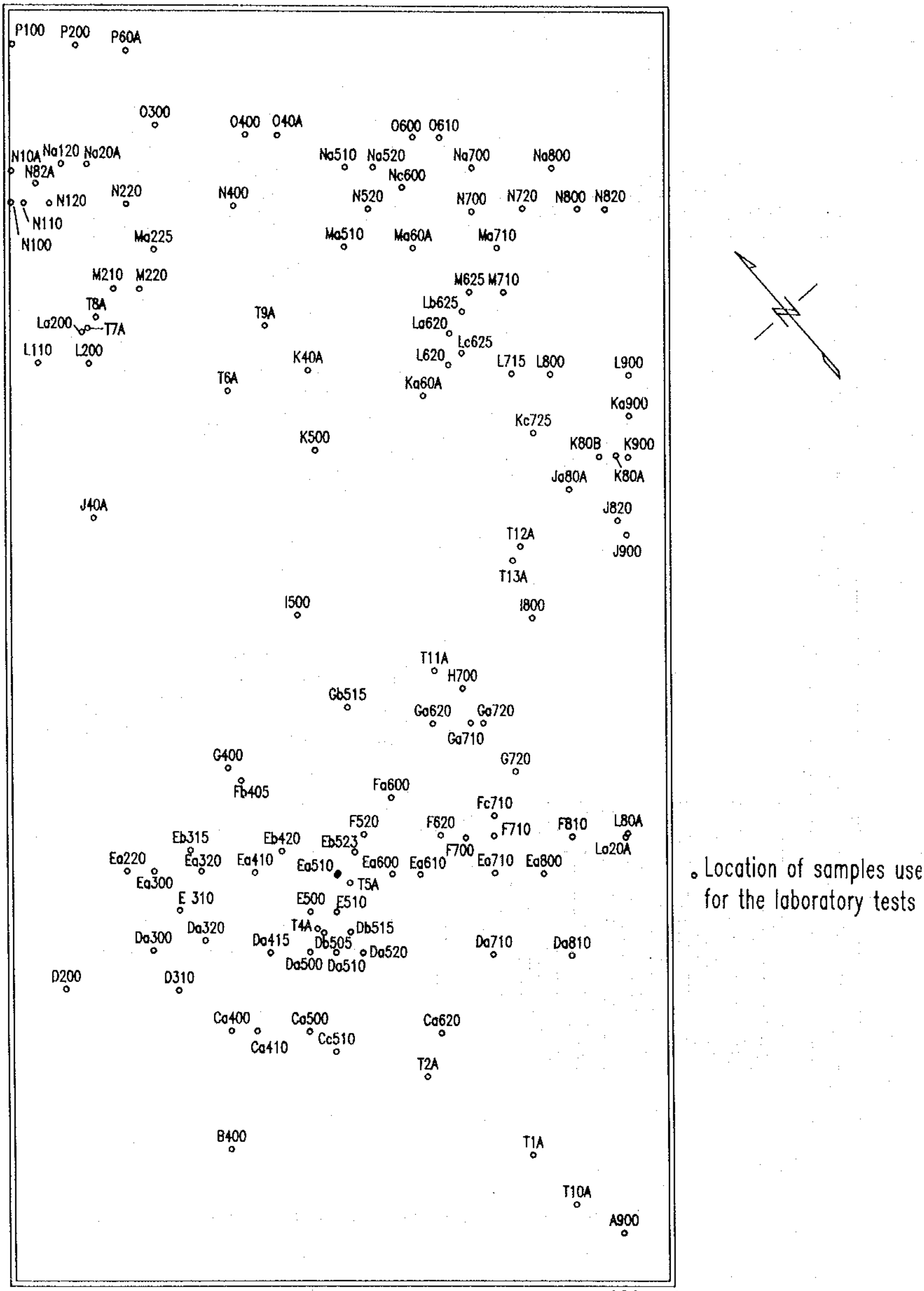


Fig. II-1-4 Sample Location for Laboratory Tests of the Orange Area

100 0 100 200 300
(metres)

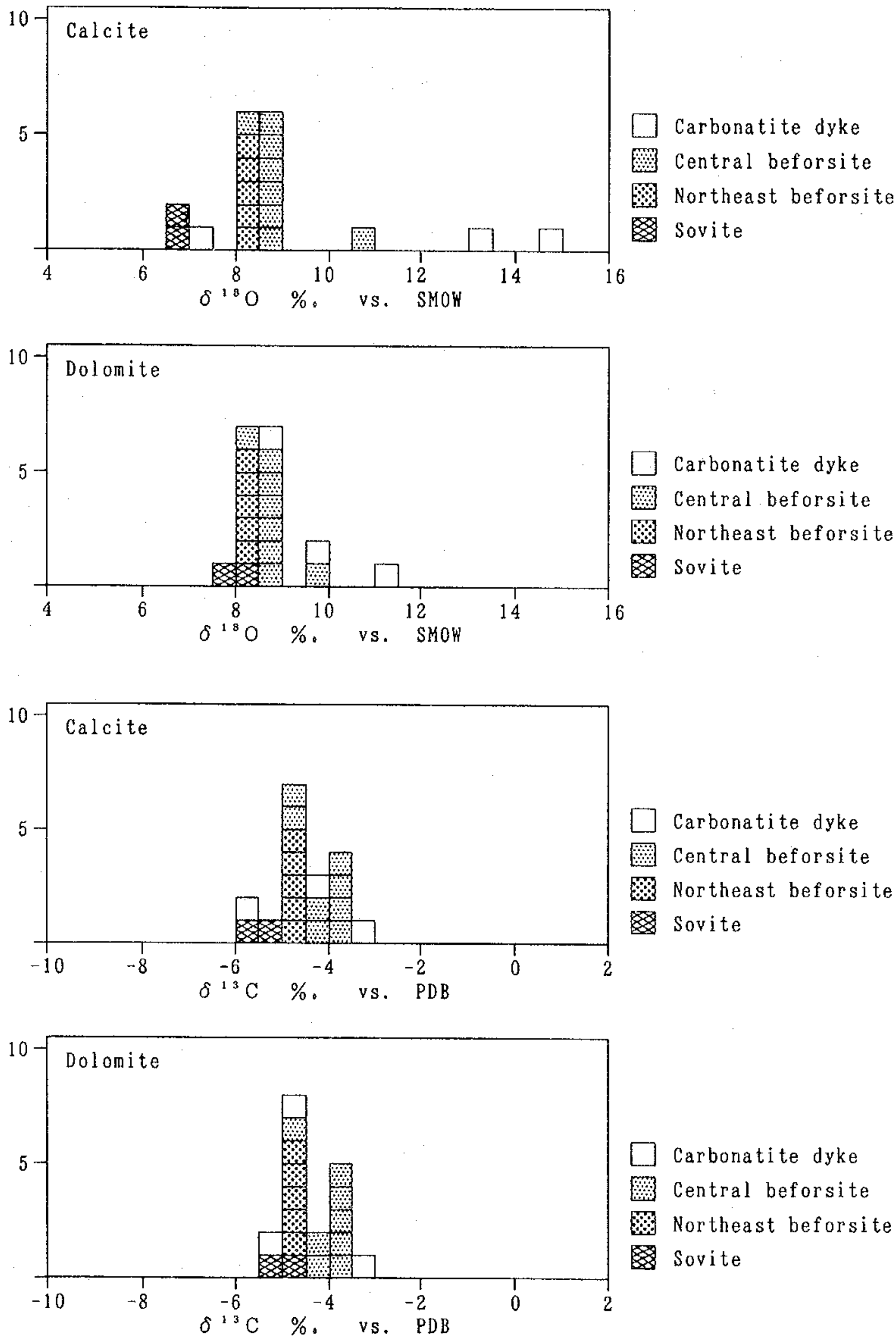


Fig. II-1-5 Histogram Showing Frequency of $\delta^{13}C$ and $\delta^{18}O$ Values

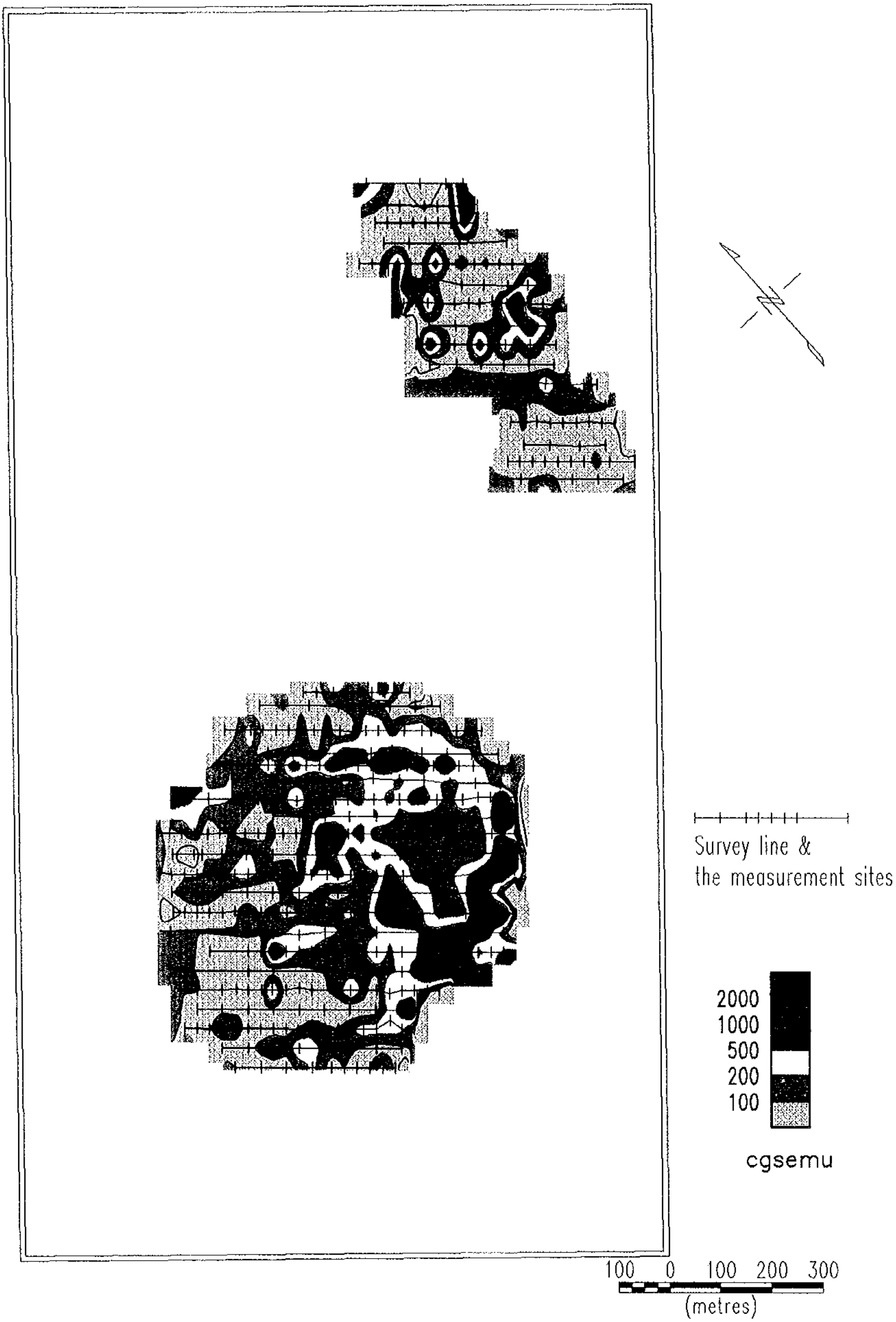


Fig. II-1-6 Contoured Map of Magnetic Susceptibility Map of the Orange Area

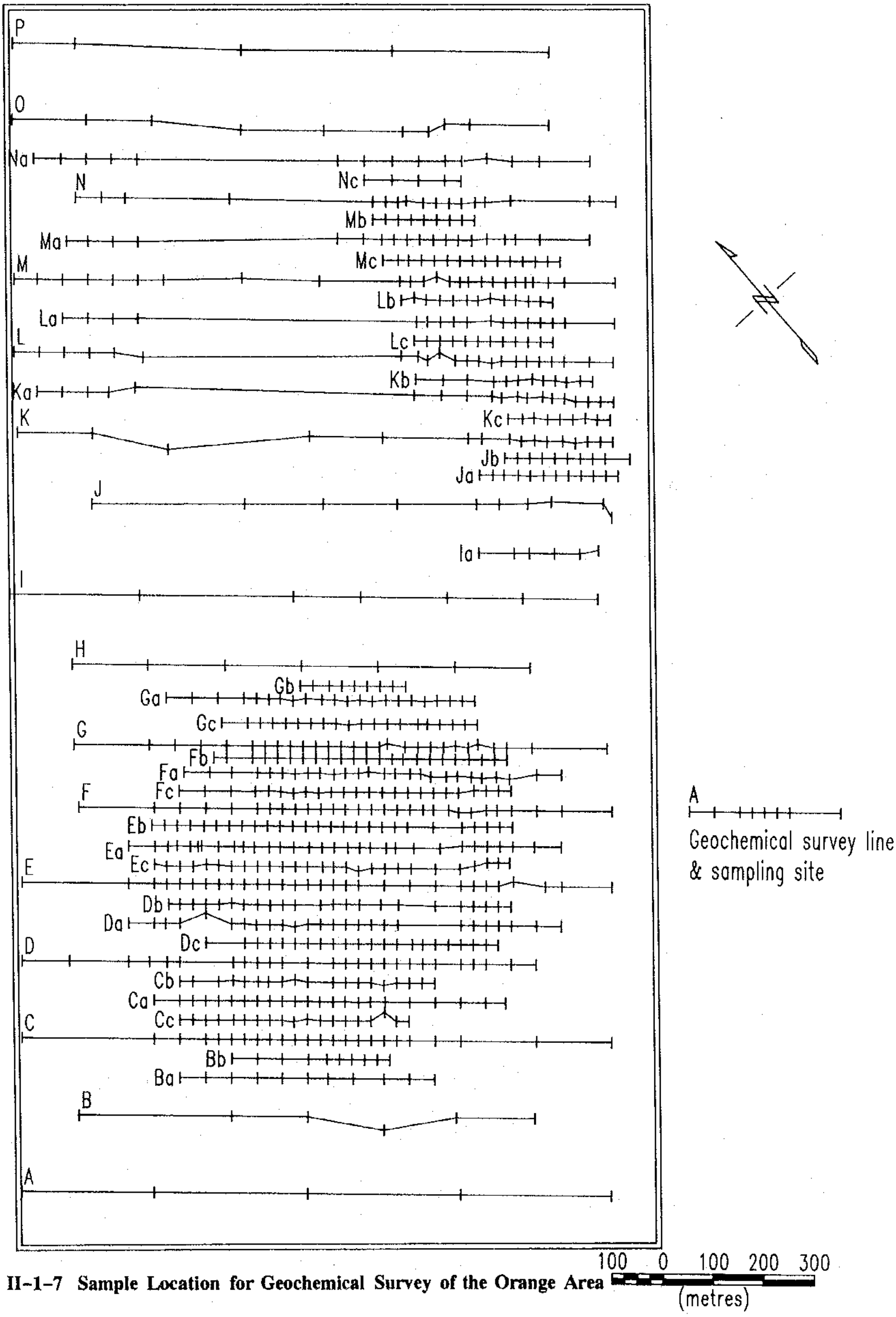


Fig. II-1-7 Sample Location for Geochemical Survey of the Orange Area

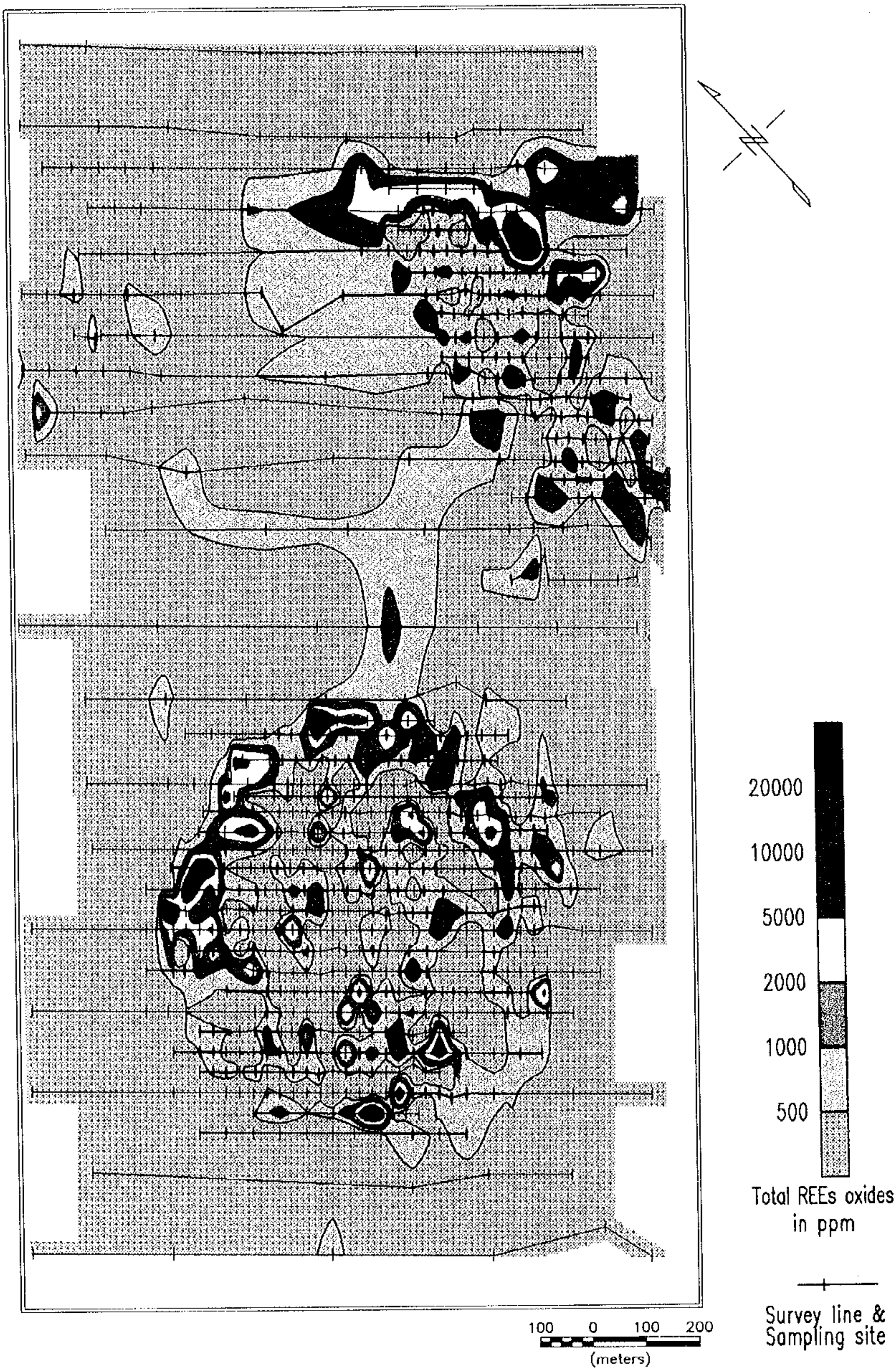


Fig. II-1-8 Contoured Map of Geochemical Distribution of the Orange Area(Total REEs Oxide)

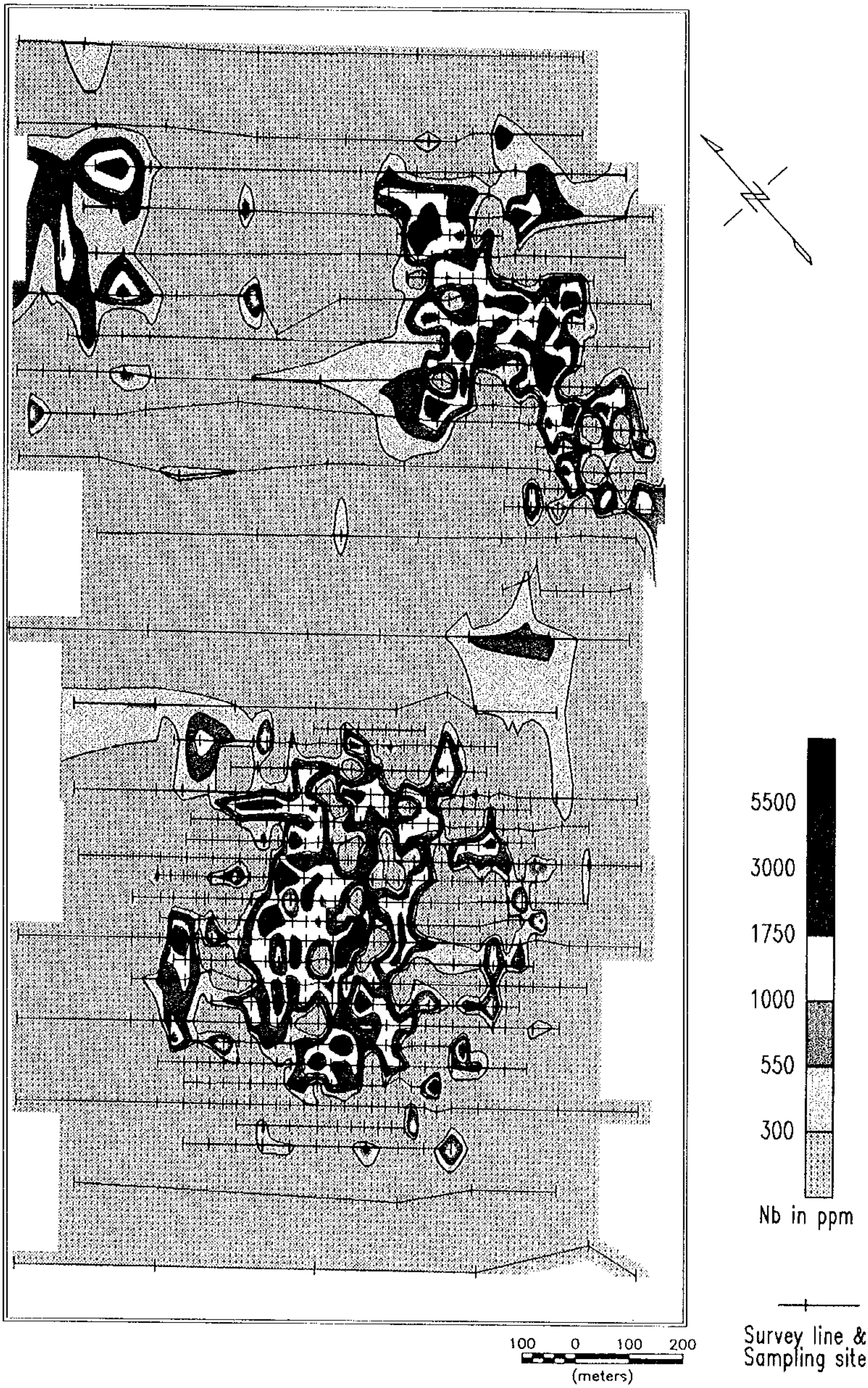


Fig. II-1-8 Contoured Map of Geochemical Distribution of the Orange Area (Nb)

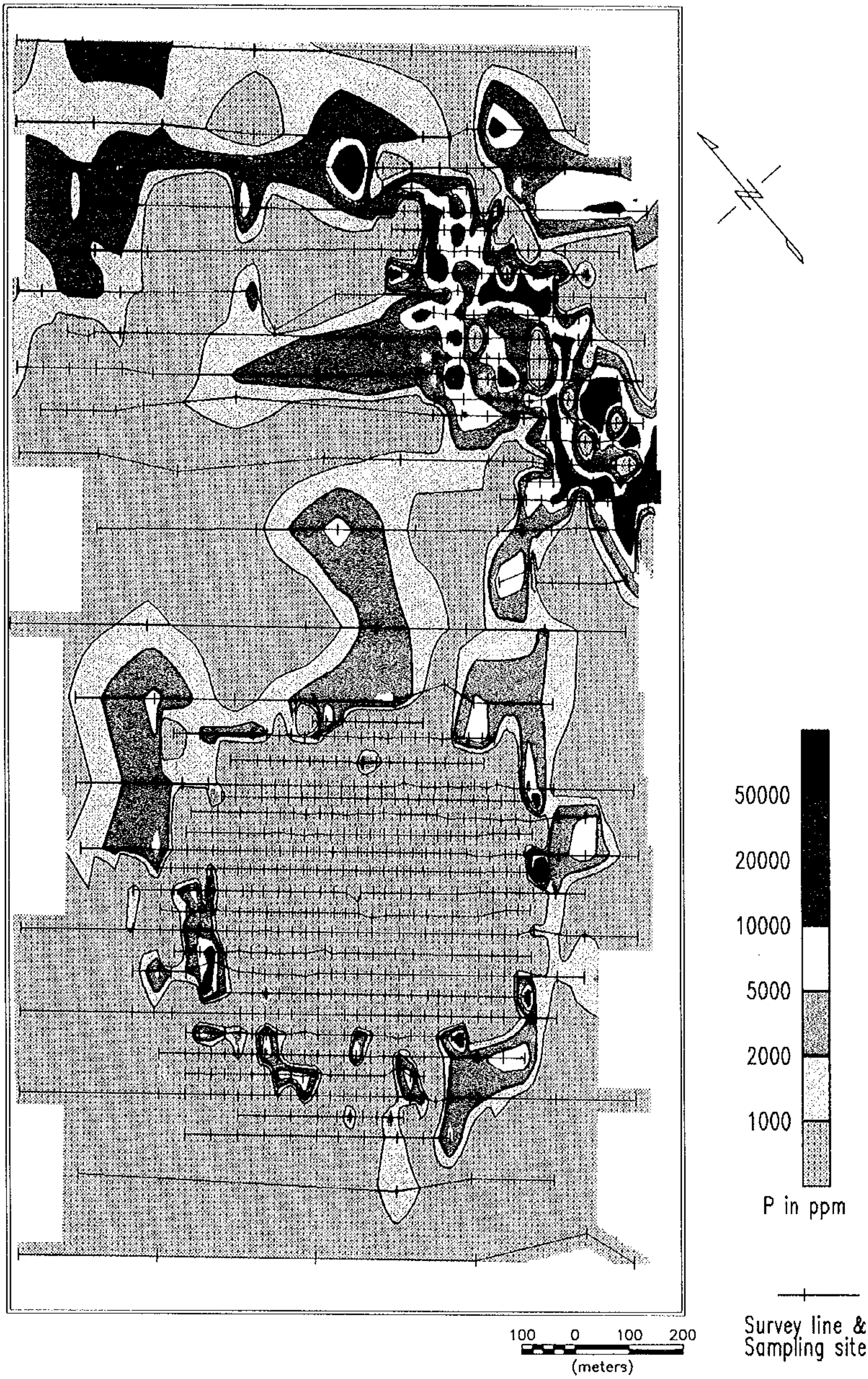


Fig. II-1-8 Contoured Map of Geochemical Distribution of the Orange Area (P)

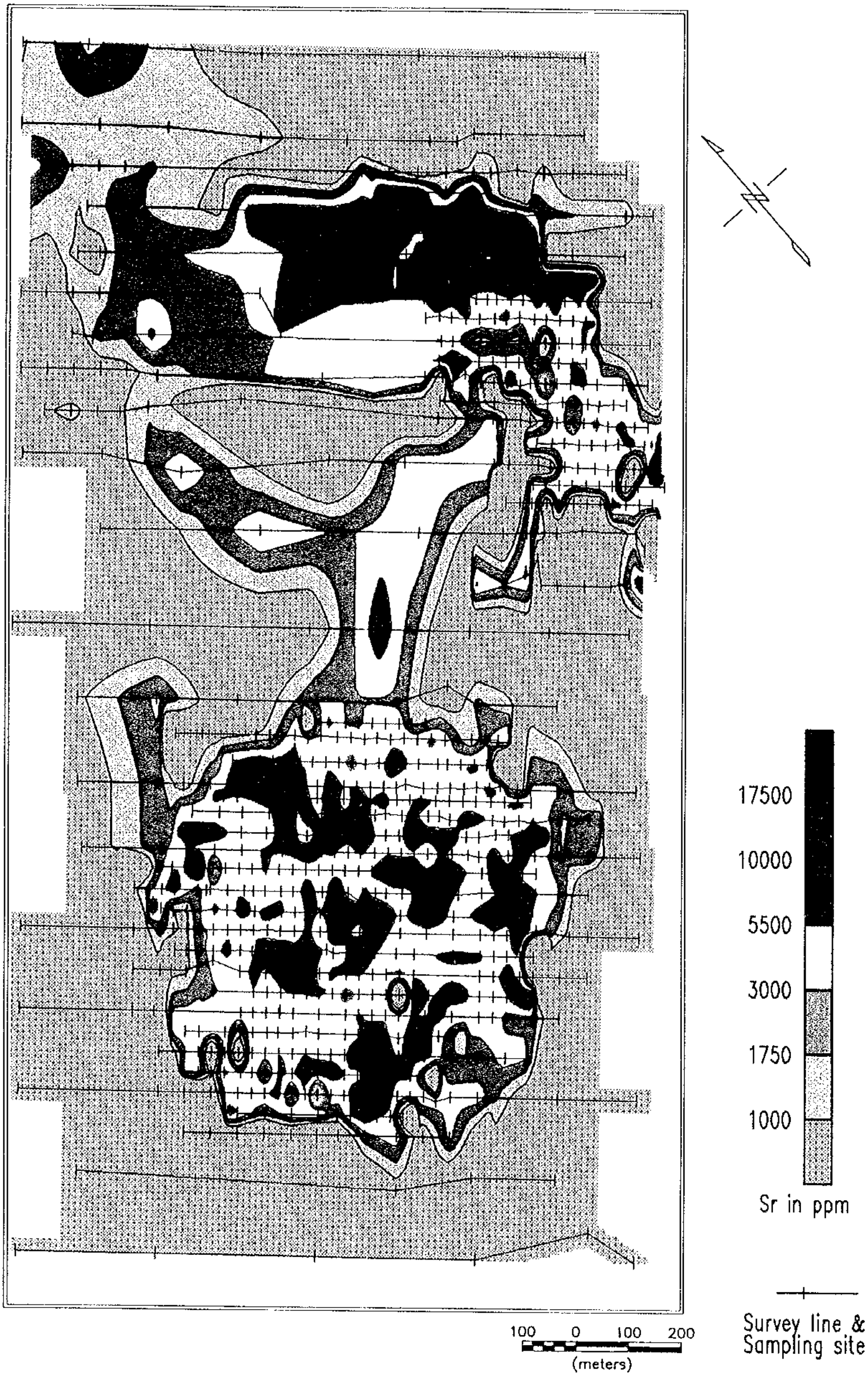
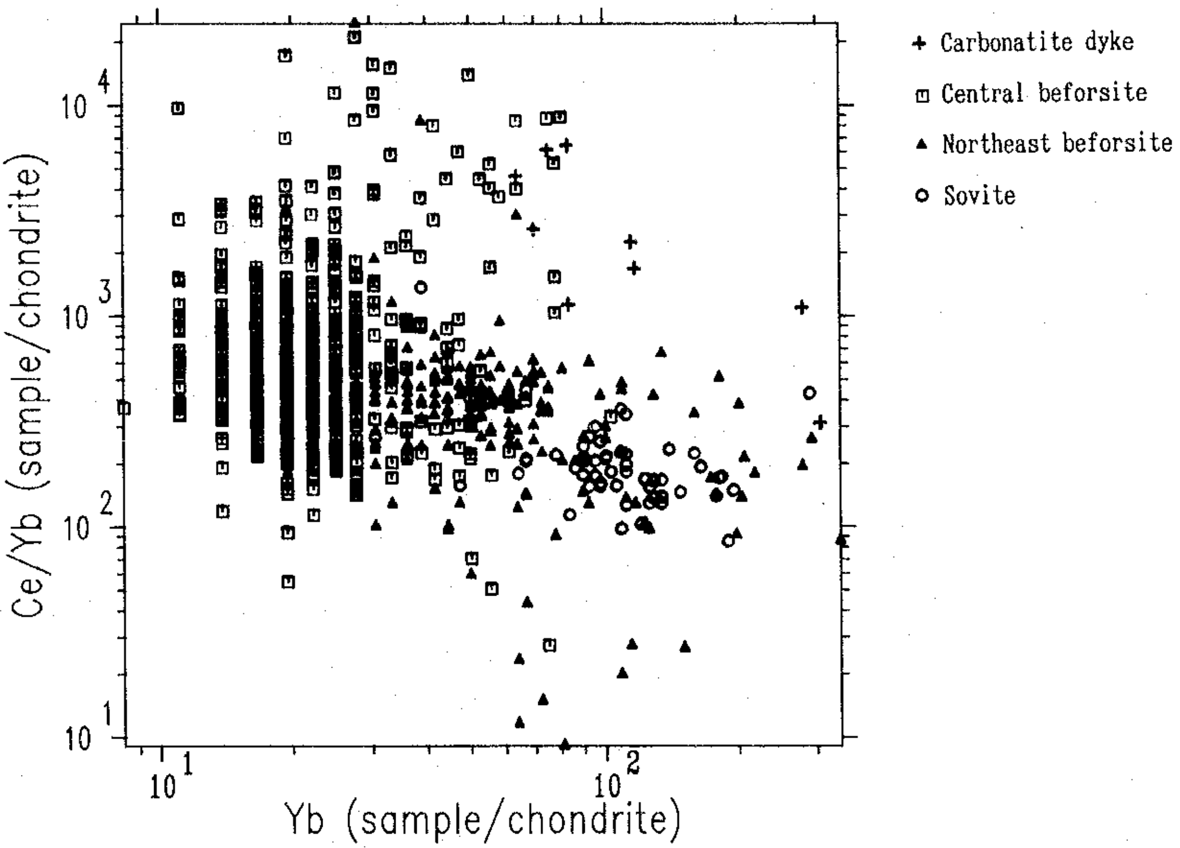


Fig. II-1-8 Contoured Map of Geochemical Distribution of the Orange Area (Sr)



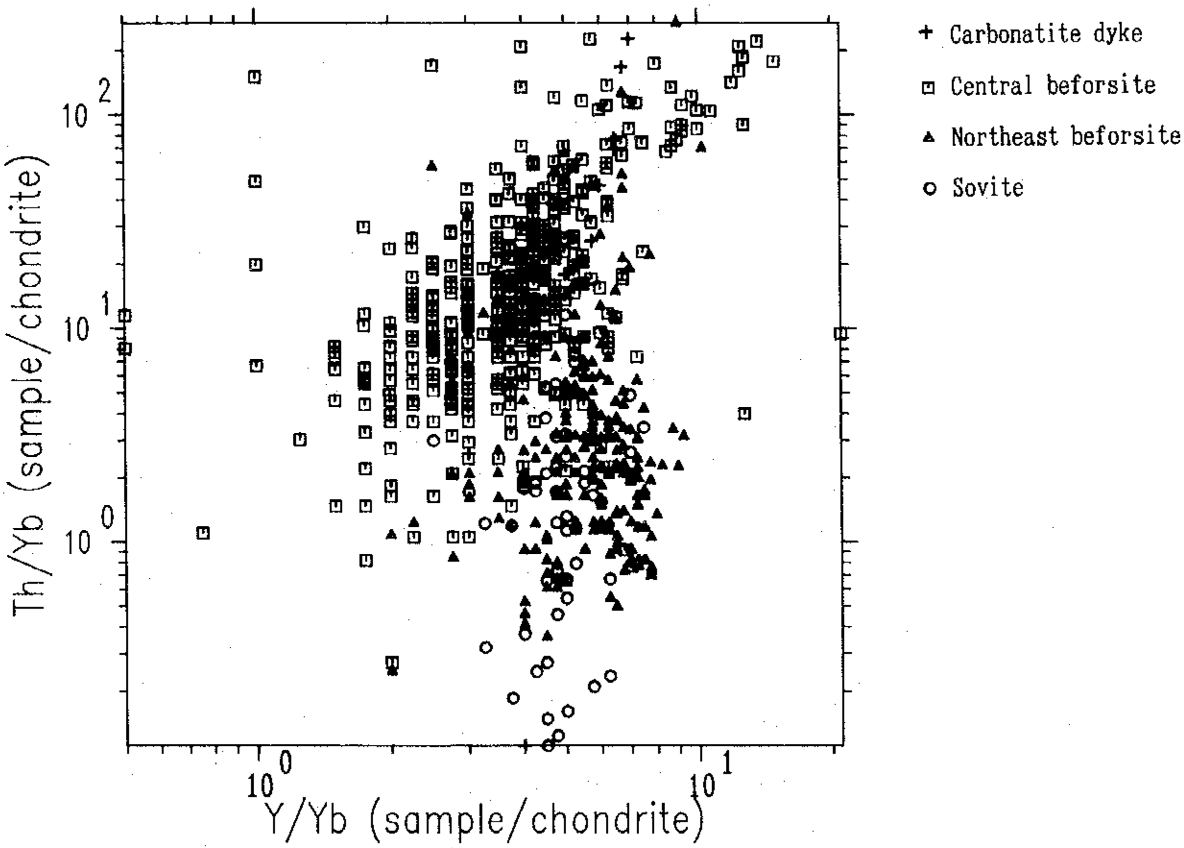


Fig. II-1-9 Y/Yb vs. Th/Yb, and Yb vs. Ce/Yb Diagrams of the Orange Area

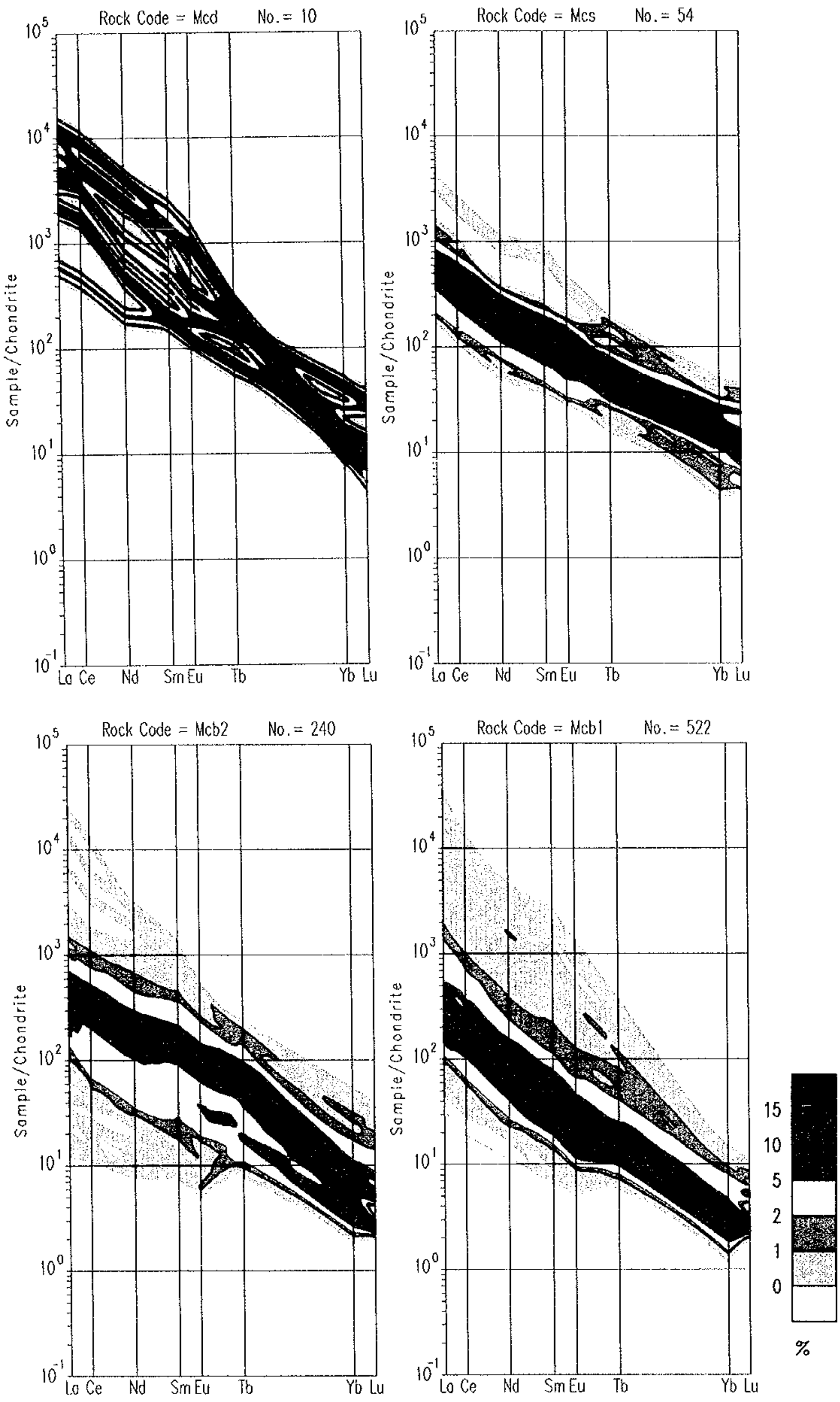


Fig. II-1-10 Rare-Earth Elements Distribution Pattern of the Orange Area (1)

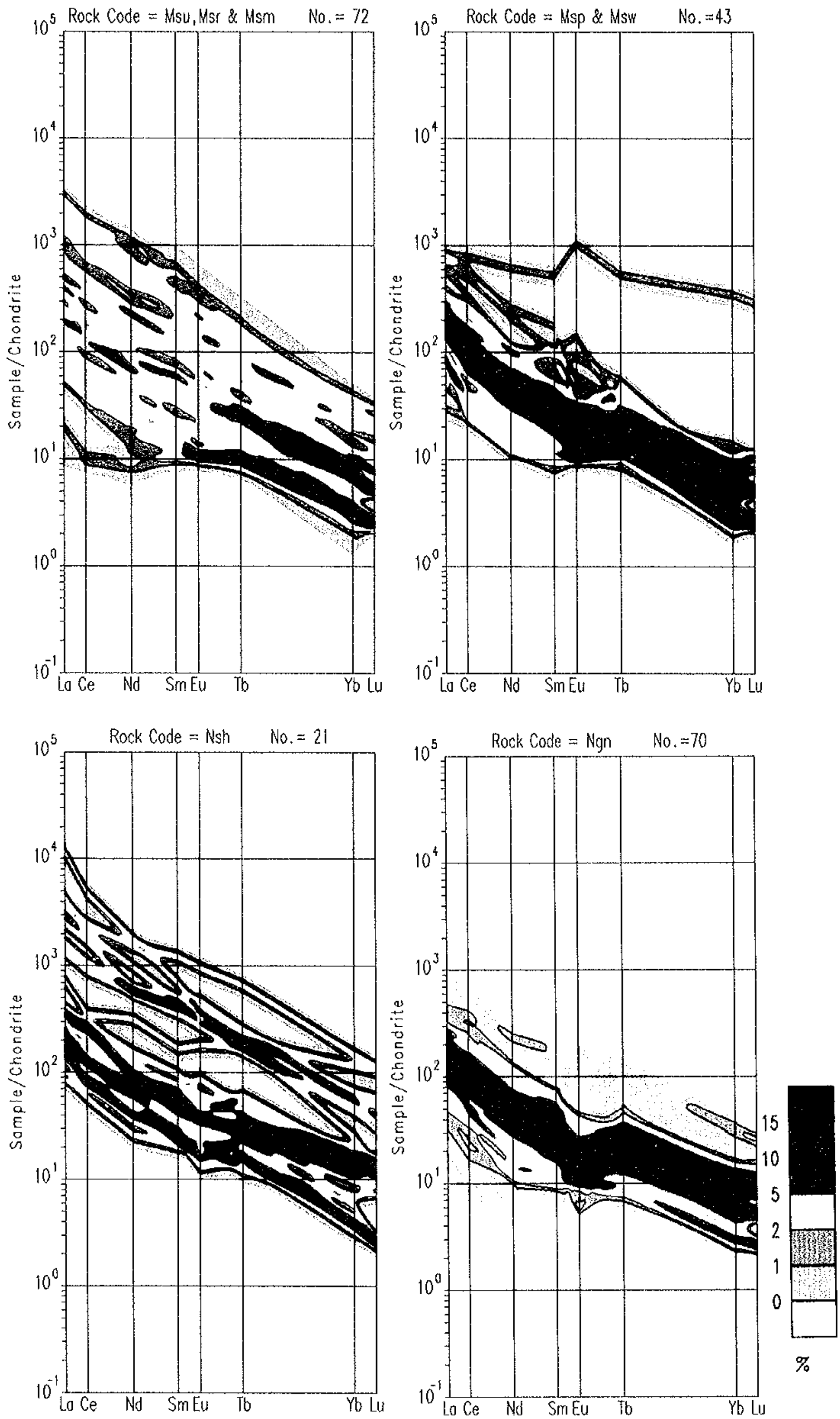


Fig. II-1-10 Rare-Earth Elements Distribution Pattern of the Orange Area (2)

Table II-1-1 Microscopic Observation by Polished Thin Section of the Orange Area

No.	Sample No.	Rock Name	Rock	Silica and silicate minerals													Carbonates				Oxides				Sulfides			Phosphates			Alteration minerals						
			Code	Qtz	Pl	Ab	Kfs	Mel	Anl	Ol	Grt	Spn	Rbk	Bt	Phl	Ms	Cal	Dol	Sd	Bst	Mag	Hem	Prv	Pyro	Py	Mc	Po	Ap			Ep	Bt	Ser	Chl	Srp	Tlc	Goe
1	Cc 510	Beforsite	Mcb1															◎				△											△				△
2	Da 415	Beforsite, Ap	Mcb1	△							△	△					△	◎				△		△													△
3	Db 505	Beforsite	Mcb1	△														◎				△															△
4	Db 515	Beforsite	Mcb1							△							△	◎				◎						△			△						◎
5	E 510	Beforsite	Mcd															◎				◎						△			△	△		△			△
6	Gb 515	Beforsite	Mcb1														△	○				△						△									○
7	Lb 625	Beforsite, Ap-Agt	Mcb2	△							△	△						◎				○		△				○									
8	Lc 625	Beforsite	Mcb2								△		△	?			○	◎						△				○						△			△
9	Nc 600	Beforsite, Cal bearing	Mcb2														○	◎			○			△				○									◎
10	T 1A	Beforsite, Ank	Mcd			△											○	◎		△								△									△

◎:abundant ○:common △:rare

Abbreviation

Qtz:quartz Pl:plagioclase Ab:albite Kfs:potassium feldspar Mel:melilite Anl:analcime Ol:olivine Grt:garnet Spn:sphene Rbk:riebeckite Bt:biotite Phl:phlogopite Ms:muscovite
Cal:calcite Dol:dolomite Sd:siderite Bst:bastnaesite
Mag:Magnetite Hem:hematite Prv:pervskite Pyr:pyrochore
Py:pyrite Mc:marcasite Po:pyrrhotite
Ap:apatite
Ep:Epidote Ser:Sericite Chl:chlorite Srp:serpentine Tlc:talc Goe:goethite
The rock codes are same as in the appendices of B－1.

Table II-1-2 XRD Analyses of the Orange Area

No.	Sample No.	Rock Name	Rock code	Silica and silicate minerals							Carbonates						Oxides		Sulfides			Phosphates			Alteration minerals				
				Qtz	Pl	Ab	Kfs	Rbk	Phl	Ms	Cal	Mcc	Dol	Ank	Sd	Mgs	Mag	Hem	Py	Mc	Po	Ap			Chl	Mnt	Atg	Tlc	Goe
1	Cc 510	Beforsite	Mcb1										●																△
2	Da 415	Beforsite, Ap	Mcb1	△							△		●																△
3	Db 505	Beforsite	Mcb1	△									●																△
4	Db 515	Beforsite	Mcb1								△		●																△
5	E 510	Beforsite	Mcd										●																△
6	Ea 420A	White mineral vein in beforsite	Vein	●							△		○																
7	Gb 515	Beforsite, Gn bearing	Mcb1									○		●															△
8	Lb 625	Beforsite, Ap-Agt	Mcb2	△									●									○							
9	Lc 625	Beforsite	Mcb2					△			○		●																
10	Nc 600	Beforsite, Cal bearing	Mcb2									○	●									○							△
11	T 1A	Beforsite, Ank	Mcd									○		●															△

●:abundant ◎:common ○:poor △:detectable

Abbreviation

Qtz:quartz Pl:plagioclase Ab:albite Kfs:potassium feldspar Rbk:riebeckite Phl:phlogopite Ms:muscovite
Cal:calcite Mcc:manganese calcite Dol:dolomite Ank:ankerite Sd:siderite Mgs:magnesite
Mag:Magnetite Hem:hematite
Py:pyrite Mc:marcasite Po:pyrrhotite
Ap:apatite
Chl:chlorite Mnt:montmorillonite Atg:antigorite Tlc:talc Goe:goethite

Table II-1-3 **Chemical Composition of Bastnaesite and Pyrochlore Analysed by EPMA from the Orange Area (1)**

Sample No.	T1A	
mineral	bastnaesite	
Point No.	1	2
	Weight percentage	
Si	0.026	0.062
Ti	0.000	0.000
La	8.946	7.987
Ce	28.256	27.503
Nd	17.243	12.469
Pr	6.093	4.955
Fe	0.219	1.186
Ca	1.316	4.335
Sr	0.325	1.222
Na	0.011	0.000
F	5.181	3.694
Cl	0.012	0.012
OH (calc.)	3.130	4.750
CO3(calc.)	27.440	28.440
Total	98.198	96.615
Atom number(total metal=1.000)		
Si	0.002	0.004
Ti	0.000	0.000
La	0.137	0.110
Ce	0.428	0.377
Nd	0.254	0.166
Pr	0.092	0.068
Fe	0.008	0.041
Ca	0.070	0.208
Sr	0.008	0.027
Na	0.001	0.000
F	0.579	0.373
Cl	0.001	0.001
OH (calc.)	0.416	0.570
CO3(calc.)	0.971	0.910

Composition of bastabaesite, assuming M(CO3)(F,Cl,OH)

The rock codes are same as in the appendices of B－1.

Table II-1-3 Chemical Composition of Bastnaesite and Pyrochlore Analysed by EPMA from the Orange Area (2)

Sample No.	Da415				Lb625				Lc625			
mineral	pyrochlore				pyrochlore				pyrochlore			
Point No.	1-core	1-rim	2-core	2-rim	1-core	1-rim	2-core	2-rim	1-core	1-rim	2-core	2-rim
	Weight percentage											
Si	0.017	0.018	0.008	0.008	0.012	0.031	0.006	0.023	0.049	0.165	0.076	0.448
Ti	0.848	0.638	0.566	0.750	0.837	0.584	0.652	0.889	1.207	1.469	1.660	1.509
Zr	0.064	0.019	0.010	0.000	0.173	0.004	0.068	0.251	0.046	0.041	0.445	0.069
Ta	0.020	0.059	0.046	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.008
Nb	49.174	50.343	49.036	48.769	48.841	49.010	49.282	48.644	47.911	47.618	45.818	48.108
Ce	0.532	0.564	0.503	0.539	0.167	0.338	0.230	0.228	0.375	0.410	0.216	0.398
Nd	0.047	0.059	0.082	0.103	0.041	0.092	0.055	0.083	0.058	0.074	0.062	0.066
Ca	9.711	10.239	10.188	10.150	11.366	10.376	10.865	11.069	10.865	11.286	11.485	11.167
Sr	1.821	1.322	1.511	1.420	0.775	1.733	1.015	0.844	1.121	0.668	0.618	0.734
Na	5.713	5.936	6.527	6.259	6.229	6.248	6.244	6.128	6.129	6.045	5.967	6.086
F	7.913	7.750	8.604	8.762	8.447	8.373	8.168	8.167	8.193	8.302	8.778	8.634
O(calc.)	24.748	25.378	24.603	24.426	24.986	24.707	24.988	22.768	24.804	25.002	24.203	25.410
Total	100.608	102.325	101.684	101.235	101.874	101.496	101.573	99.094	100.758	101.080	99.328	102.637
	Atom numbers(Si+Ti+Zr+Ta+Nb=2.000)											
Si	0.002	0.002	0.001	0.001	0.002	0.004	0.001	0.001	0.006	0.021	0.010	0.056
Ti	0.065	0.048	0.044	0.058	0.064	0.045	0.050	0.058	0.093	0.112	0.130	0.111
Zr	0.003	0.001	0.000	0.000	0.007	0.000	0.003	0.000	0.002	0.002	0.018	0.003
Ta	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000
Nb	1.930	1.948	1.954	1.940	1.927	1.951	1.947	1.940	1.899	1.865	1.842	1.829
B site	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Ce	0.014	0.014	0.013	0.014	0.004	0.009	0.006	0.014	0.010	0.011	0.006	0.010
Nd	0.001	0.001	0.002	0.003	0.001	0.002	0.001	0.003	0.001	0.002	0.002	0.002
Ca	0.884	0.918	0.941	0.936	1.040	0.957	0.995	0.936	0.998	1.025	1.070	0.984
Sr	0.076	0.054	0.064	0.060	0.032	0.073	0.043	0.060	0.047	0.028	0.026	0.030
Na	0.906	0.928	1.051	1.006	0.993	1.005	0.997	1.006	0.982	0.957	0.970	0.935
A site	1.881	1.917	2.071	2.019	2.071	2.047	2.041	2.019	2.038	2.022	2.074	1.961
F	1.519	1.466	1.676	1.705	1.630	1.630	1.578	1.705	1.588	1.590	1.726	1.606
O(calc.)	5.641	5.702	5.693	5.643	5.726	5.710	5.731	5.643	5.709	5.687	5.651	5.611

Composition of pyrochlore, assuming A2B2O6F as the formula.
The rock codes are same as in the appendices of B－1.

Table II-1-4 Oxygen and Carbon Isotopic composition of carbonatites from the Orange Area

Sp.No.	Rock Name	Rock Code	δ^{13}CPDB (‰)		δ^{18}OSMOW (‰)	
			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	Beforsite, An	Mcd	-4.3	-5.4	14.5	8.7
T 9A	Sovite	Mcs	-5.9	-5.4	6.5	8.3

The rock codes are same as in the Appendices of B－1.

Table II-1-5 Age Determination by Pb-Pb Method of the Orange Area

Sample No.	Mineral	$^{208}Pb/^{204}Pb(2\sigma)$	$^{207}Pb/^{204}Pb(2\sigma)$	$^{206}Pb/^{204}Pb(2\sigma)$	$^{208}Pb/^{206}Pb(2\sigma)$	$^{207}Pb/^{206}Pb(2\sigma)$	Accepted age(m.y.)
Eb315	Galena in Mcbl	38.286 (0.0548)	15.648 (0.0141)	18.139 (0.039)	2.0900 (0.0021)	0.8542 (0.0013)	329

Average values of two grains analyses.

The σ is a standard deviation.

Table II-1-6 Mineral Assemblage of the MQC

	Syenite Body		Sovite-syenite Body			Beforsite Body			
	Msw	Msp	Mcs	Msr	Msu	Mcb1	Mcb2	Mfn	Mcd
Quartz	- - -		- - -			- - -			
Plagioclase	- - -	——						- - -	- - -
Albite	——	——	- - -	——	——		- - -	——	- - -
K-feldspar	——	——	- - -	——	——		- - -	——	- - -
Anorthoclase									
Nepheline	- - -	- - -	- - -	- - -	——- -				
Cancrinite	——	——	- - -	——	——- -		- - -		
Melilite						- - -			
Garnet						- - -	- - -		
Sodalite	- - -		- - -						
Analcime	——	——	- - -	——	——	- - -			
Olivine					- - -	- - -			
Aegirne	——- -	——- -	- - -	- - -	- - -		- - -		- - -
Aegirine-augite	- - -	——		- - -	- - -			——	- - -
Clinopyroxene									
Hornblende	- - -								
Riebeckite	- - -		- - -		- - -		- - -	- - -	- - -
Gedrite									
Biotite	- - -	- - -	- - -	- - -	——- -				
Phlogopite	——	——	——	——	——	——	- - -	- - -	——- -
Calcite	- - -	- - -	——	——	——	- - -	- - -	- - -	——- -
Dolomite			- - -			——	——		
Ankerite			- - -			- - -	——- -		- -——
Kutnahorite			- - -						
Siderite							- - -		- - -
Magnesite						- - -			
Strontianite						- - -			- - -
Barytocalcite			- - -						
Apatite	- - -	- - -	——- -	- - -	- - -	- - -	——	- - -	- - -
Sphene	- - -	- - -	- - -	- - -	- - -	- - -		- - -	
Perovskite						- - -			
Rutile					- - -				
Zircon	- - -		- - -						
Garnet				- - -	- - -				
Fluorite									
Barite			- - -						
Magnetite	——	- - -	- - -		- - -	- - -		- - -	
Hematite			- - -			- - -			
Pyrite							- - -		
Epidote	- - -	- - -			- - -				
Allanite					- - -				
Sericite	- - -	- - -	- - -		- - -			- - -	
chlorite	- - -	- - -	- - -		——- -	- - -	- - -		
Kaolinite				- - -	- - -				
Serpentine					- - -				
Talc					- - -				
Goethite			- - -			- - -	- - -		
Pyrochlore						- - -	- - -		
Bastnaesite						- - -			- - -

Beforsite(Mcb) is subdivided in to the Central beforsite(Mcb1) and the Northeast beforsite(Mcb2).Other rock codes are same as in the appendices of B－1.

Table II-1-7 Analytical Accuracies and Detection Limits

1) Whole rock analysis

Elements(as oxides)	Analytical method[1]	Analytical accurancies detection Limit
SiO_2	GA	0.01 %
TiO_2	ICP	0.01 %
Al_2O_3	ICP	0.01 %
Fe_2O_3	AAS	0.01 %
FeO	$KMnO_4$ Titration	0.01 %
MnO	AAS	0.01 %
MgO	AAS	0.01 %
CaO	AAS	0.01 %
Na_2O	AAS	0.01 %
K_2O	AAS	0.01 %
P_2O_5	AAS	0.01 %
LOI	GM	0.01 %

2) Geochemical analysis

Elements	Analytical method1)	Analytical accurancies detection limit
La	ICP	1 ppm
Ge	ICP	2 ppm
Nd	ICP	5 ppm
Sm	ICP	0.1 ppm
Eu	ICP	0.5 ppm
Tb	ICP	0.1 ppm
Yb	ICP	0.1 ppm
Lu	ICP	0.1 ppm
Sc	ICP	0.5 ppm
Y	ICP	1 ppm
U	ICP-MASS	1 ppm
Th	ICP-MASS	1 ppm
Nb	ICP	2 ppm
Ta	ICP	2 ppm
Zr	ICP	3 ppm
Fe	ICP	0.01 %
Mn	ICP	5 ppm
Sr	ICP	1 ppm
P	ICP	100 ppm

1) GA: gravimetric analysis
AAS: atomic absorption analysis
ICP: inductivity coupled plasma
ICP-MASS: mass spectrometry of ICP

Table II-1-8 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																					
Mgr	5	280	1062	357	159.8	52.9	30.3	54.4	7.6	1.7	860	17	294	214	26	220	1168	1270	40400	5.06	2480
Mcd	10	10225	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	2376	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	392	9385	12082	3192	563.6	107.5	21.0	3.7	0.4	39.1	130	75	666	6611	48	1130	76444	20880	20583	12.90	32716
Mcb2	151	8590	11633	2041	271.3	41.5	12.4	12.1	1.4	22.1	240	28	225	5280	26	67	15468	22060	34175	9.73	27224
Msu & Msr	57	897	1590	870	145.7	31.3	9.2	9.3	1.1	66.2	176	210	156	5389	137	1620	8678	9660	14024	10.44	4218
Mcs	54	275	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	4	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	14	4	1594	405	105.2	39.9	14.4	13.7	1.2	66.1	469	38	119	822	8	631	9090	1700	12900	12.50	3862
Ngn	70	4	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																					
Mgr	5	47	59	17	3.6	0.6	0.8	0.7	< 0.1	< 0.5	3	< 1	5	10	< 2	< 3	28	15	< 100	0.14	157
Mcd	10	46	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	53	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	392	7	18	8	1.6	< 0.5	0.4	0.3	< 0.1	< 0.5	< 1	< 1	< 1	< 2	< 2	< 3	100	820	< 100	0.40	58
Mcb2	151	4	13	7	2.0	< 0.5	0.5	0.6	< 0.1	< 0.5	7	< 1	< 1	< 2	< 2	< 3	1450	269	< 100	1.29	51
Msu & Msr	57	11	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	2	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	1	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	14	2	46	13	1.6	0.8	0.5	0.4	< 0.1	< 0.5	4	< 1	2	22	< 2	< 8	210	57	134	0.53	121
Ngn	70	1	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																					
Mgr	5	179	437	153	41.6	12.92	6.98	13.02	1.82	0.74	187.4	5.20	81.2	110.6	6.80	71.2	458	447	9230	2.19	1157
Mcd	10	2153	4186	1304	193.7	43.85	9.82	4.92	0.59	6.86	72.8	10.50	233.2	239.7	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	293.4	11.63	241.2	2468	1420	2668	4.62	966
Mcb1	392	487	646	174	27.8	5.48	1.70	0.90	0.12	4.92	12.3	4.48	33.5	865.2	3.43	16.5	7021	5372	854	4.42	1665
Mcb2	151	290	469	177	33.1	7.73	3.25	2.02	0.25	2.60	36.1	3.17	18.4	1238.0	4.08	4.8	7290	6279	8640	3.73	1253
Msu & Msr	57	179	294	112	21.1	5.18	2.14	1.97	0.25	3.44	24.5	18.74	26.3	761.2	18.84	311.8	1986	1724	2838	3.50	790
Mcs	54	227	393	132	28.1	7.96	3.27	4.06	0.52	1.22	61.2	20.07	12.0	608.1	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	547.4	5.12	158.9	1125	1399	3561	2.47	392
Nsh	14	173	299	110	23.7	8.36	3.84	4.25	0.48	13.49	92.7	8.07	29.1	160.9	3.50	130.4	1813	522	2577	4.78	821
Ngn	70	62	110	38	7.9	1.96	1.38	2.12	0.31	9.28	23.9	5.20	20.7	92.6	3.37	156.9	1136	354	1087	3.15	296
Geometric average																					
Mgr	5	132	271	90	16.4	3.97	2.16	3.51	0.47	0.64	32.2	3.07	29.4	69.1	3.34	20.2	162	172	1082	1.34	722
Mcd	10	1569	3151	888	136.6	31.52	8.97	4.20	0.49	4.61	68.6	5.02	85.5	92.7	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	233.5	7.27	81.4	1696	705	1337	4.13	439
Mcb1	392	167	259	75	12.3	2.72	1.18	0.83	0.11	4.34	9.6	2.71	14.3	300.8	2.52	4.0	6340	5180	194	4.13	662
Mcb2	151	150	271	116	23.0	5.53	2.60	1.65	0.20	1.65	28.2	1.69	7.9	632.6	2.69	3.8	7008	5072	4365	3.50	757
Msu & Msr	57	87	141	53	11.0	2.95	1.48	1.45	0.20	1.27	14.7	8.45	15.3	370.9	11.25	137.9	1417	1033	1292	3.19	401
Mcs	54	201	346	119	24.6	7.16	3.01	3.79	0.47	0.83	57.1	5.69	6.3	164.5	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	279.8	4.05	81.4	972	1107	1253	2.03	281
Nsh	14	100	172	65	12.5	3.86	2.30	2.90	0.35	5.00	41.6	3.93	13.7	78.8	2.94	65.4	1144	350	1189	3.37	485
Ngn	70	52	86	30	6.4	1.51	1.18	1.79	0.26	5.94	16.0	3.24	14.0	45.9	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 in the appendices of B-1.

Chapter 2 Drilling Survey

2-1 Survey Method

From the results of the Literature Search and the Geochemical Survey in the Phase I, it was seen that two beforsite bodies of the carbonatite complex in the Orange area show concentrations of REEs, niobium, and phosphorous. Therefore, a drilling survey was conducted to reveal the underground distribution and continuity of the elements in these beforsite bodies.

Fig.II-2-1 shows the drilling sites. The drilling sites total 8 holes. Five of the holes are situated in the central beforsite and the other 3 holes are situated in the northeast beforsite. These holes are drilled vertically a depth of 150 metres each.

Actual drilling work was engaged by a Namibian drilling company, and controlled by Japanese members of this cooperation. A geological member observed all drilling cores and checked peripheral field geology. The results of the drilling work was combined with the results of the geochemical survey and utilized for integrated consideration of ore potential.

2-1-1 Outline of the Survey

The results of drilling core observations are described in the geologic columnar sections. The rock specimens were sampled every five metres in sections of the beforsite parts which were believed to show concentrations of rare earth elements and other elements. These rock specimens are treated for geochemical analyses (19 elements) and whole rock analyses (12 elements). Specifically, sections of beforisite, which have variable components, were analyzed in narrow sampling spans.

To clarify the beforsite occurrences, representative rock samples for each drilling core were sampled for observation of polished sections, X-ray analysis(XRD), and oxygen-carbon isotopic analysis. Samples with concentrations of rare earth elements were analysed quantitatively by EPMA.

Table I-1-1 shows the outline of the survey.

2-1-2 Method and Equipment

The drilling operation was carried out by a Namibian company, Rosond Exploration and Foundation (Pty.) Ltd. Drilling machines, drill bits, mud materials, oil, and cements were supplied from Namibia and South Africa. The Wire-line method was adopted with BQ size in final diameter. Two drilling machines were of Longyear-38, the other two were Byles 17 and 25, respectively.

Casing pipe, bentonite, and cement were used case on case basis for high core recovery in fractured and water lost circulation zones in each hole. Specially,in hole MJNO-2, C.M.C. materials were used to prevent collapses of the inner wall in the fractured zone.

Table II-2-1 shows a list of Drilling equipments. Table II-2-2 shows drilling materials consumed. Table II-2-3 shows drilling bits and reamers consumed . Table II-2-4 shows drilling work progress. Table II-2-5 shows the summaries of each drilling work.

2-1-3 Drilling Work

1. Mobilization and Demobilization

The drilling machines, subsidiary equipment, and consumable were mostly transported by truck from Windhoek, the capital city of Namibia, to the survey area. The drilling sites were located on the steep slopes of a mountainous area. Therefore, assembly and dismantling of the drilling equipments was done by using helicopters. This operation by the helicopter was done carefully and was suspended in the case of strong seasonal winds. The helicopter used in the first period was from Heliquip (Pty.) Ltd. in Cape Town, the one of second half is of National Airway Corporation Western Cape.
The foundations of the drilling sites and heliports were constructed by manpower. The other base sites were constructed on light works.

After completion of the drilling work, the equipment and tools were maintained in Windhoek. The drilled cores were oriented to clarify tops and bottoms, and depth. After that these were transported and stored with the Geological Survey of Namibia.

2. Working System

The drilling operation was performed under a system comprised one of supervisor, one foreman, three drilling crews and two water supply crews. Each drilling crew was comprised of one driller and 4 assistants. Each water supply crew was comprised of one driver and one assistant.
One working shift of 11 hours work per day, was used. But two sifts were used in the last drilling stage to keep to the proposed schedule. Base camp site was set up near the drilling sites.

3. Water Supply

There is no river and water in the survey area. Therefore, the drilling water was transported rapidly from the Orange river, 30 km far from the survey area, by two 4 tons trucks, each carrying a 3 ton water tank, .

2-1-4 Drilling Progress

1. MJNO-1

This hole was drilled by NXC size from 0.0 to 3.0 m, NQ-WL size from 3.0 to 51.1 m, BQ-WL size from 51.1 to 150.4 m. No trouble such as lost circulation or inner wall collapse was encountered during this operation. The drilling averaged was 23.14 m/day. Core recovery was 99.93 %.

2. MJNO-2

This hole was drilled by NXC size from 0.0 to 8.0 m, NQ-WL size from 8.0 to 32.0 m, BQ-WL size from 32.0 to 150.4 m.

Total loss of water was encountered at 34.4 m under BQ-WL size drilling. To prevent this water loss, the hole was cemented to 40.82 m. After cementing, this hole was reamed by NQ size and BX casing installed. The second water loss was encountered at 46 m under BQ size drilling. After drilling to 51.9 m, BX casing was installed to this depth, but water loss was continued. Drilling was continued under this condition. Several wall collapses were encountered from 52 to 75 m. Therefore, Bx casing was installed to 78 m. After this casing, water loss continued until 150.4 m.

Drilling performance was 11.14 m/day, and core recovery was 51.66 %.

3. MJNO-3

This hole was drilled by NXC size from 0.0 to 5.7 m, NQ-WL size from 5.7 to 35.4 m, BQ-WL size from 35.4 to 150.3 m. Water losses were encountered at 34.0 m, 36.0 m, 57.7 m, 104.0 m, respectively. These water losses were recovered by cementing.

Drilling performance was 12.53 m/day, the core recovery was 99.55 %.

4. MJNO-4

This hole was drilled by NXC size from 0.0 to 3.5 m, NQ-WL size from 3.5 to 50.3 m, BQ-WL size from 50.3 to 150.2 m. No trouble such as lost circulation or wall collapse was encountered during this operation. Drilling performance was 30.05 m/day, and core recovery was 99.7 8%.

5. MJNO-5

This hole was drilled by NXC size from 0.0 to 3.1 m, NQ-WL size from 3.1 to 51.3 m, BQ-WL size from 51.3 to 150.3 m. No troubles such as lost circulation or wall collapse was encountered during this operation. Drilling performance was 16.71 m/day, and core recovery was 95.7 6%.

6. MJNO-6

This hole was drilled by NXC size from 0.0 to 4.2 m, NQ-WL size from 4.2 to 19.2 m, BQ-WL size from 19.2 to 150.5 m. No trouble such as lost circulation or wall collapse was encountered during this operation. Drilling performance was 11.15 m/day, and core recovery was 99.27 %. This hole was done by two working shifts to keep the proposed schedule.

7. MJNO-7

This hole was drilled by NXC size from 0.0 to 3.0 m, NQ-WL size from 3.0 to 21.0 m, BQ-WL size from 21.0 to 150.5 m. No trouble such as lost circulation or wall collapse was encountered during this operation. Drilling performance was 11.15 m/day, and core recovery was 99.80

%.

8. MJNO-8

This hole was drilled by NXC size from 0.0 to 3.4 m, NQ-WL size from 3.4 to 20.0 m, BQ-WL size from 20.0 to 150.4 m. No troubles such as lost circulation or wall collapse was encountered during this operation. The drilling performance was 11.14 m/day, the core recovery was 99.73 %.

2-2 Survey Results

Appendix B-6 shows drilling logs. Fig.II-2-3 shows geochemical distribution along drilling cores. Table II-2-6 and Appendix A-2 show the results of observation of polished sections. Table II-2-7 shows the results of X-ray diffraction analyses. Table II-2-8 shows the results of EPMA analyses. Table II-2-9 shows the results of oxygen and carbon isotope analyses. Table II-2-10 shows statistical results of the geochemical analyses of the drilling cores.

2-2-1 Geology and Mineralization

1. MJNO-1

The section from 0.0 to 52.5 m is composed of weathered light brownish-grey to fresh very light grey beforsite (Mcb1). Magnetite and its weathering products of iron oxides and hydroxides are common in this section. It is somewhat rich in phlogopite and pyrite. This section shows distinct banding which dips 60 to 70 °. The section from 52.0 to 109.6 m is composed of light grey arkose which is partly brecciated with a matrix of beforsite. The section from 109.6 to 150.4 m is composed of carbonitized syenite (Msu) with light grey sovite (Mcs) veins and networks.

Normative minerals and average norms of beforsite are magnetite (2.39%), hematite (0.51%), rutile (0.28%), apatite (5.20%), forsterite (0.26%), fayalite (0.86%), calcite (48.67%), magnesite (13.62%), siderite (4.56%) and strontianite (1.15%).

Pyrite, pyrrhotite, sphalerite and galena were identified under the microscope.

$\delta^{13}C$ values of calcite and dolomite are -4.6 and -4.7 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite are +8.0 and +8.5 ‰, respectively. Calcite is enriched in ^{13}C, and dolomite is enriched in ^{18}O.

2. MJNO-2

The section from 0.0 to 136.0 m is composed of weathered brown beforsite and fractured beforsite (Mcb2) in which goethite and montmorillonite were formed by weathering. The section is somewhat rich in phlogopite and muscovite. The section from 136.0 to 150.4 m is composed of silicified trachyte (Ktd).

Normative minerals and average norms of beforsite are magnetite (5.23%), hematite (3.80%), rutile (0.07%), apatite (3.04%), forsterite (6.68%), fayalite (0.34%), calcite (46.60%), magnesite (24.19%), siderite (0.73%) and strontianite (1.07%).

3. MJNO-3

The section from 0.0 to 15.0 m is composed of weathered light brown beforsite (Mcb1), and very light grey sulphide-rich beforsite (Mcb1) which includes in pyrite and pyrrhotite. The shallower part of this section is accompanied by dark brown ankeritic beforsite, and the deeper part is accompanied by light brownish-grey magnetite-rich beforsite.

Normative minerals and average norms of beforsite are magnetite (3.14%), hematite (0.08%), rutile (0.01%), apatite (0.02%), forsterite (0.03%), fayalite (0.59%), calcite (56.50%), magnesite (34.85%), siderite (1.81%) and strontianite (1.96%).

Euhedral pyrochlore contains from 50.67 to 51.90 weight % of Nb, and from 0.47 to 0.84 weight % of Ce. Chemical formula of pyrochlore on the average is determined as $(Na_{0.93},Ca_{0.92},Sr_{0.04}Ce_{0.02})_{1.91}(Nb_{1.97},Ta_{0.00},Zr_{0.00},Ti_{0.03},Si_{0.00})_{2.00}O_{5.72}F_{1.43}$ by EPMA analyses.

$\delta^{13}C$ values of calcite and dolomite range from −4.0 to −4.6 ‰, and from −4.0 to −4.6 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite range from +8.2 to +8.5 ‰, and from +8.2 to +8.5 ‰, respectively. $\delta^{13}C$ values of dolomite are slightly higher than that of calcite. $\delta^{18}O$ values of calcite are nearly same as that of dolomite. Samples for isotopic analyses are taken from several depths. It show that $\delta^{13}C$ values increase and $\delta^{18}O$ values decrease in proportion to depth.

4. MJNO-4

The section from 0.0 to 150.2 m is composed of weathered light brown beforsite and fresh very light grey beforsite (Mcb2) which are accompanied by pyrite and pyrrhotite-rich portions and phlogopite and magnetite-rich portions. The beforsite shows distinct banding which dips 60 to 70 degrees.

Normative minerals and average norms of beforsite are magnetite (0.51%), hematite (0.02%), rutile (0.04%), apatite (0.64%), forsterite (0.97%), fayalite (2.74%), calcite (53.45%), magnesite (35.27%), siderite (3.67%) and strontianite (1.09%).

$\delta^{13}C$ values of calcite and dolomite are the same at −3.7 ‰. $\delta^{18}O$ values of calcite and dolomite are the same at 8.8 ‰.

5. MJNO-5

The section from 0.0 to 105.1 m is composed of very light grey beforsite with alternating of phlogopite-rich, magnetite-rich and sulphide-rich portions. The surface section shows weathering. The section from 34.0 to 39.0 m is intruded by dolerite. The section from 105.1 to 108.4 m is composed of dark green metasomatic syenite (Msu) blocks. The section from 108.4 to 150.3 m is composed of very light grey micro-granite (Mgr).

Normative minerals and average norms of beforsite are magnetite (2.89%), hematite (0.00%), rutile (0.02%), apatite (0.74%), forsterite (10.30%), fayalite (4.90%), calcite (47.21%), magnesite (30.87%), siderite (0.14%) and strontianite (1.03%).

Pyrite, magnetite, marcasite, and sphalerite were observed under the microscope in the beforsite.

6. MJNO-6

The section from 0.0 to 101.0 m is composed of very light grey beforsite (Mcb2) which is accompanied by alternating sulphide-rich and phlogopite-rich portions. The section from 101.0 to 147.2 m is composed of very light grey beforsite (Mcb2) which is enriched in apatite with phlogopite and sulphides such as pyrrhotite. The beforsite shows distinct banding which dips 60 degrees. In this section, black dolerite dyke intrudes.

Normative minerals and average norms of beforsite are magnetite (0.91%), hematite (0.02%), rutile (0.04%), apatite (3.94%), forsterite (0.02%), fayalite (2.52%), calcite (56.28%), dolomite (27.29%), siderite (2.15%) and strontianite (1.93%).

Euhedral pyrochlore contains from 48.18 to 50.21 weight % of Nb, and from 0.40 to 0.41 weight % of Ce. Chemical formula of pyrochlore on the average is determined as $(Na_{0.88},Ca_{0.94},Sr_{0.08}Ce_{0.01})_{1.91}(Nb_{1.91},Ta_{0.00},Zr_{0.00},Ti_{0.08},Si_{0.01})_{2.00}O_{5.72}F_{1.48}$ by EPMA analyses.

$\delta^{13}C$ values of calcite and dolomite are the same at -4.9 ‰. $\delta^{18}O$ values of calcite and dolomite are also the same at 8.3 ‰.

7. MJNO-7

The section from 0.0 to 150.5 m is composed of very light grey beforsite (Mcb2). The shallower section is accompanied by alternating of sulphide-rich and magnetite-rich portions. The intermediate to deeper section is accompanied by pale green apatite-rich beforsite. The beforsite shows distinct banding which dips 60°. The section from 24.5 and 30.5 m is intruded by a black dolerite dyke .

Normative minerals and average norms of beforsite are magnetite (0.09%), hematite (0.13%), rutile (0.01%), apatite (6.63%), forsterite (0.03%), fayalite (0.41%), calcite (56.06%), magnesite (31.26%), siderite (3.12%) and strontianite (1.26%). Pyrite, magnetite and pyrochlore are observed under the microscope.

The pyrochlore contains from 48.98 to 49.62 weight % of Nb, and 0.27 to 0.39 weight % of Ce.

$\delta^{13}C$ values of calcite and dolomite are -4.7 and -4.8 ‰, respectively. $\delta^{18}O$ values of calcite and dolomite are the same at +8.3 ‰.

8. MJNO-8

The section from 0.0 to 150.4 m is composed of very light grey beforsite (Mcb2). The shallower section is accompanied by phlogopite-rich beforsite, dark green metasomatic slate blocks and dolerite dyke. The intermediate to deeper section is accompanied by pale green apatite-rich beforsite and trachyte dyke. The beforiste shows distinct banding which dips 60°.

Normative minerals and average norms of beforsite are magnetite (0.23%), hematite (0.02%), rutile (0.04%), apatite (4.85%), forsterite (5.37%), fayalite (2.74%), calcite (48.27%), magnesite (28.73%), siderite (1.92%) and strontianite (1.09%). Pyrite, magnetite, pyrrhotite and pyrochlore are observed under the microscope.

$\delta^{13}C$ values of calcite and dolomite are the same at −4.7 ‰. $‰^{18}O$ values of calcite and dolomite are the same at +8.2 ‰.

2-2-2 Geochemical Results

Rock specimens were sampled every five metres in sections bearing beforistes. The sections which were believed to show concentrations of rare earth elements were sampled with spans closer than five metres.

Appendix A-2 shows the geochemical analyses. Table II-3-1 shows the statistical data of geochemical analyses. Fig.II-2-6 shows the geochemical distributions along the drill cores. Geochemical analyses were carried out for the following 19 elements;
La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Sc, Y, U, Th, Nb, Ta, Zr, Mn, Sr, P and Fe

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

The MJNO-1 drill section shows an average content of 1,150 ppm of Ce, but other sections show contents of less than 1,000 ppm.

The maximum contents in MJNO-1 of La and Ce are 10,930 and 10,023 ppm, respectively. The average content of rare-earth oxides in MJNO-1 exceeds 3,000 ppm, other sections show contents of less than 1,000 ppm.

REEs are more concentrated in the central and northeast beforsites than in other rock facies. But rock facies with beforsite networks in contact with beforsites have high contents of REEs.

Total rare-earth oxides contents of the central and northeast beforsite are the same according to the statistic t-test. But middle and heavy REEs are concentrated more in northeast beforsite compared with the central beforsite.

Each section has variable contents of REEs. REEs have no tendency to increase with depth.

2. **Scandium and Yttrium**

Each section shows an average content of less than of 100 ppm of Sc. The central beforsite shows an average content of 47.3 ppm. The northeast beforsite shows an average content of 4.3 ppm. Sc is concentrated in the central beforsite, compared with the north beforsite.

Each section shows an average content of less than 100 ppm of Y. The central beforsite shows an average content of 10 ppm. The northeast beforsite shows an average content of 35 ppm. Y is more concentrates in the northeast beforsite compared with the central beforsite.

3. Uranium and thorium

Each section shows an average content of less than of 100 ppm of U. The central beforsite shows an average content of 6 ppm. The northeast beforsite shows an average content of 3 ppm. U is concentrated in the central beforsite, compared with the northeast beforsite.

Each section shows an average content of less than 100 ppm of Th. The central beforsite shows an average content of 24 ppm. The northeast beforsite shows an average content of 17 ppm. The content of Th in the central beforsite is the same as that in the north beforsite.

4. Niobium and tantalum

Sections of MJNO-4, 5, 6 and 7 show average contents of over 1,000 ppm of Nb. The other sections show averages of more than 500 ppm. The maximum content is 5.2% in MJNO-7, but the high contents are not continuous. The central beforsite shows an average content of 1,111 ppm, while the northeast beforsite shows an average content of 2,073 ppm. The content of Nb in the central beforsite is same as that in the northeast beforsite.

Each sections show an average contents of less than 30 ppm of Ta. The central beforsite shows an average content of 8 ppm. The northeast beforsite shows an average content of 2 ppm. Ta is concentrated in the central beforsite, compared with the northeast beforsite. Each section has variable contents of Ta

Nb and Ta have no tendency to increase with depth.

5. Zirconium

Each section shows average contents of from 3 to 136 ppm of Zr. The central beforsite shows an average content of 20 ppm. The northeast beforsite shows an average content of 14 ppm. The content of Zr in the central beforsite is the same as that in the northeast beforsite.

6. Manganese

Each section shows average contents of from 4,700 to 7,600 ppm of Mn. The central beforsite shows an average content of 6,971 ppm, while the northeast beforsite shows an average content of 6,293 ppm. The content of Mn in the central beforsite is the same as that in the northeast beforsite.

MJNO-1 in the central beforsite shows higher contents in shallow portions and lower contents