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

PHASE I

MARCH 1994

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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PREFACE

In response to the request of the Government of the Republic of Namibia, the Japanese Government decided to conduct a 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 20 October to 23 December, 1993.

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

We hope that this report will serve for 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 of the Government of the Republic of Namibia for their close cooperation extended to the team.

February 1994

Kensuke YANAGIYA
President
Japan International Cooperation Agency

Takashi ISHIKAWA
President
Metal Mining Agency of Japan

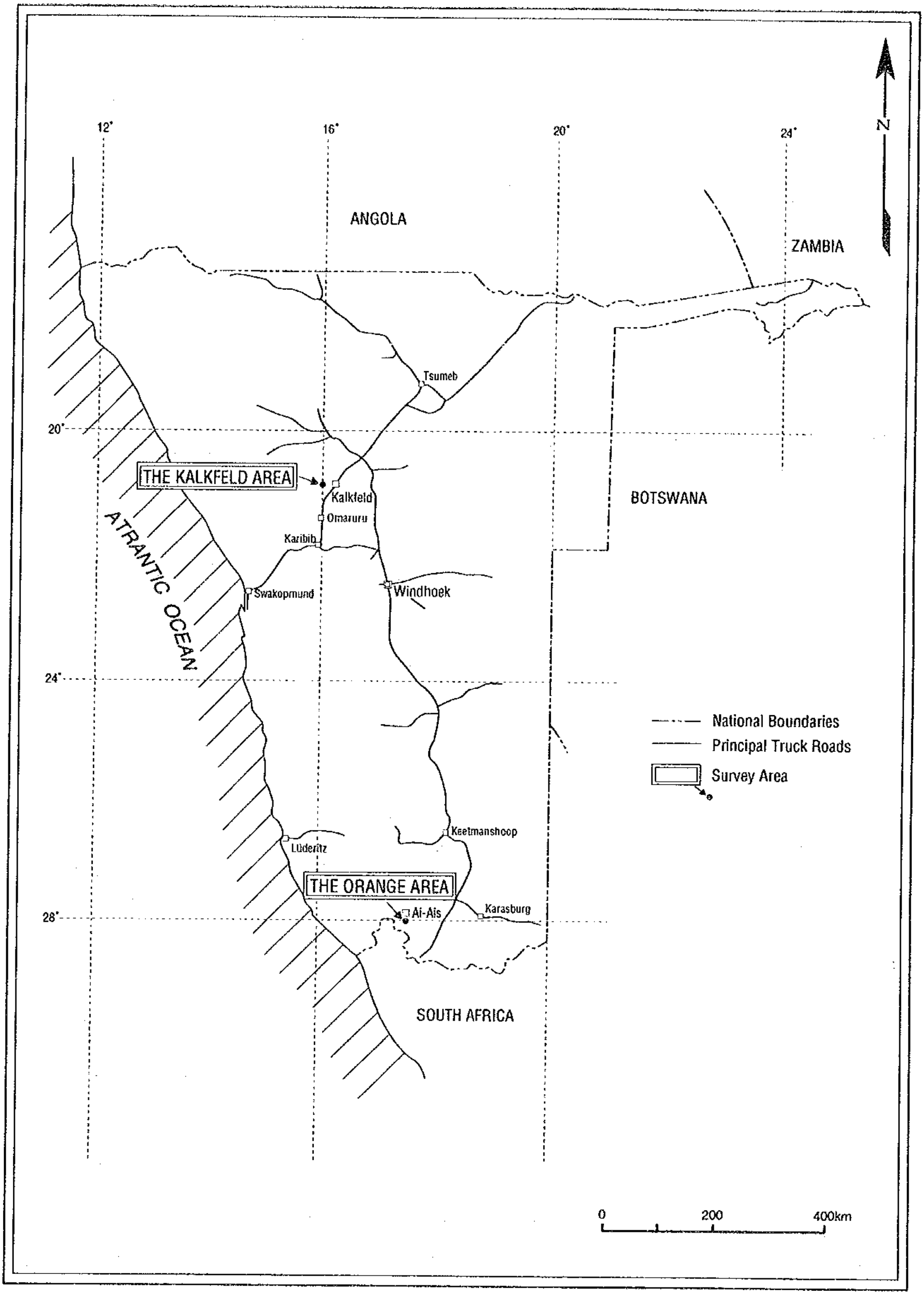

Fig.I–1–1 Locality of Survey Areas

Abstract

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

In this 1993 fiscal year as the Phase I of this project, the literature survey and geochemical survey were conducted. The literature survey includes compiled geologic mapping, selection of high potential mineralized area, and distribution analysis of rare earth elements. Geochemical survey was conducted by both narrow grid system in the carbonatite complex area and wide grid system in its peripheral area.

The results of the survey are as follows:

1) The Orange Area

The area is underlain by the Namaqua metamorphic complex of Precambrian age and the Nama group of Cambrian age. Carbonatite complex intrudes these basement rocks. The Namaqua metamorphic complex comprises gneiss. Nomoi group comprises shale and quartzite. Carbonatite complex comprises beforsite, sovite, syenite, trachyte and so on. This complex shows plutonic plug in shape. Major minerals of carbonatite are of calcite, dolomite and ankerite. Subordinated minerals are of siderite, manganocalcite, apatite, barite, magnetite, hematite, bastnaesite, monazite and pyrochlore. Last three 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 phosphorus. Compared with carbonatite in the Kalkfeld area, Nb and P are dominant.

2) Kalkfeld Area

The area is underlain by the Damara sequence of Precambrian age. Granitoids and Carbonatite complex of Cambrian age intrude this basement rocks. The Damara Sequence comprises marble. Carbonatite complex comprises volcanic breccia, beforsite, and iron ore. This complex 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 Fe-rich beforsite contain respectable content of Th. Geochemical survey indicates the concentration of La, Ce, Nd, Th, Mn, Sr and P in carbonatite complex. Particularly 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 Fe are dominant.

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 carbonatite complex 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 underground 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.

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General Remarks

Part I General Remarks

Chapter 1 Introduction

I-1-1 Background and Purpose of the Survey

This survey is two phase project starting from 1993 to 1995 in the Orange and Kalkfeld areas. This year, 1993, is the first phase of the project. There are carbonatite complexes such the Marinkas Quelle carbonatite complex in the Orange area, and the Osongombo diatreme in the Kalkfeld area. They are respected to contain valuable amount of rare earth elements and related ones. The government of the Republic of Namibia requested to conduct the technical cooperation for 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 access the potential of new deposits.

I-1-2 The Survey Area and Outline on the Works of the Phase I

Locality of survey area is shown in Fig.I-1-1. The outline on the work of the phase I is as follows.

I-1-2-1 Literature Search

The samples and documents as for geology, geophysics, geochemistry, mineralization which are kept in the Geological Survey of Namibia, Ministry of Mines and Energy (hereinafter referred to sa GSN) are analyzed. The characteristics of geology and mineralization based on these data were summarized and compiled in geologic map on a scale of 1:2,500 (hereinafter referred to as the compiled geologic map).

I-1-2-2 Geological and Geochemical Survey

The compiled geologic map was confirmed and amended by field survey. In the mineralized area before geochemical survey. The detail of the method on geochemical survey was determined by the result of based on the result of the literature search.

Rock sampling by grid system was carried out for geochemical survey to reveal the horizontal geochemical anomalies. The survey areas are divided into general and detailed geochemical survey parts, which are decided by the literature search and field survey. In the dominant parts of carbonatite and rare earth elements-bearing (hereinafter called as REE-) syenite, detailed geochemical surveys are conducted.

Sampling points, outcrops and mineralization sites were checked by measurement, and these field descriptions are used to renew the geological maps.

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

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

Items	Contents		
Data Compiling	Geological Maps Geological Literatures Landsat Data	2 maps 10 sets 1 set	
Geochemical Survey		Orange Area	Kalkfeld Area
	Survey Area	3 km^2	2 km^2
	Nos. of Samples	350 samples	150 samples
	Nos. of Test Samples		
	Thin Section	30 samples	10 samples
	Polished Section	25 samples	5 samples
	X-ray Diffraction	20 samples	10 samples
	Whole Rock Analyses	30 samples	10 samples

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

Laboratory Items and Analytical Elements	Contents
(1) Observation of Thin Section	40 samples
(2) Observation of Polished Section	30 samples
(3) X-ray Diffraction Examination	30 samples
(4) Whole Rock Analyses (SiO_2,TiO_2,Al_2O_3,Fe_2O_3,FeO,MnO,CaO,N_2O, MgO,K_2O,P2O_5 and LOI : 12 elements)	40 samples
(5) Geochemical Analyses (La,Ce,Nd,Sm,Eu,Tb,Yb,Lu,Sc,Y,U,Th,Nb, Ta,Zr,Fe,Mn,Sr and P: 19 elements)	500 samples

I-1-3 Members of the Survey

The following members were organized as the survey team, who negotiate the survey planning and conducted and actual survey.

Planing and Negotiation:

Japanese Representative

Mr. Takahisa Yamamoto	(Metal mining Agency of Japan)
Mr. Naofumi Hashimoto	(Ministry of foreign Affairs, Japan)
Mr. Yoichi Ida	(Ministry of International Trade and Industry, Japan)
Mr.Satoshi Shiokawa	(Metal Mining Agency of Japan)
Mr.Koh Naito	(Japan International Cooperation Agency)
Mr.Yoichi Okuizumi	(Metal Mining Agency of Japan)

Namibian Representatives

Mr. Josephat Vatanavi Mazeingo	(Acting Permanent Secretary, Ministry of Mines and Energy)
Dr. Brian G. Hoal	(Director of Geological Survey of Namibia)
Dr. Gabriele I.C. Schneider	(Chief Geologist of Geological Survey of Namibia)

Field Survey:

Japanese Member	
Mr. Yukuo Kinryu	(Geologist of Dowa Engineering Co.,Ltd.)
Mr. Hirohide Konno	(Geologist of Dowa Engineering Co.,Ltd.)
Mr. Hiroyuki Okamura	(Geologist of Dowa Engineering Co.,Ltd.)

Namibian Member

Dr. Gabriele I.C. Schneider	(Chief Geologist of Geological Survey of Namibia)
Bc. Herbert Roesener	(Geologist of Geological Survey of Namibia)

Field Supervisor:

Mr. Takafumi Tujimoto	(Metal Mining Agency of Japan)

I-1-4 Terms of the Survey

The survey was carried as follows:

Field Survey	22 October to 20 December, 1993
Literature Search	25 October to 28 October, 1993
Geological and Geochemical Survey	29 October to 12 December, 1993
Data Compilation	13 December to 19 December, 1993

Chapter 2 Physical Features

I-2-1 Location and Traffics

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

Windhoek — 679 km (Route B1) 7 hours — 64 km (Route C10) 1 hour — base camp site Ai-Ais — 36 km (unpaved road) 30 min. — Kanabium Farm — 20 km (unpaved road) 30 min. — Orange Area

The Kalkfeld area is situated in the Omaruru state, northern part of Namibia. The access form Windhoek by vehicle is as follows.

Windhoek — 64 km (Route B1) 45 min. — 100 km (Route B2) 1 hour — 61 km (Route C33) 40 min. — base camp site Omaruru — 71 km (Route C33) 40 min. — Kalkfeld — 20 km (unpaved road) 20 min. — Osongombo — 2.5 km (unpaved road) 10 min. — Kalkfeld area

I-2-2 Topography and River System

Namibia land covers 820,000 square kilometers. Namibia is twice wider than Japan and is in contact with Angola, Zambia, South Africa and Botswana.

The topography is divided into the forest zone of the northern part of Namibia, 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 and the desert zone. The Kalkfeld area is situated in the savannah 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 which show gentle mountainous shape. The parts intruded by carbonatites form peaks of mountains because of relatively low weathering.

In the Kalkfeld area, the parts underlain by basement marbles show flat shape. The parts intruded by granitic rocks and carbonatite show hilly shape.

River systems in the Orange and Kalkfeld areas are not wide. In the rainy season river water flows, but in the dry season the rivers dry up.

I-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.

Windhoek, the capital of Namibia, shows 13 degrees centigrade on the average in July and 23 degrees centigrade on the average in December. Annual rainfall is 600 mm in the forest zone, 20 mm in the desert zone, and 350 mm in the inland plateau on the average. Rainfall is many in summer season of October to April, and is 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.

I-2-4 Others

Both Orange and Kalkfeld areas are easily accessible by using unpaved road in private farms and/or state lands. Permission is needed to cross farms.

During the Orange area survey, the base camp is set up in Ai-Ais spa resort, during the Kalkfeld the base camp site is set up in Omaruru town.

Chapter 3 Previous Works

I-3-1 Outline of Previous Works

Advertisement Supplement to Mining Journal (1992), and Namibia Foundation (1993) inform as for history, circumstance, economy, investment and law of mining in Namibia.

Regional geologic maps are published by Geological Survey of Namibia (1982) on the scale of 1:1,000,000 and the Geological Society of South Africa (1985) on the scale of 1:4,000,000. Regional geologic maps are published from Geological Survey of Namibia (1982) on the scale of 1:1,00,000, and The Geological Society of South Africa (1985) on the scale of 1:4,000,000.

Middlemost (1974) and Gittins (1989) described the genesis of carbonatite. Gold (1966) and Hamilton et al. (1989) described the behavior of major and minor elements. Ishihara (1991) described the relation between granitoid series and RE-Y-Zr-Ta-Nb mineralization. Verwoerd (1986) and Mariano (1989) reported the economic geology and potential of carbonatite complexes.

Takenochi (1973a, 1973b, 1981) and Suwa (1981) described the research history, occurrence and structure of carbonatite complex. Sakamaki and Kamiya (1988a, 1988b) reviewed minerals, production amount, ore reserve of rare earth elements. Verwoerd (1965, 1967, 1986), and Diehl (1990) reviewed carbonatites in Namibia. Dendle (1971), Hearth (1973), Schommarz (1988), and Smithies (1990) reported the geology and mineralization related to carbonatite and alkali complex around the Orange area.

Japan Mining Engineering Center for International Cooperation (1992a,b) conducted project the selection survey for cooperative mineral exploration.

I-3-2 General Geology

Regional stratigraphy is presented by Geological Survey of Namibia (1982) and the Geological Society of South Africa (1985). According to these literatures, five main periods of lithogenic activity are shown as follows:

Tertiary to Recent (<65 Ma)

Carboniferous to lower Cretaceous (345 to 120 Ma)

Namibian (1,000 to 570 Ma)

Upper Mokolian (1,800 to 1,000 Ma)

Vaalian to lower Mokolian (2,100 to 1,800 Ma)

Vaalian to lower Mokolian (>2,100 to 1,800 Ma) are composed of Precambrian metamorphic and plutonic rocks of Khoabendus & Haib groups, Kunene anorthite complex. These rocks underlie the northwestern and southern parts of Namibia.

Upper Mokolian (1,800 to 1,000 Ma)is composed of metamorphic rocks and pyroclastic rocks of Namaqua metamorphic complex and Sinclair & Rehoboth sequences. Theses rocks underlie the

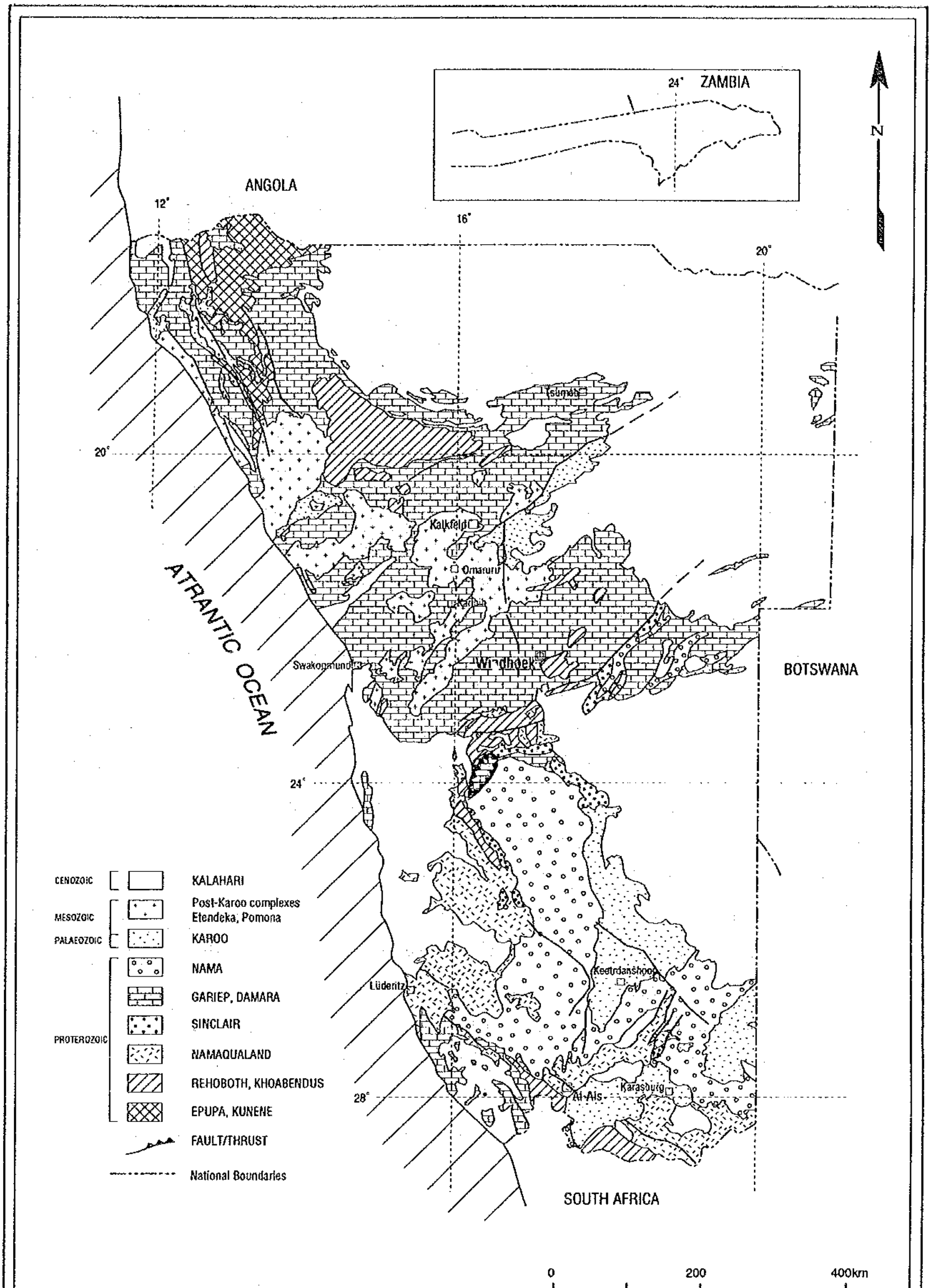


Fig.I-3-1 Geological Map of Namibia

southern part of Namibia.

Namibian (1000 to 570 Ma) is composed of sedimentary rocks and granitoids of the Rechard granite/syenite complex, the Damara sequence, the Gariep complex, the Damaran granite, the Nama group, and the Salem granite, which are the Damaran orogenic phase.

Carboniferous to lower Cretaceous (345 to 120 Ma) is composed of sedimentary rocks and pyroclastic rocks of Karoo sequence and Post-Karoo sequence. These rocks underlie central and northern part of Namibia. Alkali complex bodies, which accompany some carbonatites, align northeast to southwest along the tectonic line. carbonatite complexes are important resources of rare earth elements.

Tertiary to recent (<65 Ma) are composed of unconsolidated sediments, which cover the most parts of Kalahari and Namib desert areas.

I-3-3 Geological Setting

The Orange area is underlain by the basement rocks which comprise the Namaqua metamorphic complex (1,200 Ma) of Precambrian age and the Nama group (560 to 500 Ma) of Cambrian age. Carbonatite complex intrudes the basement rocks. The Namaqua metamorphic complex consists of some kinds of gneiss. The Nama group consists of conglomerate and slate. The Carbonatite complex consists of beforsite, sövite, syenite, trachyte, and so on. The complex intrudes in plutonic plug shape. There seems to be four intrusive bodies in the complex. The first body is situated in the northwestern part of the survey area. The body is mainly composed of brecciated syenite. The second body is situated in the central part of the survey area. The body is mainly composed of sövite and syenite. The third body is situated in the eastern part of the survey area. The body is mainly composed of beforsite The fourth body is situated in the southern part of the survey area. The body is mainly composed of beforsite surrounded circularly by sövite and syenite. Around this body, syenite is cut by sövite and beforsite. Sövite is cut by beforsite. Beforsite is cut by small dykes of trachyte and dolerite. From these occurrences, there appear syenite, sövite, beforsite and small dykes like trachyte intrude in order.

The Kalkfeld area is underlain by the basement rocks which comprise the Damara sequence (720 to 900 Ma) of Precambrian age. The Salem granite (500 to 530 Ma) of Cambrian and Carbonatite complex intrude the basement rocks. The Damara sequence in the area consists of marble. The Carbonatite complex consists of volcanic breccia, beforiste and dolerite. The complex intrudes in diatreme shape.

I-3-4 Mining History

According to Advertisement Supplement to Mining Journal (1992), Namibian modern mining started in Matchless copper mine from 1855. Diamond was discovered in 1908. In 1920, nine German diamond companies set up Consolidate Diamond Mines of South West Africa (CDM) which is subsidiary of De Beers of South Africa. Uranium exploration had become active and, Rössing was discovered. The exports of uranium and diamond is 75% of total mineral exports.

Up to now, more than one hundred mines of copper, lead, zinc, tin, tungsten, arsenic, fluorine, lithium exploited. Base metals mines include Tumeb, Rosh Pinah, Berg Aukas, Kombat, Namib Lead, Otjihase, Matchless, Swartmodder, Oamites, Klein Aub, etc. Tin and tungsten mines include Brandberg West, Uis, and Krantzberg. Navachab mine as a first gold mine in namibia exploited in 1989.

Namibian Minerals (Prospecting and Mining) Act of 1992 was drawn up by the Ministry of Mines and Energy and is will be enacted during the course of 1994. According to this Act, all mineral rights are vested in the state, so that prospecting and mining may be undertaken only under a licence issued by the minister of Mines and Energy or the mining commissioner. The license distinguishes between large-scale prospecting, small-scale prospecting, and mining activities aimed at promoting small-scale mining and prospecting. This Act contains mineral agreement, mineral export procedure, and environment protection.

Verwoerd (1965, 1967), Dendle (1971), Hearth (1973) and Schommarz (1988) surveyed carbonatites and alkali complex for base metals, rare metals, and radioactive elements around the Orange and Kalkfeld areas. The Kalkfeld carbonatite complex, situated 12 km northwest from the survey area, is mined iron ores for copper-lead smelter materials. Alkali complex, situated northeast from the survey area, mined lead-zinc vein at the small scale. No large-scale mine operates around the survey area.

Chapter 4 Consideration of the Survey Results

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

The carbonatite complex in the Orange area is called the Marinkas Quelle carbonatite complex (Schommarz, 1988). The complex intrudes the upper Mokolian Namaqua metamorphic complex which consists of quartz - feldspar gneiss in the area. The complex is located along the Kuboos-Bremen line, which aligns northeast to southwest. The carbonatite is formed at the intersection of the Kuboos-Bremen line and post-Karoo faults (Hearth, 1973).

The carbonatite complex in the Kalkfeld area is called Osongombo diatreme. The Osongombo, peripheral Kalkfeld, Ondurakorume and Okorusu carbonatite complexes align northeast to southwest in the Damarand alkaline province.

Some carbonatite complexes are formed in the tension stress part of transform fault (Prins, 1981). But the relation between carbonatites in the survey area and fault is not clear (Verwoerd, 1967). Mitchel and Garson (1981) suggest carbonatite is formed in the intercontinental hot spot or intercontinental rift.

The carbonatite complex in the Orange area consists of beforsite, sövite, syenite, and small dykes as trachyte. Major minerals of the carbonatite are of calcite, dolomite, and ankerite. Subordinate minerals are of manganocalcite, siderite, apatite, barite, magnetite, hematite, and La-Ce-Nd-Nb minerals as bastnaesite, monazite, synchysite and pyrochlore. Rare earth minerals and pyrochlore show a tendency to concentrate in beforsitic rocks in the later stage of carbonatite intrusion.

The carbonatite complex in the Kalkfeld area consists of volcanic breccia, beforsite and small dykes of dolerite. Major minerals of the carbonatite are of dolomite and ankerite. Subordinate minerals are of calcite, manganocalcite, strontianite, apatite, goethite, hematite and Nb-Th minerals as pyrochlore and iron minerals. Rare earth minerals show a tendency to concentrate in beforsitic rocks in the later stage of carbonatite activity.

I-4-2 Relationship between Geochemical Anomalies and Mineralization

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

The carbonatite complex in the Orange area contains dominant La, Ce, Nd, Nb, Mn, Sr and P elements. La, Ce, Nd, Nb, Mn and Sr elements concentrate in and around two major beforsite bodies and narrow beforsite dykes. Phosphorus concentrates in the eastern beforsite body. Sövite also concentrates La, Ce, Nd, Nb, Sr and P elements, but does not exceed the contents of the beforsites except strontium. It was shown that some types of syenite contains rare earth minerals (Verwoerd, 1967), but the rare earth content is not dominant.

The carbonatite complex in the orange area intrudes in order of syenite, sövite, beforsite. By the geochemical survey, confirmed is the concentration of rare earth and Nb elements in beforsite bodies of late stage carbonatite activity. The carbonatite contains carbonate, apatite, monazite and pyrochlore. The existence of these minerals corresponds to the results of REEs and Nb concentration by geochemical survey. Compared with the carbonatite in the Kalkfeld area, mentioned later, Nb and P elements are dominant.

The carbonatite complex in the Kalkfeld area contains dominant La, Ce, Nd, Th, Mn, Sr and P elements. La, Ce, Nd, Nb and P elements concentrate in and around beforsite and volcanic breccia. Compared with volcanic breccia, beforsite concentrates more rare earth and Nb elements. Th, Mn and Sr concentrate in iron ore bodies. Some of the basement granite and marble with brown interstitial carbonate also concentrate La, Ce, Nd, Th, Mn, Sr and P elements, but the contents do not exceed of that of beforsite and volcanic breccia.

The carbonatite complex in the Kalkfeld area intrudes in order of volcanic breccia, beforsite, and iron ore. The concentration of rare earth and Nb elements are confirmed in beforsite bodies of late stage carbonatite activity. The carbonatite contains carbonate, iron minerals, and pyrochlore. The existence of these minerals corresponds to the results of rare earth and Nb concentration.

Compared with the carbonatite in the Orange area, Th, Mn and Sr elements are dominant.

I-4-3 Potentialities of Expected Ore Deposits

The intrusive form of carbonatite is divided into corn sheet, diatreme, plutonic plug, ring dyke and so on. The carbonatite of the Orange area shows plutonic plug form, and the one of Kalkfeld area shows diatreme form. The exposure area of carbonatite is respectively about 1 and 0.2 square kilometre in the Orange area and the Kalkfeld area. The exposure area corresponds to the intrusive form.

On the other hand, the erosion form of carbonatite is divided into volcanic cone, volcanic neck, shallow plutonic and deep plutonic types (Takenouchi, 1973).

Verwoerd (1967) suggested that different feature is formed due to exposure by erosion of even essentially similar pipes according to erosion levels. Therefore, the volcanic corn remains the original form of carbonatite which isn't almost affected by erosion. The deep plutonic shape reflects strong or long erosion by which the inside of the carbonatite is visible on the surface.

The carbonatite complex called Marinkas Quelle complex in the Orange area shows the volcanic plug in intrusive shape and shallow plutonic type by erosion level.

The carbonatite complex called the Osongombo diatreme in the Kalkfeld area shows diatreme in intrusive shape and volcanic neck type by erosion level. Around the kalkfeld area, carbonatite complexes of Kalkfeld, Ondurakorume and Osongombo align northeast to southwest. These complexes show different features due to exposure by erosion of essentially similar intrusive bodies at successively shallower levels. It was suggested that the Kalkfeld complex is eroded out at deeper level, the Osongombo diatreme isn't almost eroded and the Ondurakorume complex shows intermediate level of erosion compared with the former two complexes (Verwoerd, 1967). Based on this model, the carbonatite complex in the Orange area shows the intermediate erosion level as Ondurakorume complex.

The dimensions, rock facies, and constituents of carbonatite strongly depend on the intrusive form and erosion level. The Osongombo diarteme shows volcanic neck type and is exposed in small area. The complex comprises volcanic breccia, beforsite, and iron ore and contains 0.05 to 0.21% ThO_2 (Verwoerd, 1967). Ondurakorume complex shows shallow plutonic type and exposes in intermediately wide area. The complex comprises nepheline syenite, sövite, beforsite and contains 8 million tons of 0.3 % Nb_2O_5, 3 % REO, 2.5 % $SrCO_3$, 0.03 Kg/t ThO_2, 0.02 Kg/t U_3O_8. On the other hand, kalkfeld complex shows deep plutonic type and exposes in wide area. The complex comprises syenite, sövite, iron ore and contains 0.2–0.8 % Ce, 0.05–0.5 % La, 0.1–0.25 % Nd and 0–0.77 % ThO_2. Other example as Phalaborwa complex in South Africa shows deep plutonic type and contains 0.48–0.57 % Cu, 10–25 % P_2O_5, 0.4–0.9 % REO (Verwoerd, 1986).

From the above-mentioned intrusive shape and erosion level, The carbonatite complex in the Orange area is similar occurrence to Ondurakorume complex which is rich in rare earth, Nb and P elements. The concentration tendency of these elements in the Orange area corresponds to the result of the geochemical survey which shows high contents of La, Ce, Nd, Nb, Mn, Sr and P. Mineralized potential of underground carbonatite in the Orange area is hoped to be the same condition as Phalaborwa complex, which contain more P and Cu at deeper level. Compared with the carbonatite complex of Orange area. that in the Kalkfeld is small in dimensions and shallow at erosion level. It is suggested that the REEs concentrate at considerably deeper level from the above-mentioned model.

Chapter 5 Conclusions and Recommendation

I-5-1 Conclusions

Phase I survey of this year contains the literature survey and geochemical survey. The results of this survey are described as follows:

Orange area

1) The area is covered by Mokolian Namakua metamorphic complex (1,200 Ma) of Precambrian age and Nama group sedimentary rocks of Cambrian age (560 to 500 Ma). The carbonatite complex intrudes these basement rocks in plutonic plug shape.

2) The carbonatite complex comprise a part of Kuboos-Bremen line of alkaline rock complexes, which aligns northeast to southwest. The carbonatite complex is formed at the intersection of Kuboos-Bremen line and post-Karoo faults.

3) The carbonatite complex has four main intrusive centers. The order of the intrusion as syenite, sövite, beforsite, small-scale dykes of carbonatite is observed in some centres.

4) Major minerals of carbonatite are of calcite, dolomite and ankerite. Subordinated minerals are of siderite, manganocalcite, apatite, barite, magnetite, hematite, bastnaesite, monazite, synchysite and pyrochlore. Last four minerals contain La, Ce, Nd and Nb.

5) 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 phosphorus.

6) Compared with carbonatite in the Kalkfeld area, Nb and P are dominant.

7) The erosion level is intermediate, because the complex form by erosion indicates shallow plutonic type. Therefore it should be promise for rare earth, Nb and P elements to be dominant at the shallow underground level, compared with other similar carbonatite occurrences as Ondurakorume and Phalaborwa.

Kalkfeld area

1) The area is underlain by the basement rocks which comprise Damara sequence (720 to 900 Ma) of Precambrian age. Salem granite (500 to 530 Ma) of Cambrian and carbonatite complex intrude the basement rocks.

2) This carbonatite complex called the Osongombo diatreme and its peripheral carbonatite complexes at Kalkfeld, Ondurakorume and Okorusu are situated in Damarand alkaline province, and align straight in the direction of northeast to southwest.

3) Carbonatite complex comprises volcanic breccia, beforsite, and iron ore. This complex shows diatreme in intrusive shape. The order of the intrusion as volcanic breccia, small dykes dolerite is observed.

4) Major minerals of carbonatite are of dolomite and ankerite. Subordinated minerals are of manganocalcite, calcite, strontianite, apatite, goethite, hematite, pyrochlore. Iron ore and pyrochlore contain Th and Nb.

5) Geochemical survey indicates the concentration of La, Ce, Nd, Th, Mn, Sr, P in carbonatite complex. Particularly beforsite body concentrates La, Ce, Nd, Nb and P. Iron ore concentrates Th, Mn and Sr.

6) Compared with carbonatite in the Orange area, Th, Mn and Sr are dominant.

7) The erosion level is shallow, because the complex form by erosion indicates volcanic neck type. Therefore it is assumed that rare earth, Nb and P elements would be dominant at the considerably deeper level, compared with other similar carbonatite occurrences.

I-5-2 Recommendation for the Phase II

The following recommendations for Phase II are proposed based on the results and consideration of Phase I of this fiscal year.

Orange area

It is clarified that beforsitic carbonatite concentrates REEs. But the distribution of the REEs is not homogenous in beforsitic bodies. This heterogeneity is caused by the differences of structure and mineral assemblage in beforsitic bodies. Therefore to clarify the underground occurrences of rare earth elements, it is important to conduct more detailed geological field survey and geochemical survey. And in addition to the superficial and horizontal distribution of rare earth elements, underground occurrences should be clarified by pilot drilling survey, because prominent concentration at shallow level is expected by other similar carbonatite as Ondurakorume and Phalaborwa. From these view points, Phase II survey should be carried out as follows:

1) Survey area

Two beforsite distribution area and its periphery

2) Survey Method

Geological survey

Geochemical survey

Drilling survey

3) Items of the Surveys

Geological survey

Geological structure survey

Lithology and rock texture survey

Laboratory works

X-ray diffraction, Thin section and Polished Section examinations

Geochemical survey

Rock geochemical survey

Detailed geochemical survey

Chemical analyses

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

Drilling survey

Lithology and structure survey

Chemical analyses

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

Laboratory works

X-ray diffraction, Thin section and Polished Section examinations

Kalkfeld area

The distribution area of beforsitic carbonatite which contains rare earth elements does is not wide. Th rare earth elements is assumed to be dominant at fairy deep level, compared other similar carbonatite occurrences. Therefore the survey of this area should be done at the other step after the consideration of underground occurrences of the orange area by the Phase II survey.

Part II

Details of the Surveys

Part II Details of the Surveys

Chapter 1 Literature Search

The list of literature is shown in table II-1-1. The localities of previous work is shown in Figs.II-1-1 and II-1-2, and the list of previous work is shown in Tables II-1-2 and II-1-3. compiling geological map is shown in Fig.II-1-4, and the summary of previous work is shown in Figs.II-1-5 and II-1-6.

Table II-1-1 List of Literature

Literatures	Contents
Geological map (1:1,000,000)	1 Sheet
Geological map (1:4,000,000)	1 Sheet
Geological survey and mineral exploration	20 Papers
Landsat imagery data	1 Paper
Aeromagnetic data (1:50,000)	2 Sheets
Aeromagnetic data (1:250,000)	2 Sheets
Mining and dining regulation	3 Documents

II-1-1 Interpretation of Landsat Image

Japan Mining Engineering Center for International Cooperation (hereinafter JEMEC, 1992a) reports the results of Landsat data processing and imagery interpretation in the northern part (Ondurakorume-Osongombo area), and the southern part (Marinkas Quelle area) of Namibia. The Orange area is included in the Marinkas Quelle area, The Kalkfeld area is included in the Ondurakorume - Osongombo area.

Geologic units are divided and geological structures are selected by interpretation of photographic features (color tone and texture pattern) and geographical features (drainage system, drainage density, rock resistivity, lineament, and foliation) by using the Landsat false colored imagery.

II-1-1-1 Northern part of Namibia (Ondurakorume-Osongombo area)

Distinguished are geologic units of precambrian (Mokolian and Namibian) metamorphic rocks, paleozoic plutonic rocks and mesozoic sedimentary and intrusive rocks.

The Damara sequence of namibian age strikes northeast to southwest. Plutonic rocks as Salem granite of Paleozoic age also align northeast to southwest microscopically.

It is said that carbonatite complexes as Kalkfeld, Ondurakorume and Osongombo align along the three lineaments which trend northeast to southwest. But by this imagery the structure corresponding to carbonatite alignment is not extracted.

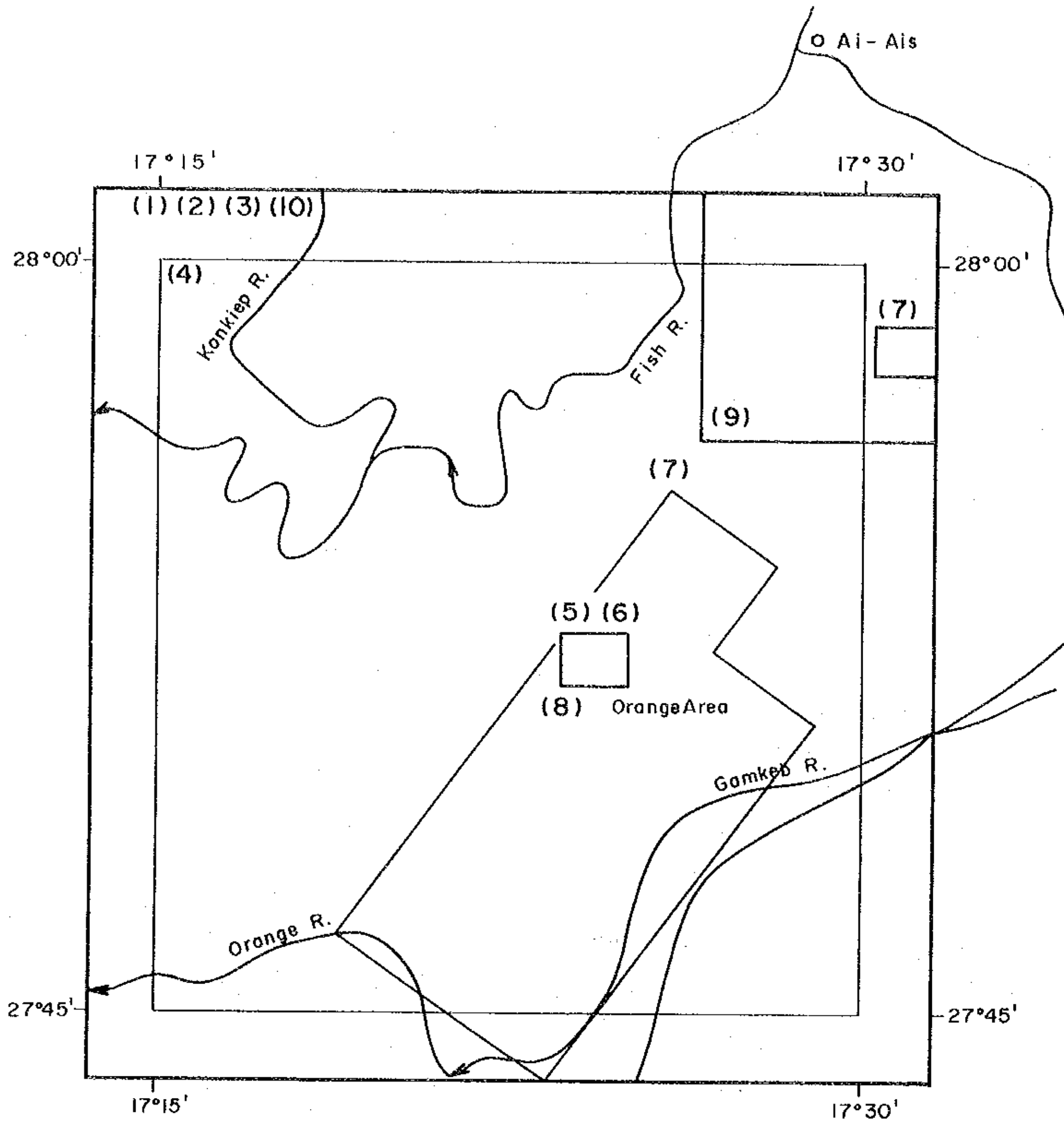


Fig.II-1-1　Locality of Previous Works in the Orange Area

TableII-1-2　List of Previous Works at the Orange Area

(1) The Geological Society of South Africa (1985)
(2) Geological Survey of Namibia (1982)
(3) Geological Survey of Namibia (1984a)
(4) Geological Survey of Namibia (1984b)
(5) Schommarz (1988)
(6) Diehl (1990)
(7) Smith (1990)
(8) Heath(1990)
(9) Dendle (1971)
(10) Japan Mining Engineering Center for International Cooperation (1992a)

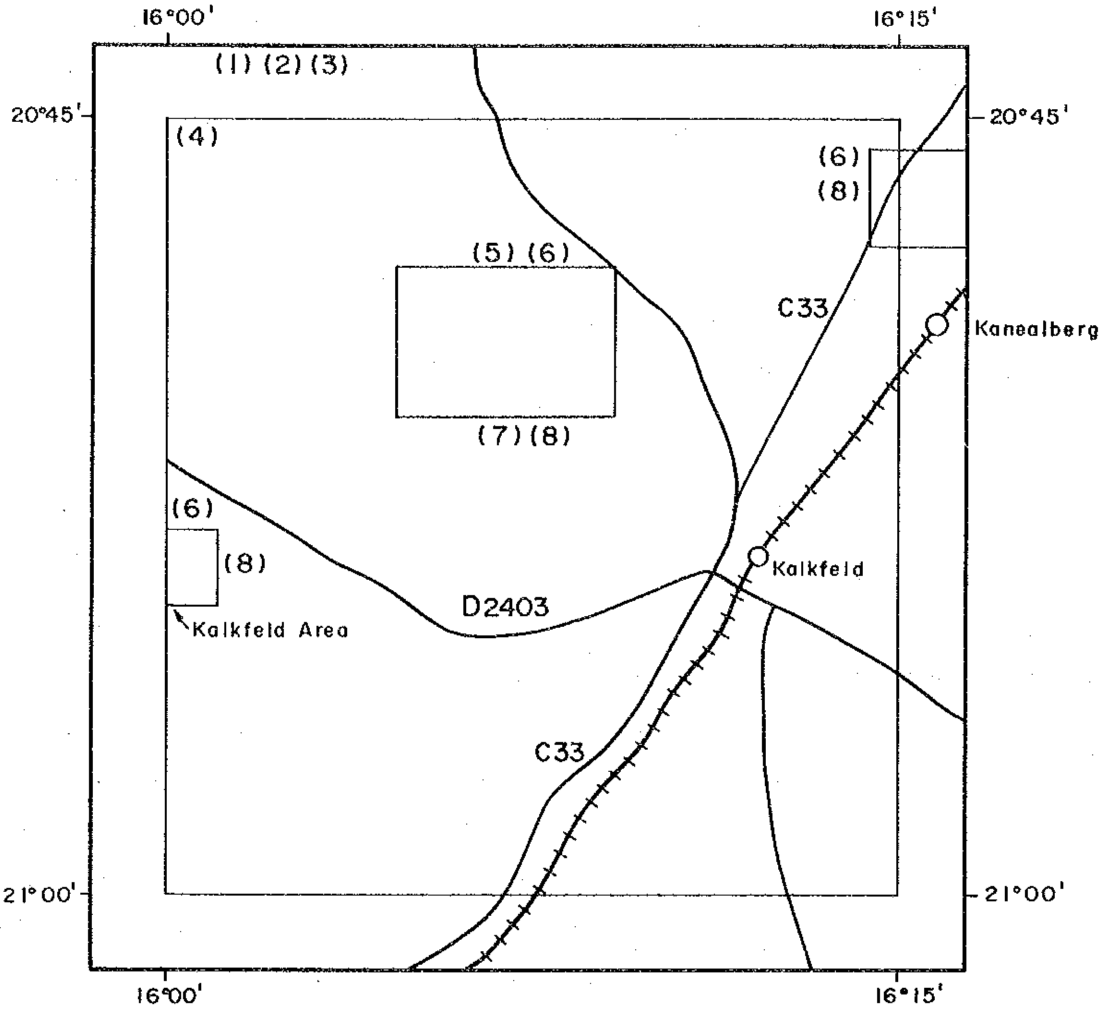


Fig.II-1-2　Locality of Previous Works in the Kalkfeld Area

TableII-1-3　List of Previous Works at the Kalkfeld Area

(1) The Geological Society of South Africa (1985)
(2) Geological Survey of Namibia (1982)
(3) Geological Survey of Namibia (1974a)
(4) Geological Survey of Namibia (1974b)
(5) Verwoerd (1965)
(6) Verwoerd (1967)
(7) Verwoerd (1986)
(8) Diehl(1990)
(9) Japan Mining Engineering Center for International Cooperation (1992a)

II-1-1-2 Southern Part of Namibia (Marinkas Quelle area)

Geological units are divided into precambrian (Mokolian and Namibian) metamorphic rocks, paleozoic sedimentary and plutonic rocks and mesozoic (Karoo) sedimentary and intrusive rocks.

The Damara sequence of Namibian age strikes northeast to southwest. Plutonic rocks as Salem granite of Paleozoic age align northeast to southwest. Alkaline complex bodies are found along the line.

The area underlain by the Karoo sequence accompanies few faults, the other area is typified by a dominant of faults. The direction of the faults is concordant with elongation of the Precambrian craton. The lineaments parallel to this structure are easy to identify. But the tectonic line corresponding to the Kuboos-Bremen line is not distinguished.

II-1-2 Geology

II-1-2-1 Regional Geology

The northern part of Namibia is underlain by a part of the shield of the Congo craton, which became stable from 1,600 Ma. Southern part of Namibia is underlain by a part of the shield of the Kalahari craton which became stable from 1,100 Ma. The Damara geosynclinal belt was formed between these cratons, and uplifted by the Pan-African orogeny. Northern shield is composed of the Vaalian and Mokolian metamorphic rocks, while southern shield is composed of the Mokolian metamorphic rocks. The Damara geosynclinal belt is composed of the Namibian sequence.

Regional stratigraphy was presented by Geological Survey of Namibia (1982) and the Geological Society of South Africa (1985). According to these literatures, five main periods of lithogenic activity are shown as follows:

Tertiary to recent (<65 Ma)

Carboniferous to lower Cretaceous (345 to 120 Ma)

Namibian (1,000 to 570 Ma)

Upper Mokolian (1,800 to 1,000 Ma)

Vaalian to lower Mokolian (2,100 to 1,800 Ma)

Vaalian to lower Mokolian (>2,100 to 1,800 Ma) are composed of Precambrian metamorphic and plutonic rocks of the Khoabendus and Haib groups, and the Kunene anorthite complex. These rocks underlie the northwestern and southern parts of Namibia.

Upper Mokolian (1,800 to 1,000 Ma) is composed of metamorphic rocks and pyroclastic rocks of Namaqua metamorphic complex and Sinclair & Rehoboth sequences. Theses rocks underlie the southern part of Namibia.

Namibian (1000 to 570 Ma) is composed of sedimentary rocks and granitoids of the Rechard granite/syenite complex, the Damara sequence, the Gariep complex, the Damaran granite, the Nama group, and the Salem granite, which are the Damaran orogenic phase.

Carboniferous to lower cretaceous (345 to 120 Ma) is composed of sedimentary rocks and pyroclastic rocks of the Karoo sequence and the post-Karoo sequence. These rocks underlie central and northern part of Namibia. Alkali complex bodies, which accompany some carbonatites, align northeast to southwest along the tectonic line. carbonatite complexes are important resources of rare earth elements.

Tertiary to recent (< 65 Ma) are composed of unconsolidated sediments, which cover the most parts of Kalahari and Namib desert areas.

II-1-2-2 Local Geology around the Survey Area

Hearth (1973) reported that the carbonatite of the Orange area is situated at the intersection of Kuboos-Bremen line and post-Karoo regional fault. The carbonatite is cretaceous in age, because it intrudes the gneiss of Kheis age. The first phase of emplacement is represented by a mixture white carbonatite and syenite. This was followed by a plug of dark brown carbonatite. The brown carbonatite is accompanied with limonite concentrates. Lead and zinc mineralization is related to the carbonatite and alkaline rocks intrusive activity.

Smithies (1990) reported that the Kuboos-Bremen line, in which the Orange area is situated, has a remarkably high degree of linearity in the direction of northeast to southwest.

The carbonatite complex in the Orange area of this survey is accompanied with the Tatasburg complex and called the Marinkas Qulle carbonatite complex. Granitic rocks of the Tatasburg complex show 505 Ma by Rb/Sr age determination. This carbonatite complex intrudes basement rocks of granitoids (1,700 to 2,000 Ma) and gneiss (1,100 Ma), and also has chemical composition of peralkaline and metalluminous rocks and dominate Nb, Zr, Y, U, Th, REEs and Ga.

Schommarz (1988) reported the result of the geological survey in the Orange area. The carbonatite and related alkaline rocks are called the Marinkas Quelle carbonatite complex in this report. This complex is situated on the Kuboos-Bremen line which extend from Richtersveld to Great Karas Mountains. Host rock of this complex is gneiss of the Namaqua Metamorphic rocks. This complex extends in the direction of northeast to southwest and has three sequent intrusive centres. The first center is mainly composed of brecciated nepheline syenite which is accompanied by rare earth mineral (synchysite). The second center is mainly composed of syenite and sövite. Syenite is affected alkali metasomatism. Some types of sövite are rich in iron minerals and biotite. The third centre is mainly composed of circular beforsite. Beforsite is ankeritic. The Nb, Sr and Zr minerals and pyrochlore are identified by the XRD analysis. This complex Intrudes quartzite and conglomerate aged 5.7 to 5.3 Ma.

The first center rocks is oldest and followed by the second and the third center rocks. Small dykes of carbonatite, which is ankeritic beforsite, cut above-mentioned major carbonatite and are distributed in a radial pattern. Gneiss around carbonatite is affected by alkali metasomatism to change fenite 300 metres width form boundary between gneiss and carbonatite. Biotite and aegirine is formed in fenitized

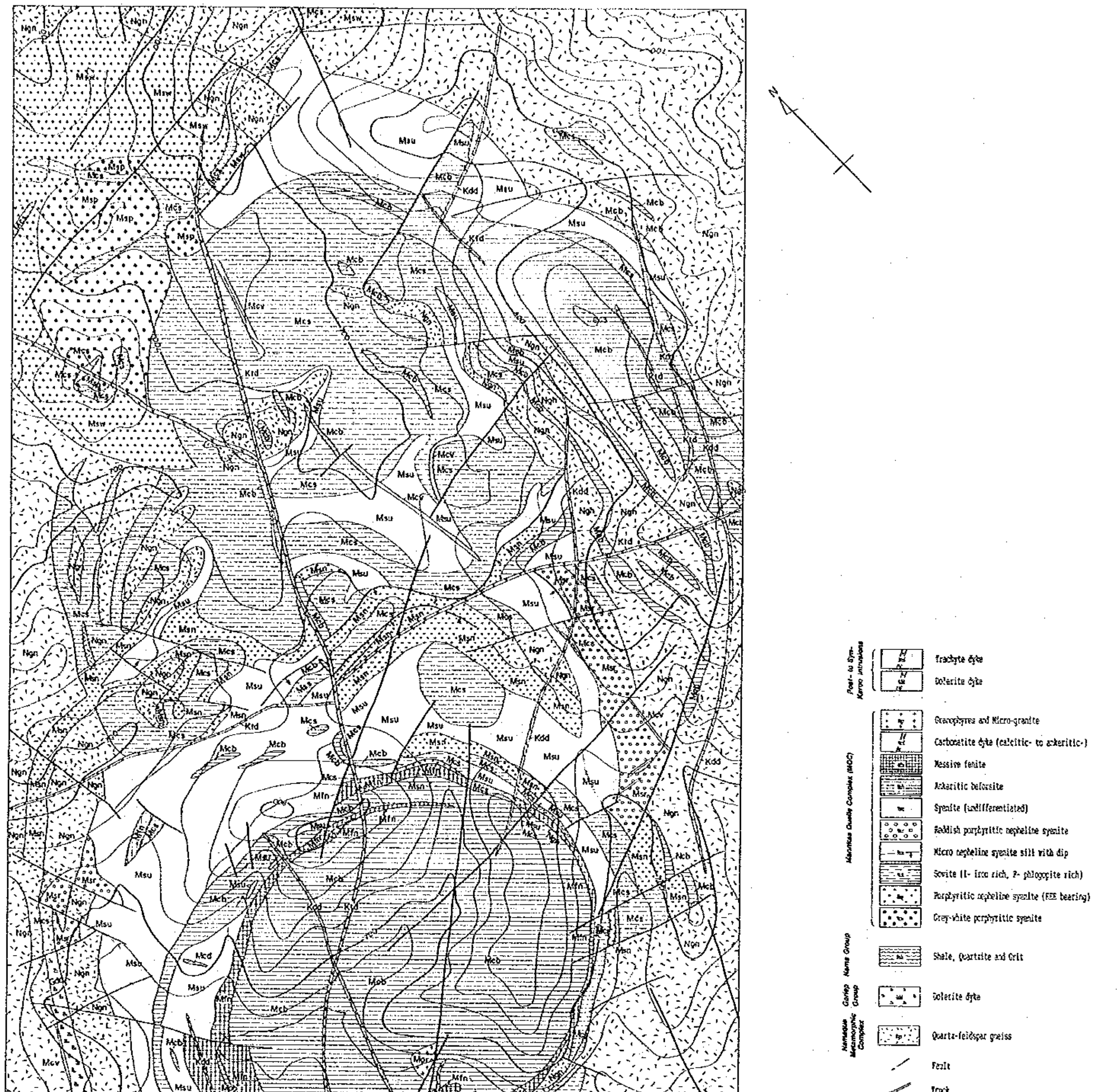


Fig.II-1-3　Compiling Geological Map of the Orange Area

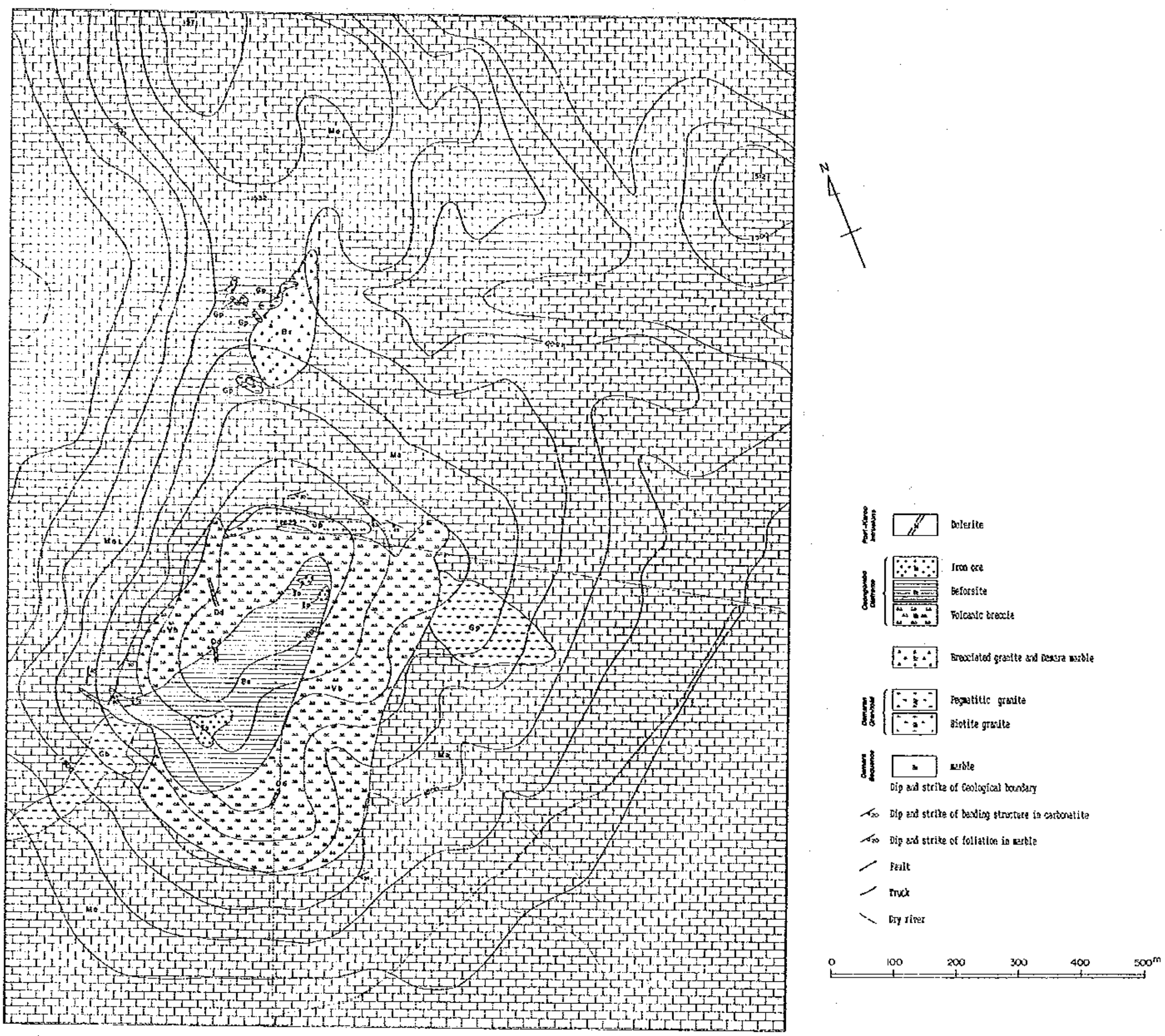
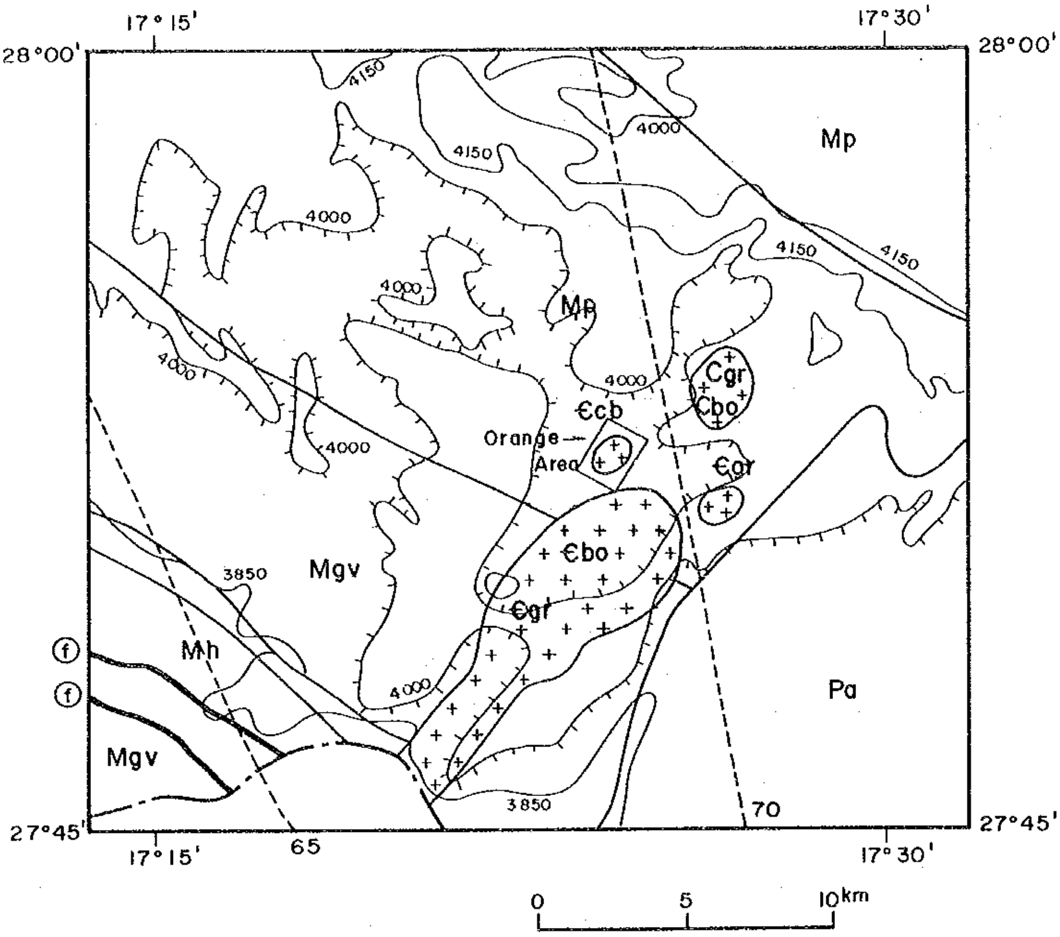


Fig.II-1-4 Compiling Geological Map of the Kalkfeld Area



€cb	: Cambrian Carbonatite
€bo	: Cambrian Bostonite
€gr	: Cambrian Granite
Mp	: Mokolian Gneiss
Mgv	: Mokolian Granitic Rocks
Mh	: Mokolian Metamorphic Rocks

: Bouguer Anomaly Contour[mgal]

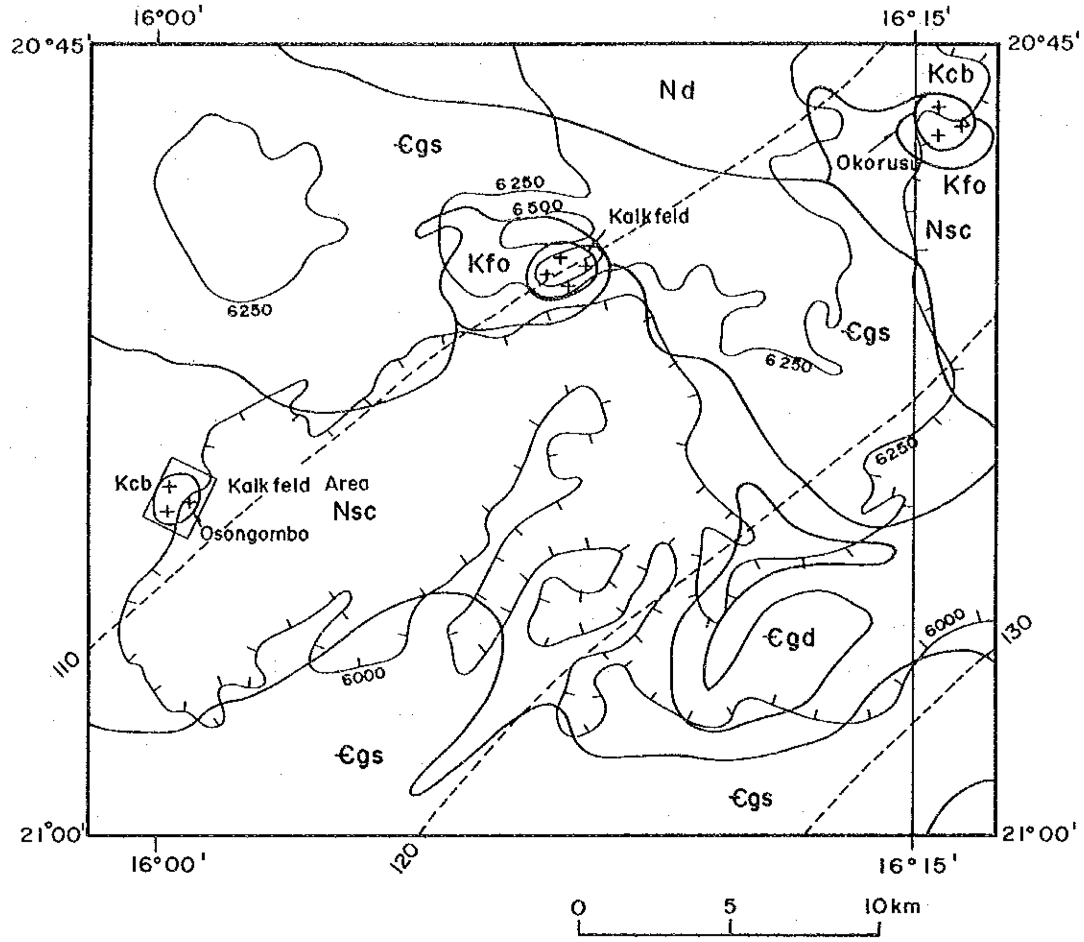
: Magnetic Induction Contour[nT]

: Fault

: Lithologic Boundary

: InternationalBoundary

Fig.II-1-5 Summary of Previous Works in the Orange Area



Kcb	Cretaceous Carbonatite
Kfo	Cretaceous Foyaite
€gd	Cambrian Granitic Rocks
€gs	Cambrian Granitic Rocks
Nsc	Namibian Damara Sequence
Nd	Namibian Damara Sequence

- - - - - - - - - - : Bouguer Anomaly Contour[mgal]

┬┬┬┬── : Tatal Magnetic Field Contour[gamma]

———— : Lithologic Boundary

Fig.II-1-6 Summary of Previous Works in the Orange Area

rocks. Trachyte and dolerite intrude at the last stage. Deans (1966) distinguishes two types carbonatites. One is apatite-magnetite type. The other is rare earth type. The beforsite of this Orange area is rare earth type. The author recommends to conduct geochemical survey by rock in order to confirm the economical potential and also suggests to concentrate heavy RE in fenitized rocks.

Verwoerd (1967) reported that the carbonatite complex in the Kalkfeld area is 0.45 km in diameter and is diatreme in shape. The complex belongs to the Damarand carbonatite complex and intrudes marble of the Damara system and the Salem granite. Marble contains tremolite, phlogopite, feldspar and pyrite. Carbonatite comprises volcanic breccia and beforsite. Beforsite contains iron ore with radioactive elements and cuts both volcanic breccia and marble as apophysis. Breccia comprise granite and quartzite. Fenitization is so week as aegirine occurrence like veinlets. Last stage dolerite intrudes carbonatite. Beforsite is mainly of ankeritic and is accompanied with calcite, silicate minerals, apatite, pyrochlore, rutil, and barite.

II-1-3 Ore Deposits

II-1-3-1 Rare Earth

Both he Orange and Kalkfeld areas are underlain by carbonatite complexes. These carbonatites contain rare earth, Nb, and P elements. Rare earth elements is of 15 elements from 57th element (La) to 71st element (Lu) on a periodic table. Rare earth elements in broad sense contained 21st elements (Sc) and 39th element (Y), (Sakamaki & Kamitani, 1988a).

II-1-3-2 Genesis of Carbonatite

Sakamaki & Kamitani (1988b) explained taht carbonatite is originated by crystallization differentiation which generate many kinds of alkaline rocks from partial melt of upper mantle.

Gittins (1989) explained that carbonatite magma generates by not separation of carbonatite and silicate liquids immiscibility but direct partial melting of carbonated mantle. Na_2CO_3 of the carbonated magma is formed from the jadeitic component as well as calcite-dolomite solid solution from the diopsidic component and olivine. This carbonated mantle is metasomatised by fluorine-rich fluids that supply Nb, P, Sr and rare earth elements, and melts to form carbonate magma that dissolves enough olivine and pyroxene to provide Al, Fe and Si necessary for crystallization of silicate minerals. Primitive carbonatite parent magma is calcitic with varied Ca:Mg ratio, and contains alkalies as well as Na, K, Al, Fe, P and silica. Therefore it composition approximates olivine- calcite carbonatite or olivine-calcite-dolomite carbonatite. Alkalies are lost as chlorides in aqueous fluid whose separation from carbonatite magma is controlled by magmatic differentiation and rate of magma ascent. Carbonatite fluids are silicon-deficient brine containing Cl and F and a solute composed of Ca, Fe, Na and Mg. Fenitization fluid derived from carbonatite magma maybe evolved episodically depending on rate of magma ascent and degree of differentiation.

Middlemost (1974) explained carbonatite–nephelinite–ijolite complex was derived from carbonated nephelinite magma. But this theory was rejected by Gittins (1989).

II–1–3–3 Structural Situation of Carbonatite

Verwoerd (1967) explained that carbonatites were as follows:

1) situated in continental platform.

2) related to vertical movement of earth crust.

3) situated in alkaline rock province.

Middlemost (1974) explained that carbonatites are

1) related to alkali magma, generates along the tectonic line in the continent.

2) situated around the continental shield or in the rift structure.

Mitchel and Garson (1981) explained that carbonatites

1) formed in the intercontinental hot spot or intercontinental rift.

2) formed in tension stress site of transform fault in Precambrian age.

3) not formed orogenic belt or depression zone of plate.

Suwa (1981) explained that carbonatites

1) intrude and extrude in the craton or its periphery.

2) is closely related to alkaline rocks which is rich in feldspar, orthoclase, nepheline and biotite.

Sakamaki & kamitani (1988b) explained that carbonatites

1) intrude and extrude in the continent or its perehery.

2) contain mainly calcite and dolomite.

3) forms complex rocks with basic rocks and alkaline rocks

Takenocuchi (1973a) explained as follows:

1) Up–doming occurs after the accumulation of magma and gases in the earth crust, followed by intensive explosion and forming of the shock zone.

2) Brecciation and joint are obvious the shock zone

II–1–3–4 Formation Age of Carbonatite

Verwoerd (1967) described the formation ages of carbonatite in Namibia.

1) Middle Precambrian

2) Late Precambrian

3) Lower Jurassic

Suwa (1981) described that carbonatites were formed in 2,000 Ma, 1,000 Ma, 100 to 200 Ma, Tertiary and Recent.

Sakamaki & kamitani (1988b) described that carbonatite and alkaline rocks complexes were dominant in africa after separation of Gondowana up to Recent.

Diehl (1990) described that carbonatites in Namibia were formed in Namibian (570 to 920 Ma) and Mesozoic age.

II-1-3-5 Form of carbonatite

Gold (1966) and Verwoerd (1967) described as follows:

1) Carbonatites are classified like plutonic plug, corn sheet, dyke, and ring dyke according to intrusive form. carbonatite is typically situated in the center of alkaline rocks.

2) Oval and circular section are common and approximately 1 miles in diameter.

II-1-3-6 Structure of Carbonatite

Verwoerd (1967) reviewed the southern Africa carbonatites as follows:

1) Carbonatite shows the volcanic evidence as volcanic corn, uplift, caldera.

2) An ideal plutonic carbonatite complex consists in plan of concentric rings comprising syenite, foyaite, ijolite, dunite, and carbonatite from the outside inward.

3) The complete sequence of the concentric rings is rarely shown being dependent on erosion level or transgressive emplacement of younger members.

4) Alkaline small dykes are formed after carbonatite.

5) Later dykes of carbonatite often cut the central carbonatite, fill concentric fractures or radiate from it.

6) Carbonatite plugs are characterized by a concentric, near-vertical structure due to emplacement in consecutive stages.

7) In most case the evidence suggests that the contact between member of the complexes are approximately vertical.

Middlemost (1974) explained the characteristics of carbonatites as follows:

1) Carbonatite occurs as the core of in oval or circular peralkaline rocks.

2) Host rocks are brecciated and updome.

3) An ideal plutonic carbonatite complex comprises fenite, nepheline syenite, urtite, ijolite, melteigite, and carbonatite from the outside inward.

Takenouchi (1981) reviewed alkaline complex as follows:

1) Alkaline complexes show the forms like plutonic plug, corn sheet, ring dyke.

2) Carbonatite accompanies nepheline bearing alkaline complex unsaturated with silica.

3) Carbonatite forms at the later stage of successive alkaline volcanic activity.

4) Alkaline rocks and host rocks are affected by fenitization which is accompanied by leaching of silica and addition of Na, K and Fe. Mafic minerals are replaced to alkaline amphibole and aegerine. Feldspar changes to albite and calcite. The metasomatic rocks change to syenitic rocks by fenitization.

Diehl (1990) described rare earth elements concentrate in the beforsite of later stage carbonatite.

II-1-3-7 Concentration of Rare Earth Elements

Ishihara (1991) described the relationship between the concentration of rare earth elements and granitoid series as follows:

1) Granitoid series are divided into magnetite-series and ilmenite-series by oxygen fugacity of magma. REEs, Y, Zr, Ta and Nb concentrate in magnetite-series rocks

2) Magnetite-series rocks are divided into M-type and A-type. REEs, Y, Zr, Ta and Nb concentrate in A-type. Granitoids with rare earth elements are rich in F and Li.

3) Carbonatite contains bastnaesite, monazite and pyrochlore.

4) Granitoid contains monazite, xenotime, zircon, cassiterite and tantalite.

Sakamaki & kamitani (1988a) described chemistry of rare earth elements as follows:

1) Atomic valance of rare earth elements is mainly +3. Therefore rare earth elements do not enter into the rock forming minerals but remain in the residual liquid. And rare earth elements concentrate into pegmatite and carbonatite, because ion radius of these elements is closely equal to the Ca.

2) Eu has +2 ion valance to enter into feldspar with Ca at the early stage of magmatic differentiation. Ce has +4 ion valance to concentrate into hydroxides at the late stage of magmatic differentiation under the oxidized condition.

3) Rare earth elements have a tendency to make compounds of halide, phosphate and carbonate, because they normally have +3 ion valance. Typical halide is fluorine, Phosphate is xenotime and monazite. Carbonate is bastnaesite.

II-1-3-8 Minerals from Carbonatite

Verwoerd (1967) and Diehl (1990) described mineral assemblage from southern African carbonatites as follows:

1) Major minerals are calcite, dolomite, ankerite and siderite.

2) Subordinate minerals are apatite, barite, magnetite, hematite, pyrrhotite,ilmenite, pyrite, biotite, phlogopite, aegirine, soda amphibole, alkali feldspar, nepheline, pyrochlore, pervoskite, rutile, zircon, baddeleyite and strontianite

3) Rare earth minerals of carbonatite are monazite, synchysite, bastnaesite, ancylite, cerianite and carbocernaite.

4) Rare earth minerals of pegmatite and granitoid are monazite, allanite, gadolinite and yttro-fluorite.

5) Apatite, pyrochlore and rare earth minerals of carbonatite are important economically.

II-1-3-9 Occurrence of Minerals

Takenouchi (1981) reviewed the occurrence of minerals as follows:

1) The carbonatite of early stage is calcitic or dolomitic, that of late stage is ankeritic to sideritic.

2) Pyrochlore is rich in the carbonatite with magnetite and apatite.

3) Rare earth minerals and barite is rich in siliceous carbonatite with dolomite and ankerite.

4) Rare earth minerals of carbonatite is mainly composed of bastnaesite and monazite. Carbonatite is accompanied by strontianite.

5) Rare earth minerals, barite, quartz is assumed to be formed by hydrothermal activity.

Sakamaki & kamitani (1988b) reviewed as follows:

1) Carbonatite is rich in light rare earth bearing minerals as bastnaesite. Placer is rich in light and middle rare earth bearing minerals as monazite. Ion absorption type is rich in middle rare earth elements and Y.

2) The content of rare earth oxides doesn't exceed 1% except carbonatite and pegmatite.

II-1-3-10 Geochemistry of Carbonatite

Verwoerd (1967) described about geochemical character of carbonatite as follows:

1) Sr, Ba, Nb, Ce and La more concentrate in carbonatite than alkaline rocks.

2) P, Zr, Hf, Y and Th concentrate in carbonatite and peripheral alkaline rocks.

3) The content of Sr often exceeds that of Ba, Nb, and Ta.

4) The content of Nb often exceeds that of Ta.

5) Carbonatite often contains radioactive minerals.

6) The content of Th usually exceeds that of U.

7) Pyrochlore, Baddeleyite and apatite are crystallized by segregation. Copper sulfides, synchysite, and hematite are crystallized by metasomatism.

Mitchel & Garson (1981) described as follows:

1) Carbonatite and alkaline complex are rich in U, Th, Nb, Zr, and rare earth elements.

Hamilton et al. (1989) described as follows:

1) Ba, Ce, Cr, Cu, Zr, Eu, Gd, Hf, La, Lu, Sm, Ta and Yb concentrate in carbonatite in the high pressure (1-6 Kb) and the low temperature (1,050-1,250 degrees centigrade) from distribution tests between phonolite and nephelinite system.

Middlemost (1974) mentioned that peralkaline rock is rich in P, Ba, Sr, Nb, Zr, Th, Ti, Na, K, Mo and rare earth elements,

Gold (1966) and Takenouchi (1981) mentioned that carbonatite is rich in volatile components as P and F elements, as well as Fe, Mn, Ba, Sr, Nb, Zr, Th, Ti, K, Na and rare earth elements.

II-1-3-11 Classification of Carbonatite

Takenouchi (1973a) was classified carbonatites by erosion level as follows:

1) Volcanic corn type: formed conical hill by lava and/or pyroclastic rocks

2) Volcanic neck type: accompanied by breccia and agglomerate. Carbonatite change from calcitic,

dolomitic and sideritic from early to late stage. Carbonatite is accompanied by nepheline syenite, ijolite and alnoite. Fenitization is dominant metasomatism.

3) Shallow plutonic type: rich in calcitic and dolomitic rocks. Na is added by fenitization. Carbonatite is accompanied by dykes of ijolite, pyroxenite and dunite.

4) Deep plutonic type: formed by syenite, pyroxenite, dunite and pegmatite with few dykes.

Mariano (1989) divided carbonatites into three types as follows:

1) Primary Magma Melt Type: includes bastnaesite parisite

2) Hydrothermal Type: includes bastnaesite and monazite

3) Supergene Laterite Type

Verwoerd (1967) divided carbonatites in Namibia into three types as follows:

1) Subvolcanic carbonatite complex: Okorusu, Ondurakorume, Kalkfeld, Osongombo, Swartbooisdrif, Epembe, and Chamais

2) Volcanic carbonatite complex: Brukkaros

3) Possible carbonatite : Ost-Bokiesbank, Garub, Granitberg, Eureka and Hatzium II

II-1-3-12 Carbonatites in Namibia

Verwoerd (1967) described the characteristics of carbonatites in southern Africa as follows:

1) Carbonatites distribute in the subduction zone of limestone distribution area.

2) Carbonatite is related to intensive igneous activity.

3) Carbonatite forms 1 miles in diameter in plutonic plug shape with the concentric circle.

4) Carbonatite becomes rich in magnesium and iron according to crystallization differentiation.

5) Carbonatite is rich in strontium.

6) Economic evaluation of carbonatite is not clarified.

II-1-3-13 Carbonatite Mines and Rare Earth Mines

Sakamiaki & Kamitani (1988b) reviewed Baiyun Obo, Mountain Pass, Lo Gnan and Xun Wu, which are rare earth mining deposits related to carbonatite

Baiyun Obo carbonatite (433 Ma) intrudes Precambrian gneiss (700 to 760 Ma). REO reserve is 35 million tons. 45 % TFe reserve is 1.15 billion tons. Nb_2O_5 reserve is 0.78 million tons. Main Minerals are of carbonates, magnetite, amphibole, fluorite and phlogopite. Rare earth minerals are of monazite, bastnaesite, allanite. Nb mineral is of pyrochlore.

Mountain Pass carbonatite intrudes gneiss and granite of Precambrian age (800 to 900 Ma). REO content is 5 million tons. Ore grade is 5 to 10 % REO, which reserve is 100 million tons. Major minerals are of carbonates, barite and celestite. Rare earth minerals are of bastnaesite, parisite and monazite.

Both Lo Gnan and Xun Wu are residual type deposits. The weathered residual layers on Mesozoic granites is mined. Lo Gnan deposit is rich in middle to heavy rare earth elements as Gd, Dy, Yb and Y. Xun Wu deposit is rich in light to middle rare earth elements as La, Nd, Sm. Total rare earth grade is 1,500 to 4,000 ppm.

II-1-3-14 Economical Potential of Carbonatite

Mariano (1989) described that carbonatite is the main sources of rare earth elements, Nb and P. Some carbonatite pyrochlores contain Ta abundance at economic levels. In regions of lateritic weathering of carbonatites, pyrochlore is destroyed and Nb partitions into supergene rare earth minerals of the crandallite group. Apatite is the most important mineral presently being mined in carbonatite complex and its phosphate content is higher than that of marine phosphorites. Other commodities associated with carbonatites include barite, Cu, fluorite, Sr, V, Th, and U.

Verwoerd (1986) described that apatite is important commodity from carbonatite. Copper and fluorine and magnetite are important economically. The mined case of carbonatites in Africa is Phalaborwa complex in South Africa, which produces P and Cu. The output of P from this carbonatite occupies 18% of total P produce. The rare earth elements is not produced from African carbonatites.

II-1-3-15 Utilization of rare earth elements

Sakamaki & Kamiya (1988b) reviewed the utilization of rare earth elements. La and Y are not used as catalysts for oil refine after 1985. Therefore the demand of light rare earth elements is decreasing. But increasing of supply related to alloy, steel, ceramics and electronics, middle and heavy rare minerals as Sm, Eu, Gd and Y is are required. Therefore, the occurrences of the rare earth minerals and evaluation of their potential are demanded urgently.

II-1-4 Geophysical Survey

Geological Survey of Namibia (1984) published aeromagnetic maps on the scale of 1:50,000 in Alexander Bay Area (2817AB), on the scale of 1:250,000 in these area. The Orange area is included in Alexander Bay Area. Geological Survey of Namibia (1974) publishes aeromagnetic maps on the scale of 1:50,000 in Omaruru Area (2016CC), on the scale of 1:250,000 in Otjiwarongo Area. The Kalkfeld area is included in these areas.

II-1-4-1 Orange Area

The aeromagnetic map in Alexander Bay Area (2817AB) by magnetic induction contours is interpreted as follows:

1) Magnetic strength is classified by rock type if the anomalies are sifted southward systematically. This area is underlain by Vaalian, Mokolian, Karoo rocks. Magnetic strength of Mokolian is stronger

than that of Vaalian, and that of Karoo is week. Vaalian comprises granodiorite. Mokolian comprises gneiss. Karoo comprises unmetamophic sedimentary rocks.

2) Vaalian occupies northern half part in the area. Strong magnetic area aligns in the direction of northeast to southwest.

3) Mokolian occupies southern half part in the area. Strong magnetic area aligns in the direction of northwest to southeast.

4) Karoo is situated in the southeastern part of in the area. Long wave component is dominant.

5) Mokolian is intruded by alkaline complexes which have strong magnetic area.

6) The carbonatite in the Orange area is located at the intersection part of between northeastern to southwestern strong magnetic part and Mokolian northwestern to southeastern strong magnetic part.

II-1-4-2 Kalkfeld Area

The aeromagnetic map in Omaruru Area (82016CC) by total magnetic field contours is interpreted as follows:

1) Magnetic strength is classified by rock type. This area is underlain by Damara Series of Namibian, and Cambrian rocks. Magnetic strength of Cambrian rocks is strong, and that of Namibian is week. Namibian comprises marble and gneiss. Cambrian comprises granitic rocks. Metamorphic grade of Cambrian is lower than Namibian.

2) Cambrian rocks occupy northern and southern part in the area. The strong magnetic part in northern part align in two directions of northeast to southwest, and northwest to southeast. The strong magnetic part in the southern part aligns in two directions of northeast to southwest, and east to west.

3) Namibian is situated in the central part. Long wave component is dominant in this part.

4) Alkaline rocks intrude Cambrian rocks. Strong magnetic parts are correspond to the distribution area of these rocks.

5) The carbonatite in the Orange area is located at the intersection part of between northeastern to southwestern strong magnetic part and Mokolian northwestern to southeastern strong magnetic part, in which the Kalkfeld carbonatite is accompanied.

6) The magnetic anomaly is not identified in the Kalkfeld area of this survey.

II-1-5 Exploration Activities

Verwoerd (1967) reported the survey results of South Africa and Namibia carbonatites. This survey was trusted by Atomic Energy Board of South Africa, and was conducted to clarified the occurrences and radioactive anomalies of carbonatites. By this literature, Kalkfeld carbonatite complex was discovered in 1953. 40% FeO ore is estimated at 4 million tons. This ore contains 0.5% ThO_2. Ondurakorume carbonatite complex is richer in apatite than that of Kalkfeld carbonatite complex. P_2O_5 grade is 17.3% at maximum and 7% on the average. 0.3 Nb_2O_5 ore is estimated 8 million tons, which

is 2.5% at maximum. Ce_2O_3 content reaches up to 0.9%.
Amphibolitic beforsite contains strontianite and ancylite. Galena is contained in carbonatite, but is not economic. Pyrochlore occurs in Kalkfeld, Ondurakorume and Osongombo carbonatite complexes.

Dendle (1971) described that the results for geological survey and mineral exploration in the Kawaggasnek–Kanabium area which is located to the northeast of the Orange area. Quartz porphyry and dolerite intrude Kheis metamorphic rocks, which are overlain by Damara and Karoo sequence intruded by post–Nama Bremen igneous acidic rocks. Mineralization are appeared around these intrusive rocks. Silver and lead mineralization is recognized in quartz porphyry of pre–Karoo. Wollastonite is recognized in Bremen igneous acidic rocks. In Kanabium area, silver, lead and copper mineralize related to quartz porphyry, which chemical analysis results show Cu : 679 ppm and Mo :2 ppm. Gossan shows Pb : 4.78 % and Ag : 3.3 oz/ton. Some veins if this area were mined by 1971. In Kawaggasnek area, Pb: 5,200 ppm and Zn: 4,010 ppm are got by chemical analysis.

The carbonatite in the Orange area was discovered by Blignault in 1967. Reo Tint Exploration Ltd. explorated for the purpose of base metals and found two carbonatite, one of which has dimensions of 1.8 km by 1.0 km, and is located in the survey area. The other, located 2.5 km to the southwest of survey area, is 0.7 km in diameter, is accompanied by brown carbonatite with iron ore. The lead and zinc are mineralized related to carbonatite activity.

Smithies (1990) described the results of geology and mineralization for carbonatite and alkaline complexes in the Orange area. Exploration of sulfides veins of lead and silver is a target of this survey. The veins are accompanied by alkaline igneous rocks as Tatasburg complex and Kanabium Breccia Body, which is related to Pan–African Kuboos–Bremen Line.

The carbonatite complex called Marinkas Quelle carbonatite complex is accompanied by Tatasburg complex. Quartz veins with fluorite are recognized in Tatasburg complex. Alteration of porphyry type has a mineral assemblage of quartz–sericite–pyrite in this complex. Kanabium Breccia Body comprises volcanic breccia and porphyritic intrusive rock, which is accompanied by networks of sulfides of lead and silver.

Diehl (1990) reported the survey result of Lafdal–Bergville carbonatite complex, explored in 1982 by ROUNA, which shows assay of 0.05 to 0.63 % Y and 0.17 to 14.4 % ThO_2. Eureka carbonatite complex was explored by drillings down to 20 m bellow the surface. By these drillings 30,000 tones of crude ore and 1,900 tons of REO are confirmed.

Verwoerd,W.J. (1986) described that Tsumeb Corporation Ltd. explorated the Otisazu carbonatite complex in the Okahandja District to access potential of apatite reserve. 3–5 % P_2O_5, and 200 to 500 ppm cu are contained in sövite and pyroxenite. Nooitgedachet carbonatite complex contains 3–4 % P_2O_5.

Chapter II Orange Area

II-2-1 Survey method

Geological survey and whole rock geochemical survey were carried out, and the laboratory tests were taken in Japan.

The base map for field survey was used to expand the topographic maps published by the Chief Directorate, Surveys and Land Information at Mowbray in 1971 (Sheet No. 2817AB GAMKAB) in a scale of 1 to 50,000, to that of 1 to 2,500.

The sampling intervals for the whole rock geochemical survey were selected as 100 metres by 50 metres in the general survey area, and as 50 metres by 75 metres in the detail survey area. Sampling positions were arranged by surveying using surveying compass. The original positions for surveying were situated at the two tops of the eastern ridge in the area. Geological survey was carried out along the geochemical survey lines and correlate with the previous geological map prepared by Schommarz (1988).

Laboratory tests were carried out as follows:

1) thin section and polished section observations to determine texture and mineral assemblage
2) X-ray diffractive analysis (hereinafter referred to as the XRD analysis) to identify the minerals
3) whole rock chemical analysis.

II-2-2 Geology

II-2-2-1 Regional geology

The regional Geological map after Blignault and Kroner (1974) is shown in Fig.II-2-1. Carbonatite complexes in the area belong to the group of alkaline intrusive which situate along the NE-SW direction of the Kuboos - Bremen line (Kroner and Blignault, 1976). The group of the alkaline intrusive intrude in the Namaqua metamorphic complex, the Gariep group and the Nama sequence. Rb-Sr age of Marinkas Kwela (Quelle) syenite shows 505.88 ± 18.68 Ma (Smithies,1990).

The Marinkas Quelle Carbonatite Complex was described primary by Blignault(1971), and the detail geological map was made up by Schommarz (1988).

II-2-2-2 Details of geology

The geological map and the lithostratigraphy in the area are shown in Fig.II-2-2 and in Fig.II-2-3, respectively.

It consists of the Namaqua metamorphic complex, the Gariep group, the Nama sequence, the Marinkas Quelle carbonatite complex (hereinafter referred to as the MQC) and the syn- to

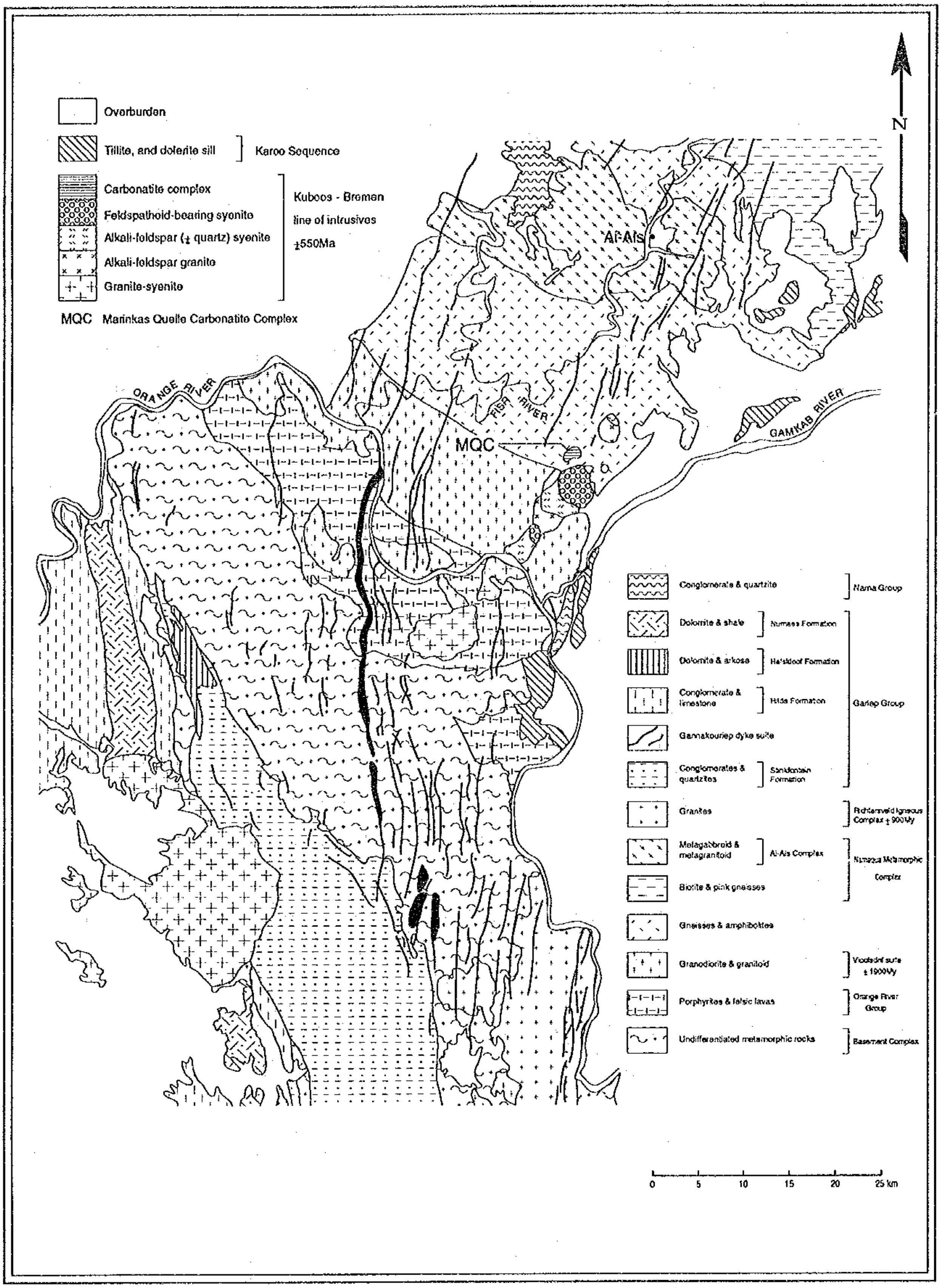


Fig.II-2-1 Regional Geological Map around the Orange Area

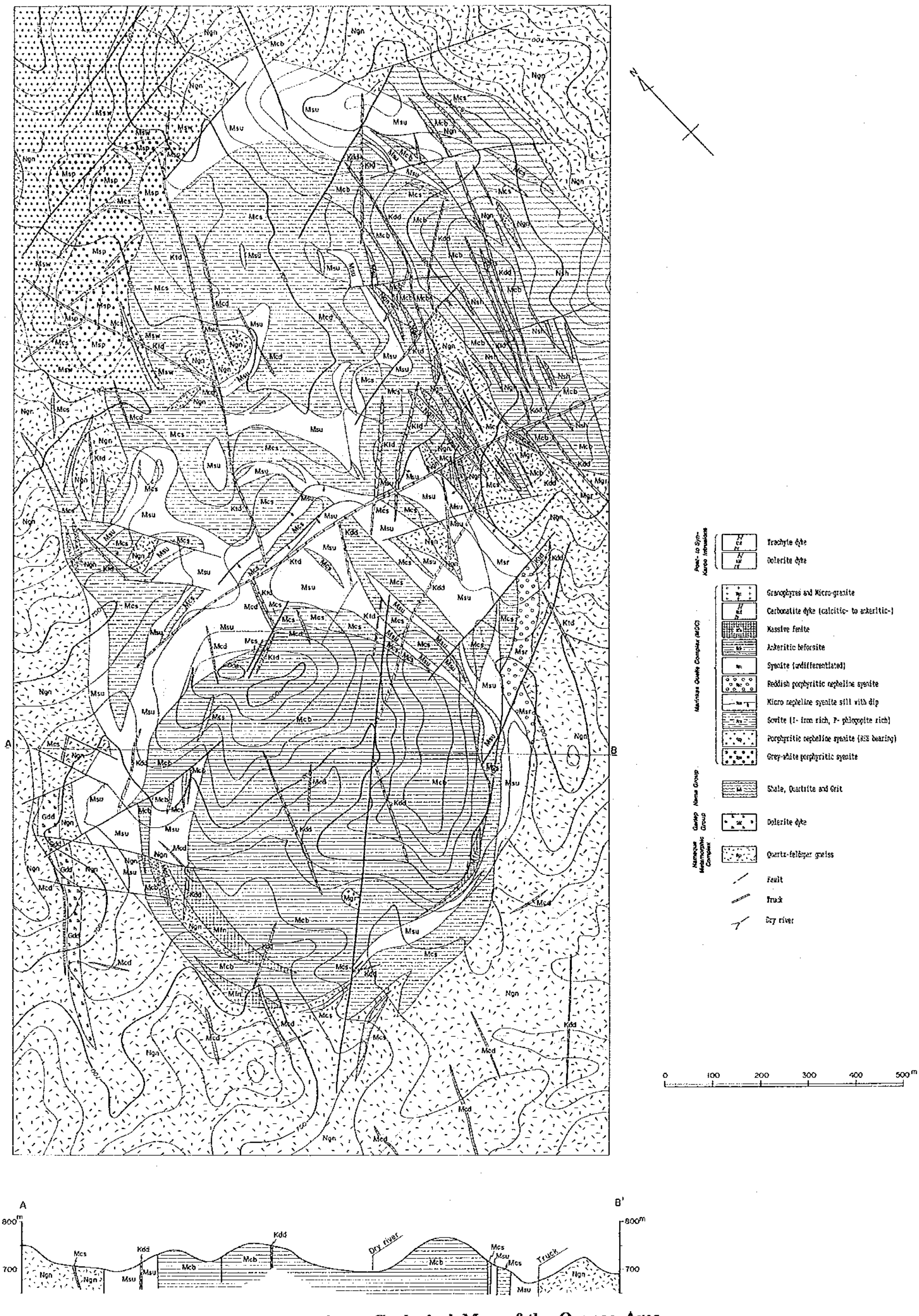


Fig.II-2-2 Geological Map of the Orange Area

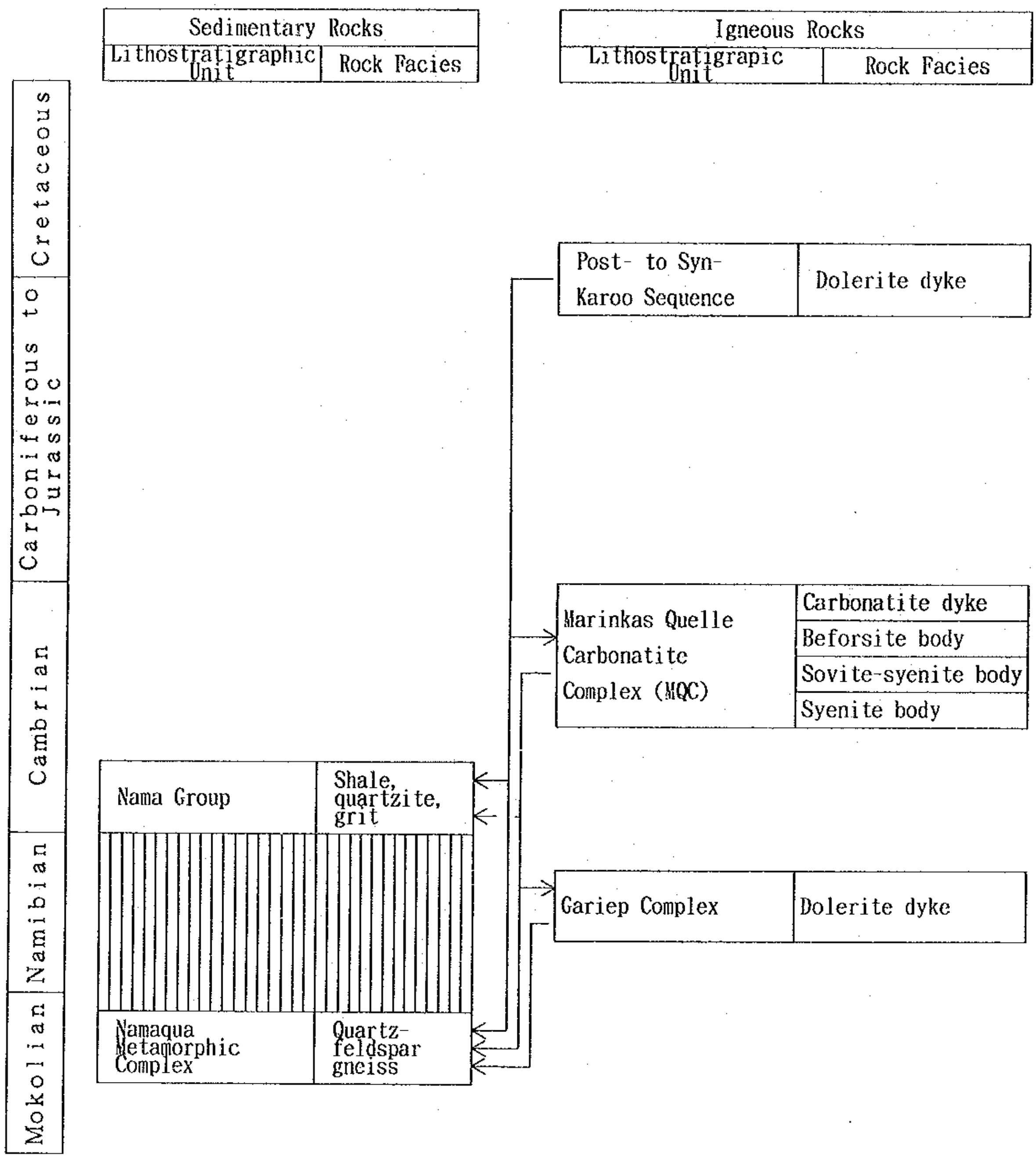


Fig.II-2-3 Lithostratigrapy at the Orange Area

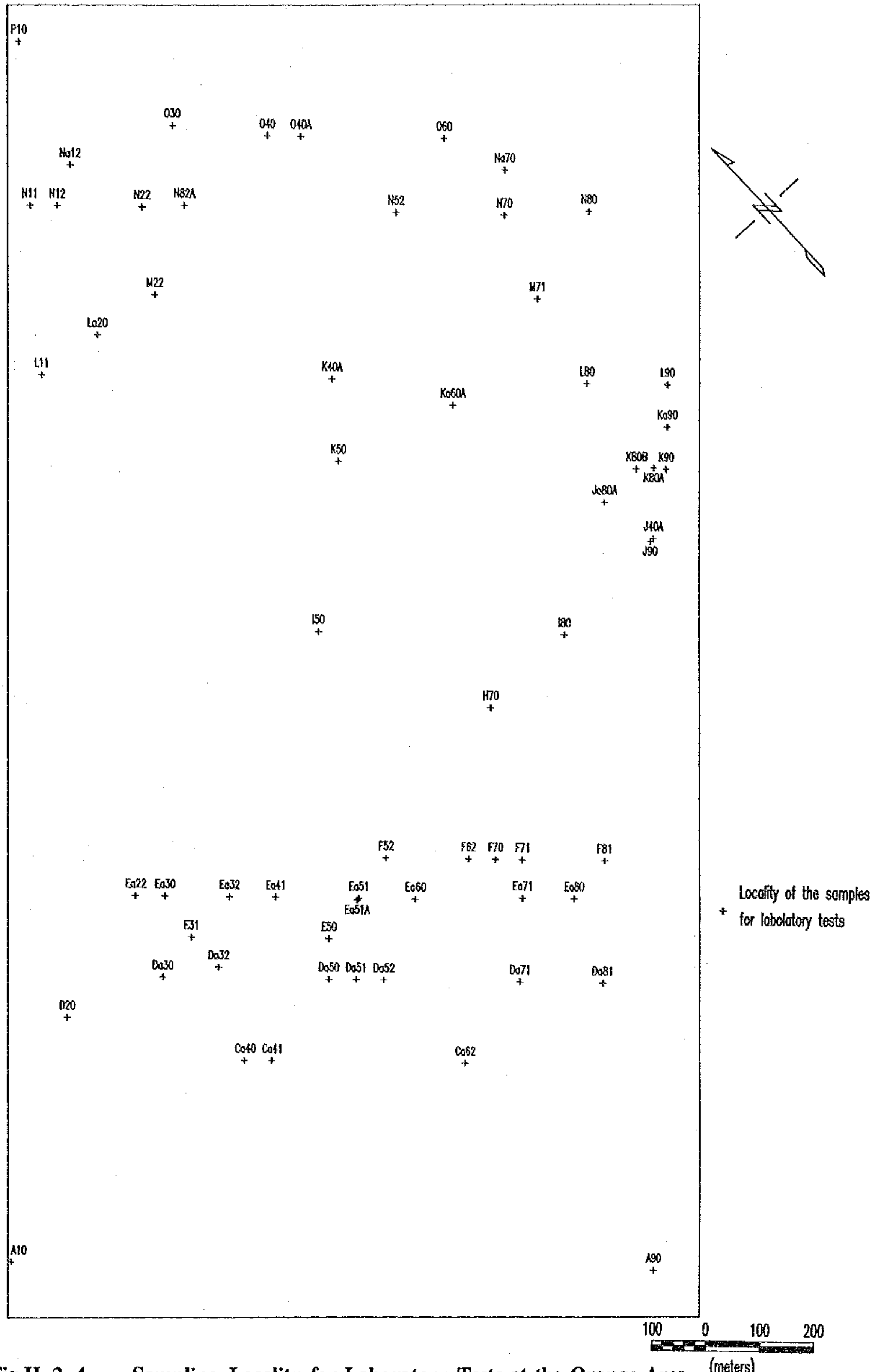


Fig.II-2-4 Sampling Locality for Laboratory Tests at the Orange Area

TableII-2-1 Mineral Assemblage at the Orange Area determined by the Microscopic Observation of Thin Sections

No.	Sample No.	Rock name	Rock Code	Main rock forming minerals																		Accessery minerals							Secondary minerals										
				Qtz	Pl	Ab	Kfs	Anc	Ne	Ccn	Anl	Ag	Agt	Cpx	Ged	Hbl	Rbk	Bt	Phl	Cal	Dol	Grt	Spn	Rt	Zrn	Ap	Fl	Op	Ser	Chl	Bi	Phl	Kln	Cal	Aln	Ep	Fe	Py	Lex
1	Ja 80A	Trachyte	Ktd				△	◎	○				△					○										△	△	△				△				△	
2	K 80A	Trachyte	Ktd	○		◎														△							△	○											
3	K 80B	Dolerite	Kdd		◎									△		○		△		△								○	△	△									△
4	J 90	Albite-porphyry	Mgr			◎					△																	○											
5	Ca 40	Syenite	Mfn		△		◎						◎				△		△				△			△		△	△					△					
6	D 20	Beforsite	Mcd			△														◎						△													
7	M 22	Sovite	Mcd																		◎					△													
8	K 90	Beforsite	Mcb2																		◎					△													
9	L 80	Beforsite	Mcb2																		◎									△									
10	M 71	Beforsite	Mcb2																		◎																△		
11	N 52	Beforsite	Mcb2				△														◎					△											△		
12	N 70	Beforsite	Mcb2				△														◎					△													
13	Ca 41	Beforsite	Mcb1																○		◎					△				△									
14	Da 32	Beforsite	Mcb1																○		◎							△									△		
15	E 50	Beforsite	Mcb1																		◎																		
16	Ea 30	Beforsite	Mcb1																△		◎							△											
17	Ea 41	Beforsite	Mcb1																		◎																△		
18	Ea 60	Beforsite	Mcb1																		◎																△		
19	Ea 71	Beforsite	Mcb1	△																	◎																△		
20	F 70	Beforsite	Mcb1																		◎																△		
21	F 71	Beforsite	Mcb1																		◎																		
22	Ca 62	Porphyritic syenite	Msu				◎			◎	△		○						○	◎			△			△		△	△					△					
23	E 31	Syenite	Msu			○	◎												○	○			△			△		△		△					△		△		
24	Ea 22	Syenite	Msu			○	◎						△						△	○		△				△		△	△	○		△				△			
25	F 81	Syenite	Msu				◎		△	△			◎					△					△			△		△	△										
26	I 50	Porphyritic syenite	Msu				◎		△	○	△		△					○		△				△				△					△	△					
27	K 50	Syenite	Msu				◎		○	○			△					◎				△	△			△		△	△										
28	I 80	Syenite	Msr				◎		△	○	△	○						△		○		△	○			△		△					△						
29	Ea 32	Sovite	Mcs			◎													△	△						△													
30	Ea 80	Sovite	Mcs																△	△						△													
31	H 70	Sovite	Mcs				◎			△	△								△	△																			
32	K 40A	Sovite	Mcs				△			△	△								△	△																			
33	N 80	Sovite	Mcs			△													△	△																			
34	La 20	Porphyritic syenite	Msp		△		◎		△	○	△		○						○									△	△	△				△		△			
35	N 11	Syenite	Msp		○		◎			○	△		△					○		◎			△			○		△	△	△									
36	N 22	Syenite	Msp		○		○			○			○					△		○			△			△		△											
37	L 11	Porphyritic syenite	Msw	○	○		○						△				△	△		○					△														
38	Na 12	porphyritic syenite	Msw			◎	◎			○	○		○						△	○					△			○	△	△						△			
39	Na 70	Porphyritic syenite	Msw			△	◎		○		△		△						○	△			△			△		△	△	△									
40	O 30	Syenite	Msw				◎		○	△	○		△			○		△		△			△			△		△	△										
41	O 60	Syenite	Msw			◎	◎													△						△		△											
42	P 10	Syenite	Msw			△	◎			◎	△		△					△		△						△		△		△				△					
43	A 90	Gneiss	Ngn	◎	◎		◎								△	△		○		△			△			△	△	△	△	△									
44	Da 30	Gneiss	Ngn	△			◎																△			○		△	△	△	△			△					
45	Da 81	Gneiss	Ngn		○		◎						◎						△	○						△		△	△	△									

◎:abundant ○:common △:rare

Abbreviation

Qtz:quartz Pl:plagioclase Ab:albite Kfs:potassium feldspar Anc:Anorthoclase Ne:nepheline Ccn:cancrinite Anl:analcime
Ag:aegirine Agt:aegirine-augite Cpx:clinopyroxene Ged:gedrite Hbl:hornblende Rbk:riebeckite Bt:biotite Phl:phlogopite Cal:calcite Dol:dolomite
Grt:garnet Spn:sphene Rt:rutile Zrn:zircon Ap:apatite Fl:fluorite Op:opaque minerals
Ser:sericite Chl:chlorite Kln:kaolinite Aln:allanite Ep:epidote FeHO:Fe hydroxide Py:pyrite Lex:leucoxene

TableII-2-2 Opaque Mineral Assemblage at the Orange Area determined by the Refractive Microscopic Observation

No.	Sample No.	Rock Name	Rock Code	Oxide and HydroOxide						Sulphide							Remarks
				Mag	MagT	Ilm	Hem	Fe-HO	GoeP	Py	Mc	Po	Mar 1)	Sp	Ccp	Gn	
1	Da50	Beforsite	Mcb1	○−△		○	△2)	◎									
2	Da51	Beforsite	Mcb1	○			△2)	○		△		△		△			
3	Da52	Beforsite	Mcb1	△			△2)	○									
4	Da71 No.1	Beforsite	Mcb1	○			△2)	○				△					
5	Da71 No.2	Beforsite	Mcb1	△			△2)	◎				△					
6	E 50	Beforsite	Mcb1	○			△2)										
7	Ea22	Syenite	Msu			△		○		△		◎−○					Monoclinic Po
8	Ea41	Beforsite	Mcb1	◎			△2)										
9	Ea51 No.1	Beforsite	Mcb1	◎			△2)	△3)				△					
10	Ea51 No.2	Beforsite	Mcb1	○		△	△2)										
11	F 52	Beforsite	Mcb1	○			△2)			△							
12	F 62	Beforsite	Mcb1	○									○				
13	F 70	Beforsite	Mcb1			△	◎						○				
14	J 40A	Iron ore	Mcs	●			△2)										
15	J 90	Granitic rock	Mgr							○−△	○						Py-Mc aggregate replaces Po
16	Ja80A	Trachyte	Ktd			△				○							
17	Ka60A	Syenite	Msu	○		△	○2)				△	◎					
18	Ka90	Beforsite	Mcb2				○	△									
19	L 90	Black shale	Nsh							○		△					Fine inclusions of Po in Py
20	La20	Porphyritic syenite	Msp		△	○			△	○−△		○−△					
21	N 12	Leuco-syenite	Msw			○			△			○					Py-Mc aggregate partly replaces Po
22	N 22	Syenite	Msp			○				○					△		
23	N 80	Sovite	Mcs						△	○							
24	N 82A	Sovite	Mcs						○			△					Fine Po relics remain in GoeP
25	Na12	Porphyritic syenite	Msw			○				○−△		○			△		Hexagonal Po

●:abundant ◎:common ○:poor △:rare

Abbreviation

Mag:Magnetite MagT:titanomagnetite Ilm:ilmenite Hem:hematite FeHO:Fe:hydroxide GoeP:goethite after pyrite

Py:pyrite Mc:marcasite Po:pyrrhotite Mar:martite Ccp:chalcopyrite Gn:galena

1): Martite consists of Hem which replaces Mag. Some of martite are replaced by Fe hydroxide.

2): Hematite partly/completely replaces magnetite along cracks.

3): Fe hydroxide partly replaces the rim of pyrrhotite.

TableII-2-3 Mineral Assemblage at the Orange Area determined by the XRD analysis

No.	Sample No.	Rock Name	Rock Code	Silica and silicate minerals													Carbonate										Oxide			Sulfide		Sulfate	Phosphate	
				Qtz	Ab	Kfs	Ne	Ccn	Sdl	Anl	Rbk	Ag	Agt	Phl	Ms	Chl	Cal	Mcc	Dol	Ank	Sd	Mgs	Ku	Str	Bcc	Bs	Mag	Hem	Goe	Py	Mc	Brt	Ap	Mnz
1	J 90	Granitic rock	Mgr		●																									△	△		△	
2	K 80A	Fine granophyre?	Mgr	◎	●	●							△				△													△				
3	D 20	Beforsite vein	Mcd		○						○	○		●				●															△	
4	M 22	Sovite	Mcd														●			○	△			△										
5	T 1A	Beforsite	Mcd			△											○			●				△		△							△	△
6	Ca40	Fenite	Mfn		○	●					△		○				△										△						△	
7	K 90	Beforsite	Mcb2								△								●														△	
8	Ka90	Beforsite	Mcb2								△						△		●														△	
9	L 80	Beforsite	Mcb2																●		△												△	
10	M 71	Beforsite	Mcb2								△	△		△		△			●										△				○	
11	N 70	Beforsite	Mcb2			△											○			●									△				◎	
12	N 72	Beforsite	Mcb2		●	◎						●		◎			○			●										△			△	
13	Ca41	Beforsite	Mcb1											◎				△	●					△									○	
14	Da32	Beforsite	Mcb1											◎		○			●														○	
15	Da52	Beforsite	Mcb1																●														△	
16	E 50	Beforsite	Mcb1																	●		○					△	△	△					
17	Ea30	Beforsite	Mcb1											○			△		●															
18	Ea41	Beforsite	Mcb1																●			◎					△	△	△					
19	Ea61	Beforsite	Mcb1																●							△			△					
20	Ea71	Beforsite	Mcb1	△															●										△					
21	T 5A	Beforsite	Mcb1																●										△					
22	Ca62	Porphyritic syenite	Msu		◎	●		○		○		△		◎			◎										△						△	
23	Ea22	Syenite	Msu		◎	●				○				○		○	◎																	
24	F 81	Syenite	Msu				○			○			○	○			●																△	
25	I 50	Porphyritic syenite	Msu			●		◎		○				◎			○										△							
26	K 50	Syenite	Msu		○	●	○	○		○				●													○							
27	T 11A	Syenite	Msu		◎	●	○				○		○	△			○										△							
28	I 80	Porphyritic syenite	Msr		◎	●		○		○			○	○			○																	
29	Ea32	Sovite	Mcs		●									○		△	●																△	
30	Ga62	Sovite	Mcs	△							△			○			●		△									△					△	
31	Ga72	Sovite	Mcs	○												△	●												△				○	
32	J 40A	Iron ore	Mcs											○				○					△		○		○	△	△			△		
33	K 40A	Sovite	Mcs			○		△		△		△		◎			●																	
34	N 80	Sovite	Mcs		○									△			●		○															
35	T 13A	Sovite	Mcs								○						●																△	
36	T 2A	Sovite	Mcs	△	○	◎	○										●																	
37	T 9A	Sovite	Mcs		△	○	○	△	△								●																	
38	L 20	Porphyritic syenite	Msp		◎	○		○		○		○		△		△	○																	
39	La20	Porphyritic syenite	Msp		◎	●		○		○				△		△	○																	
40	N 22	Syenite	Msp		●	○		◎		○		○		○			○																	
41	Na12	Porphyritic syenite	Msw		◎	◎		○		○		○			△	△	○																	
42	Na70	Porphyritic syenite	Msw		◎	●		◎		○				●			△																	
43	O 40A	Syenite	Msw		●	●	○	△		△			◎	△			△										△							
44	O 30	Syenite	Msw		◎	◎		○	◎	△	○			◎			△										△							
45	O 40	Porphyritic syenite	Msw		◎	●		◎		○				○			△										△							
46	O 60	Leuco-Syenite	Msw		●	●									○		△										△							
47	P 10	Nepheline syenite	Msw		●	◎		◎		○		○		◎			○										△							
48	P 20	Leuco-Syenite	Msw		●	○		△		△				△			●																	
49	A 90	Gneiss	Ngn	●	●	○								△		○	△																	
50	Da30	Gneiss	Ngn	◎		●	△						△	○		○	△																○	
51	T 10A	Gneiss	Ngn	●	●	◎	△							△		△																		
52	T 12A	Gneiss	Ngn	●	◎	◎		△			△		○				△										△							

●:abundant ◎:medium ○:little △:detectable

Abbreviation

Qtz:quartz Ab:albite Kfs:potassium feldspar Ne:nepheline Ccn:cancrinite Sdl:sodalite Anl:analcime
Rbk:riebeckite Ag:aegirine Agt:aegirine-augite Phl:phlogopite Ms:muscovite Chl:chlorite
Cal:calcite Mcc:manganese calcite Dol:dolomite Ank:ankerite Sd:siderite Mgs:magnesite Ku:kütnohorite Str:strontianite Bcc:barytocalcite Bs:bastanaesite
Mag:Magnetite Hem:hematite Goe:goethite Py:pyrite Mc:marcasite Brt:barite Ap:apatite Mnz:monazite

TableII-2-4 Chemical Composition of Whole Rock Analysis at the Orange Area

1

No.	1	2	3	4	5	6	7	8	9	10	11	12
Sample No.	M22	Ea32	H70	K40A	T13A	T9A	Da32	Ea30	Ea41	Ea60	Ea71	F70
Rock Name	Sovite	Sovite	Sovite	Sovite	Sovite	Sovite	Beforsite	Beforsite	Beforsite	Beforsite	Beforsite	Beforsite
Rock Code	Mcd	Mcs	Mcs	Mcs	Mcs	Mcs	Mcbl	Mcbl	Mcbl	Mcbl	Mcbl	Mcbl
SiO_2 %	0.43	25.59	28.96	19.12	4.54	9.13	6.89	2.13	0.58	0.40	0.34	2.63
TiO_2	0.01	0.27	0.13	0.21	0.02	0.08	0.07	0.10	0.01	0.02	0.01	0.01
Al_2O_3	0.01	6.28	7.09	5.86	0.03	2.68	2.34	0.35	0.01	0.01	0.01	0.01
Fe_2O_3	2.00	1.39	1.26	0.90	1.46	0.54	0.74	1.64	11.42	3.43	2.97	5.78
FeO	6.87	2.74	1.77	1.61	0.52	0.60	4.29	5.03	0.16	2.13	1.74	1.00
MnO	1.32	0.25	0.12	0.13	0.40	0.16	0.94	1.05	1.22	0.86	0.83	0.98
MgO	3.96	1.69	0.76	0.73	1.56	0.25	16.05	16.94	19.90	19.96	20.34	16.96
CaO	39.17	33.82	28.53	35.71	49.89	45.72	27.61	27.36	23.46	27.52	27.65	28.87
Na_2O	0.04	2.15	0.93	2.11	0.77	1.13	0.09	0.04	0.03	0.02	0.02	0.04
K_2O	0.29	1.11	4.93	2.96	0.18	0.99	0.91	0.54	0.01	0.01	0.01	0.02
P_2O_5	0.14	2.36	1.45	0.89	1.78	0.02	2.98	0.05	0.04	0.03	0.03	0.04
CO_2	41.64	20.00	21.04	26.90	35.58	37.06	34.22	43.12	40.60	44.64	44.66	40.77
$H_2O(+)$	1.14	2.00	1.62	1.62	0.42	0.37	1.06	0.90	0.98	0.54	0.46	1.56
$H_2O(-)$	0.14	0.13	0.36	0.26	0.18	0.07	0.26	0.23	0.14	0.25	0.11	0.23
Total	98.04	99.94	99.05	99.13	97.52	98.89	98.60	99.54	98.61	99.88	99.25	99.07
La ppm	1600	180	128	142	360	183	213	80	12	42	111	319
Ce	3530	433	252	276	571	274	513	198	97	126	208	510
Nd	1210	160	86	87	280	137	190	47	24	30	47	135
Sm	154.0	33.2	11.8	13.9	52.1	20.3	33.9	< 0.1	< 0.1	< 0.1	1.0	14.4
Eu	31.0	10.6	4.3	4.4	13.1	5.0	9.3	1.1	< 0.5	< 0.5	1.1	3.2
Tb	33.3	19.5	9.6	8.4	10.1	6.6	27.8	28.8	45.1	22.3	21.0	21.8
Yb	4.6	4.2	2.5	3.5	5.3	3.6	2.2	0.8	0.9	0.6	0.6	0.8
Lu	1.2	1.0	0.6	0.7	1.0	0.5	0.7	0.8	1.2	0.6	0.5	0.6
Sc	5.1	0.7	< 0.5	< 0.5	2.2	1.6	4.3	2.6	2.3	3.2	2.3	2.6
Y	79	62	36	49	111	51	43	8	6	7	6	10
U	< 1	2	94	8	3	3	9	< 1	6	4	1	4
Th	147	42	18	9	18	14	2	13	6	9	8	20
Nb	13	123	355	358	462	4	252	49	795	1360	312	722
Ta	< 2	8	20	6	3	< 2	9	< 2	3	< 2	< 2	2
Zr	< 3	174	261	259	< 3	708	11	< 3	3	< 3	< 3	4
Sr	12810	3270	2170	4080	7340	6140	3960	5020	4140	4600	5760	4200

2

No.	13	14	15	16	17	18	19	20	21	22	23	24
Sample No.	T5A	K90	L80	M71	L11	Na70	060	P10	La20	N22	T7A	I80
Rock Name	Beforsite	Beforsite	Beforsite	Beforsite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite	Syenite
Rock Code	Mcb1	Mcb2	Mcb2	Mcb2	Msw	Msw	Msw	Msw	Msp	Msp	Msp	Msr
SiO_2 %	0.03	0.54	0.53	0.78	70.30	52.74	65.01	50.29	53.13	47.28	57.24	51.28
TiO_2	0.01	0.01	0.01	0.03	0.17	0.45	0.07	0.46	0.32	0.70	0.03	0.24
Al_2O_3	0.04	0.11	0.01	0.01	12.89	20.30	18.20	22.09	20.72	16.06	15.34	15.44
Fe_2O_3	3.12	0.20	0.61	3.09	1.27	1.83	0.47	1.70	0.20	4.52	1.06	2.62
FeO	3.30	3.85	2.84	3.87	1.10	1.39	0.13	1.58	1.67	1.87	0.20	2.45
MnO	0.79	1.17	0.80	0.66	0.08	0.14	0.06	0.13	0.06	0.12	0.17	0.20
MgO	19.24	17.72	15.53	16.03	0.87	0.28	0.03	0.13	0.36	0.49	0.25	0.64
CaO	28.90	29.85	31.55	29.13	1.21	2.15	1.22	1.43	2.84	5.64	4.23	7.52
Na_2O	0.09	0.05	0.06	0.24	4.47	8.79	9.13	11.23	6.00	9.90	1.05	5.65
K_2O	0.03	0.04	0.01	0.10	4.55	5.72	2.80	5.20	7.20	4.63	12.99	6.59
P_2O_5	0.04	2.30	7.31	2.89	0.12	0.21	0.44	0.14	0.15	0.56	0.13	0.51
CO_2	41.72	41.46	37.46	41.80	1.48	2.38	1.26	3.78	2.88	3.98	4.85	3.62
$H_2O(+)$	0.37	1.20	1.36	0.52	0.38	3.04	0.90	1.50	3.78	3.62	0.91	2.06
$H_2O(-)$	0.07	0.12	0.21	0.45	0.13	0.19	0.33	0.24	0.10	0.25	0.07	0.16
Total	97.80	98.69	98.44	99.72	99.07	99.72	100.08	99.98	99.47	99.75	98.66	99.06
La ppm	106	104	215	187	33	85	18	20	12	71	264	33
Ce	134	250	410	326	73	127	40	42	32	95	482	68
Nd	51	98	177	138	24	39	15	11	11	25	230	25
Sm	5.2	15.3	33.0	19.7	3.1	2.4	3.9	0.8	< 0.1	< 0.1	33.4	< 0.1
Eu	0.5	5.1	8.9	7.6	0.8	1.4	1.6	0.6	< 0.5	< 0.5	1.9	0.9
Tb	5.8	13.4	14.2	27.0	9.4	10.6	2.8	6.3	7.1	20.7	7.1	13.3
Yb	1.1	1.6	2.1	2.1	2.7	2.0	0.8	0.7	0.6	1.2	0.7	1.9
Lu	0.7	0.6	0.3	0.5	0.7	0.3	0.1	0.2	0.2	0.5	0.2	0.7
Sc	8.1	0.6	0.6	0.8	3.5	< 0.5	0.5	< 0.5	< 0.5	2.1	0.8	< 0.5
Y	14	27	44	40	20	20	22	6	4	14	12	13
U	6	< 1	< 1	1	7	6	22	7	10	34	56	9
Th	9	8	4	47	16	8	33	10	4	9	36	11
Nb	7	66	18	4090	39	218	432	170	514	688	1290	639
Ta	< 2	< 2	< 2	5	< 2	7	5	5	< 2	6	< 2	14
Zr	< 3	< 3	< 3	4	122	180	11	118	40	169	10	849
Sr	5470	3860	5470	3740	139	1490	148	932	2310	1820	1700	598

No.	25	26	26	28	29	30
Sp. No.	F81	I50	K50	T11A	J90	Da30
Rock Name	Syenite	Syenite	Syenite	Syenite	Micro-granite	Geniss
Rock Code	Msu	Msu	Msu	Msu	Mgr	Ngn
SiO_2 %	25.74	52.87	55.82	61.15	66.51	54.94
TiO_2	0.56	0.46	0.38	0.12	0.01	0.47
Al_2O_3	7.27	19.69	19.51	14.67	18.20	17.13
Fe_2O_3	1.03	0.23	0.20	2.16	1.00	3.22
FeO	4.25	2.35	3.48	0.64	0.58	0.13
MnO	0.23	0.04	0.08	0.07	0.01	0.15
MgO	1.70	0.19	1.62	0.48	0.01	1.30
CaO	30.34	1.76	0.61	2.53	0.12	4.73
Na_2O	2.97	7.19	3.86	3.45	10.91	0.42
K_2O	1.57	8.84	10.94	11.76	0.05	8.78
P_2O_5	2.29	0.05	0.16	0.08	0.05	1.82
CO_2	18.75	3.84	0.96	1.66	0.68	2.94
$H_2O(+)$	1.90	2.36	1.02	0.58	0.52	2.44
$H_2O(-)$	0.04	0.11	0.33	0.06	0.25	0.42
Total	98.83	100.07	99.03	99.42	98.92	99.07
La ppm	186	2	9	26	30	155
Ce	343	11	10	25	64	360
Nd	125	4	5	13	20	160
Sm	20.2	< 0.1	< 0.1	0.1	1.6	41.0
Eu	5.6	< 0.5	< 0.5	0.5	0.8	12.5
Tb	15.8	9.9	15.0	6.8	5.6	13.9
Yb	2.7	0.5	0.4	0.8	0.3	6.4
Lu	0.8	0.3	0.2	0.3	0.2	1.0
Sc	< 0.5	0.5	< 0.5	0.8	< 0.5	< 0.5
Y	37	2	2	1	3	99
U	5	6	29	4	2	31
Th	14	8	12	5	6	15
Nb	339	254	249	48	53	662
Ta	30	15	6	< 2	< 2	26
Zr	653	94	116	291	6	907
Sr	2870	431	154	295	15	671

post-Karoo intrusions in the area.

Schommarz (1988) considered that the MQC consists of 3 intrusive centres. This consideration is accepted in this report and the classification of the lithology on the MQC is almost same with Schommarz (1988).

Results of the laboratory tests such as rock thin section observation, polished section observation, the XRD analysis and whole rock chemical analysis are shown in Table II-2-1 to Table II-2-4, respectively.

1. Namaqua metamorphic complex (Ngn)

This complex distributes surrounding the MQC, and widely distributes outside of the area. It consists of the quartz-feldspar gneiss in the area. It has a large amount of quartz and feldspar grains which sizes are more or less than 1 mm in the diametre. Foliation with strike of the NW-SE direction and the dip to south ic commonly observed in the metamorphic complex. Brecciated structure is common around the MQC. Most of breccia have various sizes of fragments, and dark green veinlets composed of dark green to bluish green amphibole, aegirine, aegirine-augite, phlogopite, carbonate minerals, apatite, etc fill in the boundaries of fragments. Brown carbonatite veins occur interstitially in the breccia. The contact zone with the MQC is replaced by carbonates and alkaline feldspars, and it becomes difficult to identify original rock facies in the field.

A large amount of alkaline feldspars caused by fenitization and alkaline metamorphism are identified under the microscopic observation and by the XRD analysis. Main rock forming minerals consist of quartz, plagioclase (albite), potassium feldspar, aegirne-augite, gerdite, hornblende, riebeckite, biotite and phlogopite. Garnet, sphene, zircon, apatite, calcite, fluorite and opaque mineral are identified as accessary minerals. Parts of feldspars and mafic minerals are replaced by sericite and chlorite, respectively, by secondary alteration. Cancrenite are identified in some rock specimens (T12A, N10, O61) in the north of contact zone with the MQC.

2. Gariep Group (Gdd)

It occurs as the dolerite of the Gannakouriep dyke suite in the south-west of the area, and is intruded by the carbonatite dyke (Mcd), mentioned latter.

3. Nama sequence (Nsh)

It distributes at the east of the MQC and occurs as the xenolith in the MQC, and consists of black shale, quartzite and grit. Brecciated structure occurs in size of 10 cm to several metres. Dark green to bluish green mineral veinlets fill in boundaries of fragments. Brown carbonatite veins are observed in the breccia. Weak bedding plane is observed in black shale. Quartzite is light greenish grey to white coloured. Grading texture is observed in some quartzite blocks. Grit is greyish white to light green coloured, and consists of quartz and feldspar grains. This sequence seems entirely brecciated, as distribution of each facies is not concordant with the occurrence which is estimated by strikes and dips of bedding plane and grading texture observed at the outcrops. Lithostratigrapy of each rock facies is not unknown.

4. Marinkas Quelle carbonatite complex (MQC)

The MQC distributes as a shape of an ellipse elongated to the NE–SW direction and occuring as intrusive intruded in the Namaqua metamorphic complex and the Nama sequence. It is known that there are three portions of intrusive centres and dykes in the MQC (Schommarz, 1988). The lithology of the MQC refers to that of Schommarz (1988), but fine syenite facies includes in porphyritic syenites (undifferentiated, Msu) to simplify. The MQC is subdivided to three bodies, such as the syenite body situated in the north, the sövite–syenite body in the central zone, and the beforsite body in the south and east. The mineral assemblages of the each rock facies in the MQC are shown in Table II–2–5.

4–1 Syenite body (Msw, Msp)

It distributes at the north of the area as a half moon shape. It consists of white – grey porphyritic syenite (Msw) and porphyritic nepheline syenite (REE bearing, Msp).

The white – grey porphyritic syenite (Msw) is creamy white to grey, partly greenish grey coloured. Brecciated structure is common, and fragments of gneiss, and back shale is contained in the body as xenolith. It consists mainly white feldspar whose grain size is more or less than 5 mm in diametre, and contains characteristically small amount of mafic minerals. Veinlets composed of dark green to bluish green amphibole, aegirine, phlogopite and carbonate minerals etc fill in boundaries of brecciated fragments.

A large amount of alkaline feldspars caused by fenitization and alkaline metamorphism are identified under the microscopic observation and by the XRD analysis. Main rock forming minerals consist of quartz, plagioclase (albite), potassium feldspar, nepheline, cancrenite, analcime, aegirne–augite, hornblende, riebeckite, biotite and phlogopite. Sphene, zircon, apatite, calcite and opaque mineral are identified as accessary minerals. Parts of feldspars and mafic minerals are replaced by sericite, and chlorite and epidote, respectively, as secondary alteration.

Porphyritic nepheline syenite (Msp) is creamy white to light greyish green, partly light pink coloured. It contains white to light yellow feldspar phenocryst and aegirine–augite phenocryst whose grain sizes are 1 to 5 mm in diametre, and biotite phenocryst whose grain size is 0.1 to 1 mm in diametre. Aggregate of feldspar mega–crystals (more than 5 cm in diametre) occurs at some outcrop. Brecciated structure occurs, and calcitic carbonatite dyke is commonly found.

Main rock forming minerals consist of plagioclase (albite), potassium feldspar, nepheline,

TableII-2-5 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	———	———	- - -	———	———- - -		- - -		
Sodalite	- - -		- - -						
Analcime	———	———	- - -	———	———	- - -			
Aegirne	———- - -	———- - -	- - -	- - -	- - -		- - -		- - -
Aegirine-augite	- - -	———		- - -	- - -			———	- - -
Clinopyroxene									
Hornblende	- - -								
Riebeckite	- - -		- - -		- - -		- - -	- - -	- - -
Gedrite									
Biotite	- - -	- - -	- - -	- - -	———- - -				
Phlogopite	———	———	———	———	———	———	- - -	- - -	———- - -
Calcite	- - -	- - -	━━━	———	———	- - -	- - -	- - -	━━━- - -
Dolomite			- - -			━━━	━━━		
Ankerite			- - -			- - -	━━━- - -		- - -━━━
Kutnahorite			- - -						
Siderite							- - -		- - -
Magnesite						- - -			
Strontianite						- - -			- - -
Barytocalcite			- - -						
Apatite	- - -	- - -	———- - -	- - -	- - -	- - -	———	- - -	- - -
Sphene	- - -	- - -	- - -	- - -	- - -	- - -		- - -	
Rutile					- - -				
Zircon	- - -		- - -						
Garnet				- - -	- - -				
Fluorite									
Barite			- - -						
Magnetite	———	- - -	- - -		- - -	- - -		- - -	
Hematite			- - -			- - -			
Pyrite							- - -		
Epidote	- - -	- - -			- - -				
Allanite					- - -				
Sericite	- - -	- - -	- - -		- - -			- - -	
chlorite	- - -	- - -	- - -		———- - -	- - -	- - -		
Kaolinite				- - -	- - -				
Goethite			- - -			- - -	- - -		
Pyrochlore						- - -	- - -		
Monazite									- - -
Bastnaesite						- - -			- - -

cancrenite, analcime, aegirine, aegirne–augite, biotite and phlogopite. Sphene, apatite, calcite and opaque mineral are identified as accessary minerals under the microscopic observation and the XRD analysis. Parts of feldspars and mafic minerals are replaced by sericite, and chlorite and epidote, respectively, as secondary alteration. Nb–synchisite was found in this body (Schomamrz, 1988), but not identified in this survey.

4–2 Sövite–syenite body (Mcs, Msu, Msr, Msm)

This body remains a ring structure in the centre of the area, and partly deformed. It consists of sövite (Mcs), porphyritic syenite (Msr), syenite (undifferentiated, Msu), and fine syenite sill (Msc).

Sövite (Mcs) is widely distributed in the area, especially in the basin of the central area. It consists of coarse grained calcite, and partly aggregate of coarse grained aegirine–augite and/or riebeckite showing foliation. Aggregate of phlogopite was observed at the contact zone with the beforsite body, and it shows banding structure. The float of iron ore was found in the area where sövite distributed at the central basin.

Calcite is a major mineral, but also quartz, albite, potassium feldspar, nepheline, cancrinite, sodalite, analcime, aegirine, aegirine–augite, riebeckite, dolomite, hematite, chlorite and goethite are identified as accessary minerals under the microscopic observation and by the XRD analysis.

Reddish porphyritic syenite (Msr) distributes at the contact zone with the gneiss (Ngn) in the east. It contains characteristically pink coloured feldspar phenocryst.

Main rock forming minerals consist of plagioclase (albite), potassium feldspar, cancrenite, analcime, aegirine, biotite and phlogopite. Garnet, sphene, apatite, calcite and opaque mineral are identified as accessary minerals.

Undifferentiated syenite (Msu) are widely distributed in the area. It shows creamy white, greenish grey, grey to light grey coloured, and have a variety of grain size of rock forming minerals. It shows brecciated structure around the beforsite body, and green veinlets fill in the boundary of the fragments interstitially.

Main rock forming minerals consist of plagioclase (albite), potassium feldspar, nepheline, cancrenite, analcime, aegirine, aegirine–augite and biotite. Sphene, apatite, calcite and opaque mineral such as magnetite are identified as accessary minerals. A part of mafic minerals are replaced by chlorite as the secondary alteration in the eastern margin of the ankeritic beforsite.

Fine syenite sill (Msm) distributes in the centre portion of the complex as a dyke with more or less than 1 m width.

4–3 Beforsite body (Mcb, Mfn, Mgr)

Ankeritic beforsite (Mcb) consists of the two bodies at the southern portion and the eastern one. The southern body has a shape of ring structure. Surface of the outcrops is reddish brown to brown coloured by weathering, and shows clearly difference of the surface colour against the surrounding rocks such as gneiss, syenite and sövite. Banding structure with almost vertical dips are found in the body, and strikes are concordant with the shape of the body. Aggregate of phlogopite and goethite are commonly observed in the body.

The main rock forming mineral of the southern beforsite body is two types such as dolomite and ankerite identified by the XRD analysis. Phlogopite, chlorite, calcite, siderite, strontianite, magnetite, hematite, goethite and apatite are identified as accessary minerals. Bastnaesite as the REE mineral is identified in a specimen (Ea61) by the XRD analysis.

The eastern body has a shape of a spheroid elongated to the N–S direction in the east portion of the area. It is surrounded by gneiss of the Namaqua metamorphic complex, shale and quartzite of the Nama sequence, and syenites and sövite of the MQC. They, except sövite, are strongly brecciated and associate with carbonatite veins and dykes interstitially. Surface of this body shows reddish brown to brown coloured by weathering. Dolerite and trachyte which have a direction parallel with the banding structure observed in beforsite occur in this body. The banding structure parallel with the shape of the body is commonly observed caused by the difference of strength against the weathering. Apatite is found along the banding structure and as bluish coloured veins with more the 1 cm of width in the body.

The main rock forming minerals of the southern beforsite body are two such as dolomite and ankerite, identified by the XRD analysis. Riebeckite, aegirne, phlogopite, chlorite, calcite, siderite, goethite, pyrite and apatite are identified as accessary minerals. Bastnaesite as the REE mineral is identified in a specimen (Ea61) by the XRD analysis. The specimens in which albite, potassium feldspar, aegirne and phlogopite are identified by the XRD include the xenolith of fenitized syenite fragments.

Fenite (Mfn) distributes around the southern beforsite body. The main rock forming minerals are plagioclase (albite) and potassium feldspar. Aegirine, riebeckite, phlogopite, magnetite, apatite, sphene, calcite and sericite are identified as accessary minerals.

Granophyre or micro–granite (Mgr) is found in the centre of the southern beforsite body and the south margin of the eastern beforsite body. It is white to light grey coloured holocrystalline rock. It consist of mainly plagioclase (albite) and small amount of analcime, pyrite and marcasite. Yellow jarosite is found in the weathering surface of the eastern body.

4–4 Carbonatite dyke (Mcd)

The carbonatite dyke (Mcd) occurs as dyke or veinlet intruded in most of other rock facies. It consists of both ankeritic beforsite and calcitic sövite. The surface of both rock facies is brown coloured by the weathering of iron oxides.

It consists of calcite, dolomite, ankerite, apatite and goethite, and strontianite and bastnaesite are identified in some specimens by the XRD analysis.

5. Syn- to post-Karoo Intrusions (Kdd, Ktd)

It consists of dolerite dyke (Kdd) and trachyte dyke (Ktd). Both have a relatively narrow width of less than 2 m. The dykes intrude in all rock facies. The strike of the dykes is concordant with that of the banding structure in the east Beforsite body.

II-2-3 Geochemical Survey

II-2-3-1 Methodology

Whole rock geochemical survey was carried out. The two beforsite bodies and the porphyritic nepheline syenite (Msp) which was recommended as the REE bearing body by Schommarz (1988) are selected to carry out the detail survey. The direction of survey lines set up to cross cut the MQC from the south east to the north west.

Selected elements to analysis are 19 elements as follows :

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

Detectable limits and accuracies for each element are shown in Table II-2-6.

II-2-3-2 Result of Whole Rock Geochemical Survey

Sampling locality for the geochemcal survey is shown in Fig.II-3-5. Statistical values of maximum contents, minimum contents, average contents and, standard deviation for each rock facies are shown in Table II-2-7. The grade of fenitization, carbonatization and weathering are not considered in calculation of the statistics, so they do not show the primary contents of each facies. Beforsite (Mcb) is divided two subgroups of the south body (Mcb1) and the east body (Mcb2), as these have different characters on the distribution and the contents of elements.

Data of the carbonatite dyke take out for contouring, as it makes extremely high anomalies. The characteristics of the distribution on each elements are as follows:

1. REEs (La, Ce, Nd, Sm, Eu, Tb ,Yb and Eu)

REEs which belong the lanthanum series act as similar behavior in geochemistry. Ce is selected to discuss about the distribution of the REEs, because it shows highest content in REEs.

Distribution of Ce content is shown in Fig. II-2-4.

The carbonatite dyke (Mcd) which intrude at the latest stage of the MQC, have relatively highest concentration of Ce in average. High concentrated zone more than 1,000 ppm is limited to inside and/or surrounding of the beforsite bodies. High concentrated zone in the Nama sequence are caused by high content of the REEs in carbonatite veinlets occuring in the sequence. Sövite have relatively high content in average, but a considerable concentration zone is not found. Brecciated porphyritic

TableII-2-6 Analytical Accurancies and Detectable Limits

1)Whole Rock Analysis

Elements(as Oxides)	Analytical Method[1]	Analytical Acurancies Detective 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 Acurancies Detective 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	50 ppm

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

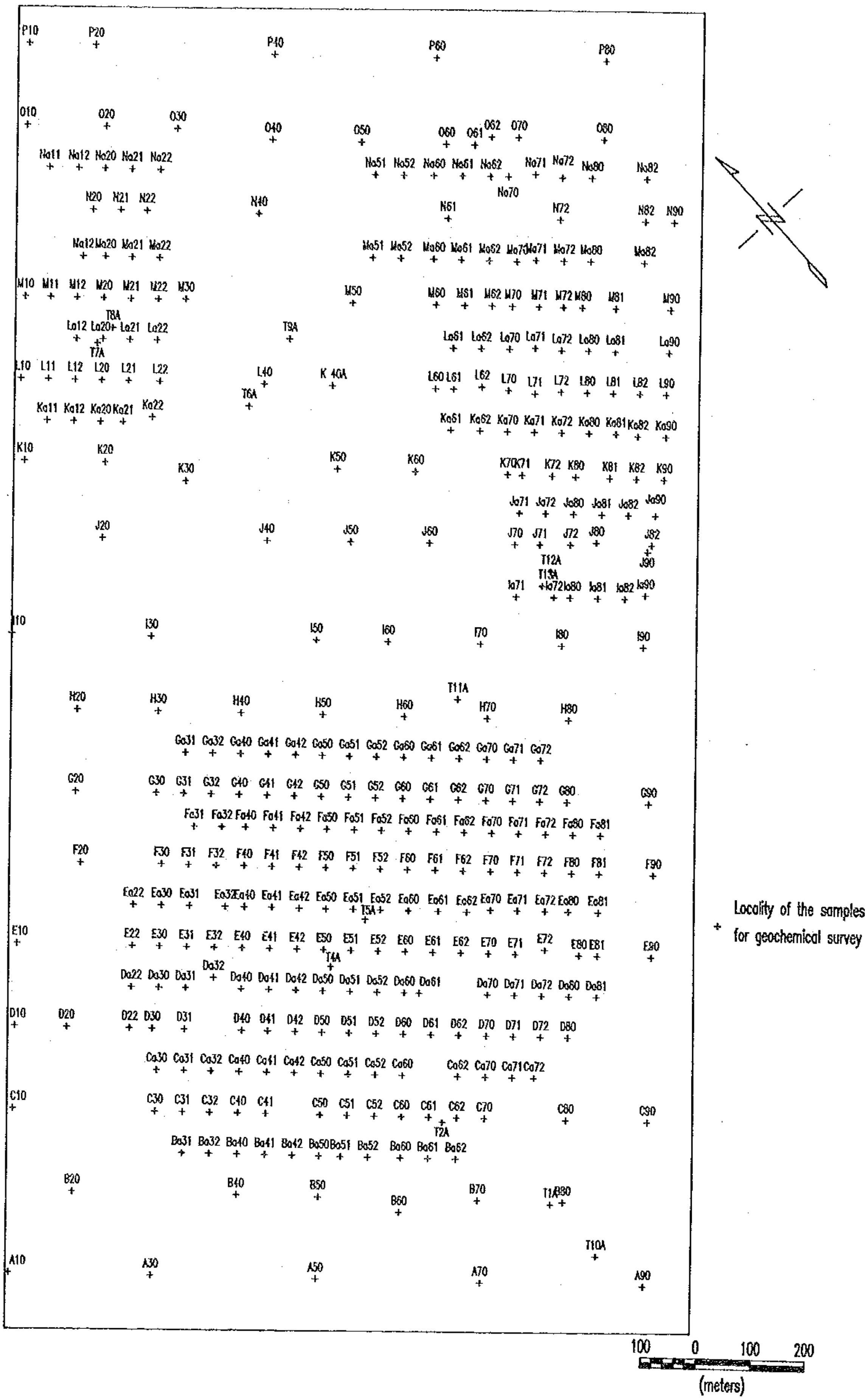


Fig.II-2-5 Sampling Locality for Geochemical Survey at the Orange Area

TableII-2-7 Statistical Values of Geochemical Analysis at the Orange Area

	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 (%)
Maximum Contents																				
Carbonatite dyke	9	5130	9060	3290	622	127	46	10	3	20	119	26	716	848	73	113.0	37700	13300	5370	8.61
Beforsite (East Body)	40	9450	11470	2020	235	36	47	7	1	12	151	28	47	5280	10	67.0	12500	20120	22600	9.73
Beforsite (South Body)	106	2570	4270	1250	191	37	45	3	1	10	56	31	233	4730	35	54.0	9450	7440	19300	8.11
Syenite (Undif.)	33	667	1062	422	93	19	42	18	2	12	105	210	156	3310	63	1620.0	4120	3470	11500	6.61
Sovite	46	692	868	280	52	14	39	24	1	7	111	268	90	8770	67	857.0	7600	9160	19500	6.64
Po. Syenite (REE Bearing)	17	264	482	230	33	2	21	4	1	3	30	286	56	3170	15	700.0	2180	3030	3930	4.61
Po. Syenite	26	295	711	463	186	77	46	70	8	10	1280	118	332	3020	16	449.0	2530	3540	87400	4.76
Nama Sequence	11	931	1530	437	89	35	71	11	2	66	469	38	119	822	8	631.0	9090	1700	12900	12.50
Namaqua Metamorphic Complex	68	448	560	186	41	16	96	19	3	66	190	31	141	952	31	907.0	4340	877	18240	18.30
Minimum Contents																				
Carbonatite dyke	9	211.0	439.0	173.0	35.6	9.1	6.2	1.8	0.8	0.5	40.0	1.0	1.0	5.0	2.0	3.0	5880	1130	222	1.44
Beforsite (East Body)	40	48.0	14.0	5.0	0.1	0.5	4.8	0.6	0.1	0.5	8.0	1.0	1.0	2.0	2.0	3.0	1450	269	138	1.29
Beforsite (South Body)	106	12.0	48.0	13.0	0.1	0.5	5.5	0.4	0.1	1.7	5.0	1.0	1.0	2.0	2.0	3.0	3570	2570	54	1.84
Syenite (Undif.)	33	2.0	10.0	4.0	0.1	0.5	4.0	0.4	0.1	0.5	1.0	1.0	1.0	38.0	2.0	17.0	266	123	173	1.06
Sovite	46	69.0	128.0	43.0	1.1	2.4	2.2	1.3	0.1	0.5	17.0	1.0	1.0	2.0	2.0	3.0	783	1640	78	0.22
Po. Syenite (REE Bearing)	17	11.0	27.0	9.0	0.1	0.5	5.5	0.6	0.2	0.5	4.0	2.0	4.0	2.0	2.0	10.0	355	551	237	0.90
Po. Syenite	26	9.0	20.0	8.0	0.1	0.5	2.8	0.3	0.1	0.5	3.0	1.0	4.0	39.0	2.0	4.0	47	139	228	0.07
Nama Sequence	11	49.0	81.0	28.0	0.1	0.6	3.8	0.2	0.1	0.5	4.0	1.0	2.0	22.0	2.0	8.0	210	82	134	0.53
Namaqua Metamorphic Complex	68	1.0	9.0	3.0	0.1	0.5	1.4	0.2	0.1	0.5	2.0	1.0	1.0	2.0	2.0	4.0	171	6	170	0.32
Arithetic Average Contents																				
Carbonatite dyke	9	2390.0	4275.4	1576.7	234.1	45.7	28.4	4.8	1.4	7.3	75.6	9.7	241.3	210.0	12.6	21.0	13731	8079	2303	5.95
Beforsite (East Body)	40	398.2	562.7	156.0	22.5	5.9	17.3	1.8	0.4	2.3	31.5	4.0	10.2	1408.3	2.6	5.6	6488	4312	7563	3.59
Beforsite (South Body)	106	254.1	406.5	110.8	12.5	3.2	20.8	0.9	0.6	3.8	10.9	4.1	21.7	622.6	4.0	4.1	6468	4870	651	3.95
Syenite (Undif.)	33	91.0	163.5	61.8	9.3	3.0	14.7	2.3	0.6	1.8	18.7	20.6	20.0	509.5	16.7	397.3	1338	1233	2833	3.12
Red Po. Syenite	1	33.0	68.0	25.0	0.1	0.9	13.3	1.9	0.7	0.5	13.0	9.0	11.0	639.0	14.0	849.0	1560	598	2220	3.74
Sovite	46	208.8	366.3	127.1	23.0	6.6	10.3	5.2	0.7	1.1	59.7	17.4	12.2	588.0	8.8	122.0	2053	4396	4493	1.70
Po. Syenite (REE Bearing)	17	82.5	146.6	48.8	4.4	1.3	12.1	1.5	0.5	1.0	15.7	44.0	15.4	580.6	4.4	208.9	1153	1591	1351	2.69
Po. Syenite	26	80.3	156.6	56.0	11.7	4.6	10.6	4.6	0.7	1.2	67.6	32.6	28.2	525.7	5.6	126.3	1106	1274	5005	2.32
Nama Sequence	11	235.7	352.9	116.1	19.9	9.0	28.7	4.8	0.8	15.3	113.1	9.7	35.5	193.7	3.9	159.8	2077	595	2601	5.02
Namaqua Metamorphic Complex	68	63.7	114.6	39.1	3.8	1.6	14.2	3.2	0.6	9.4	24.0	5.3	20.7	93.7	3.4	158.0	991	292	1111	3.04
Standard Deviations																				
Carbonatite dyke	9	1591.6	2700.6	1086.4	182.9	36.5	15.2	3.0	0.5	6.0	24.9	9.5	269.7	260.6	21.7	34.6	10837	4835	1948	2.15
Beforsite (East Body)	40	1453.4	1755.5	306.0	37.1	5.8	7.8	1.2	0.3	2.7	22.9	6.9	11.3	1452.5	1.6	10.1	2243	3313	6206	1.73
Beforsite (South Body)	106	430.6	671.0	184.3	28.2	5.3	7.4	0.4	0.2	1.6	8.2	5.6	33.6	790.5	5.3	5.3	1155	859	2400	1.25
Syenite (Undif.)	33	123.1	206.4	80.3	17.8	4.0	7.7	3.2	0.3	2.9	19.8	38.2	28.8	651.7	14.8	334.1	816	1085	3030	1.25
Sovite	46	95.4	132.8	47.9	10.6	2.7	6.9	4.4	0.3	1.3	20.3	43.0	16.1	1366.1	14.9	215.2	1566	1719	4640	1.43
Po. Syenite (REE Bearing)	17	58.6	107.9	49.0	8.0	0.7	5.2	0.9	0.3	0.7	7.3	64.5	13.0	723.2	4.1	189.9	446	803	998	1.29
Po. Syenite	26	76.9	163.3	88.2	35.3	14.6	8.2	13.4	1.5	1.9	243.3	39.9	61.7	660.5	3.6	139.9	544	851	16534	1.22
Nama Sequence	11	254.4	420.4	123.2	31.9	11.3	20.4	3.0	0.5	20.1	131.5	12.5	35.4	237.9	2.4	168.5	2355	505	3590	3.76
Namaqua Metamorphic Complex	68	63.8	90.1	30.7	6.0	2.5	13.4	3.8	0.4	11.3	31.1	6.5	24.5	156.3	4.9	175.9	729	190	2410	3.06
Geometric Average Contents																				
Carbonatite dyke	9	1716.6	3162.4	1095.6	156.1	31.9	22.8	4.0	1.3	4.8	71.4	4.4	79.7	76.8	5.6	7.8	10813	5946	1375	5.36
Beforsite (East Body)	40	156.4	243.7	88.9	8.6	4.1	15.8	1.5	0.3	1.5	26.3	1.8	5.9	434.6	2.4	3.9	6081	3267	3762	3.27
Beforsite (South Body)	106	131.8	232.2	63.0	1.9	1.7	19.4	0.8	0.5	3.6	9.4	2.5	11.6	213.7	2.8	3.5	6365	4788	188	3.78
Syenite (Undif.)	33	46.6	87.3	33.6	1.2	1.5	12.9	1.5	0.5	1.0	11.7	8.6	11.2	304.9	11.3	271.2	1123	783	1595	2.85
Sovite	46	192.5	344.1	118.8	19.9	6.1	8.7	4.3	0.6	0.8	55.9	5.4	6.1	141.9	3.8	27.5	1683	4076	2114	1.25
Po. Syenite (REE Bearing)	17	62.2	114.2	35.8	0.8	1.1	11.0	1.3	0.4	0.8	13.6	21.6	12.1	280.0	3.4	124.9	1047	1377	1020	2.34
Po. Syenite	26	54.0	106.5	33.1	2.6	1.5	8.8	1.5	0.4	0.7	16.4	14.3	15.0	279.6	4.6	61.6	925	960	1432	1.85
Nama Sequence	11	150.3	218.2	77.8	3.9	4.0	21.2	3.4	0.6	6.6	60.4	4.9	18.1	94.9	3.3	89.0	1292	418	1122	3.66
Namaqua Metamorphic Complex	68	42.6	87.5	30.5	1.2	1.1	10.5	2.2	0.5	5.9	16.0	3.3	13.8	45.7	2.5	92.7	778	219	589	2.20

nepheline syenite (Msp) which respected the concentration of the REEs, shows no difference with other syenites in the contents of the REEs.

Bastnaesite and monazite are identified by the XRD analysis in the specimens highly containing the REEs .

2. Sc and Y

Distribution of Y content is shown in Fig. II-2-5.

High concentrated zone is found in the north east part where the Nama sequence distributes. The beforsite bodies show relatively low concentration of Sc and Y.

3. U and Th

Distribution of Th content is shown in Fig. II-2-6.

A sample which collected in the carbonatite dyke show the content of 690 ppm, but almost all of the samples have low contents in Th and U. It shows relatively high concentrated zone around the marginal zone of the southern beforsite body.

4. Nb and Ta

Distribution of Nb content is shown in Fig. II-2-7.

The high concentrated zones more than 1,000 ppm of Nb are found in and around both beforsite bodies and in the north part of the MQC. Pyrochlore is identified by the XRD analysis in the specimen which contains a high contents of Nb.

5. Zr

Distribution of Zr content is shown in Fig. II-2-8.

The distribution of Zr content shows low concentration in the beforsite bodies and sövite.

6. Mn

Distribution of Mn content is shown in Fig. II-2-9.

High concentrated zones more than 3,000 ppm of Mn are concordant with the distribution of the beforsite bodies. It seems that the content of Mn in the beforsite bodies is homogeneous compared to that of other elements such as the REEs in a logarithmic scale.

7. Sr

Distribution of Sr content is shown in Fig. II-2-10.

Carbonatites in the MQC such as carbonatite dyke, beforsite and sövite show high content of Sr. High concentrated zones are concordant with the distribution of these rock facies. Strontianite