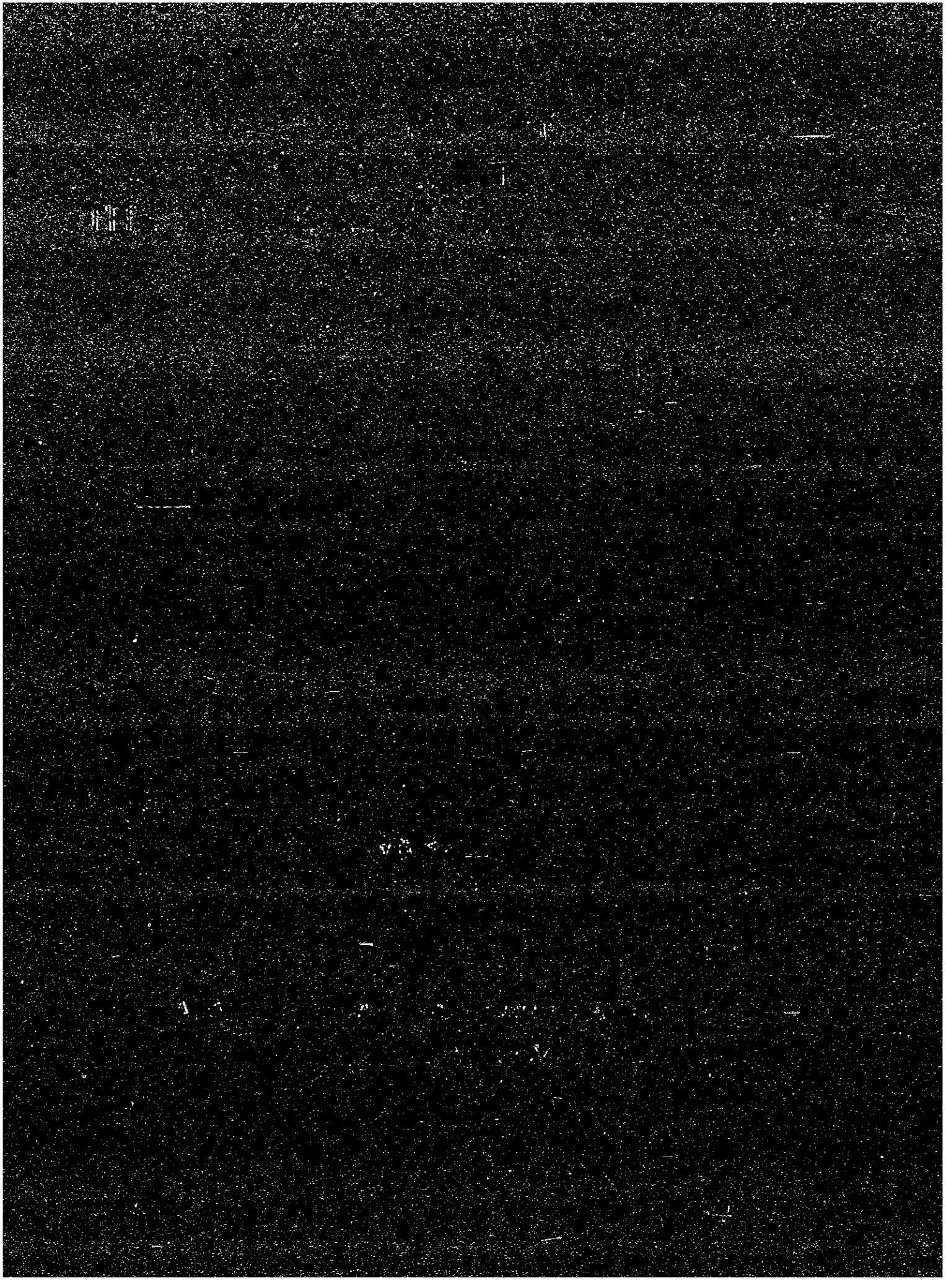

REPORT
ON
THE COOPERATIVE MINERAL EXPLORATION
IN
THE CHILWA ALKALINE AREA
REPUBLIC OF MALAWI

(PHASE Ⅱ)

MARCH 1988

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 Malawi, the Japanese Government decided to conduct a Mineral Exploration in the Chilwa Alkaline Area 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 Malawi a survey team headed by Mr. Tsuyoshi Yamada from 29 July to 6 December, 1987.

The team exchanged views with the officials concerned of the Government of the Republic of Malawi and conducted a field survey in the Chilwa Alkaline area. 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 Malawi for their close cooperation extended to the team.

February, 1988

Kensuke Yanagiya
President
Japan International Cooperation Agency

Junichiro Sato
President
Metal Mining Agency of Japan

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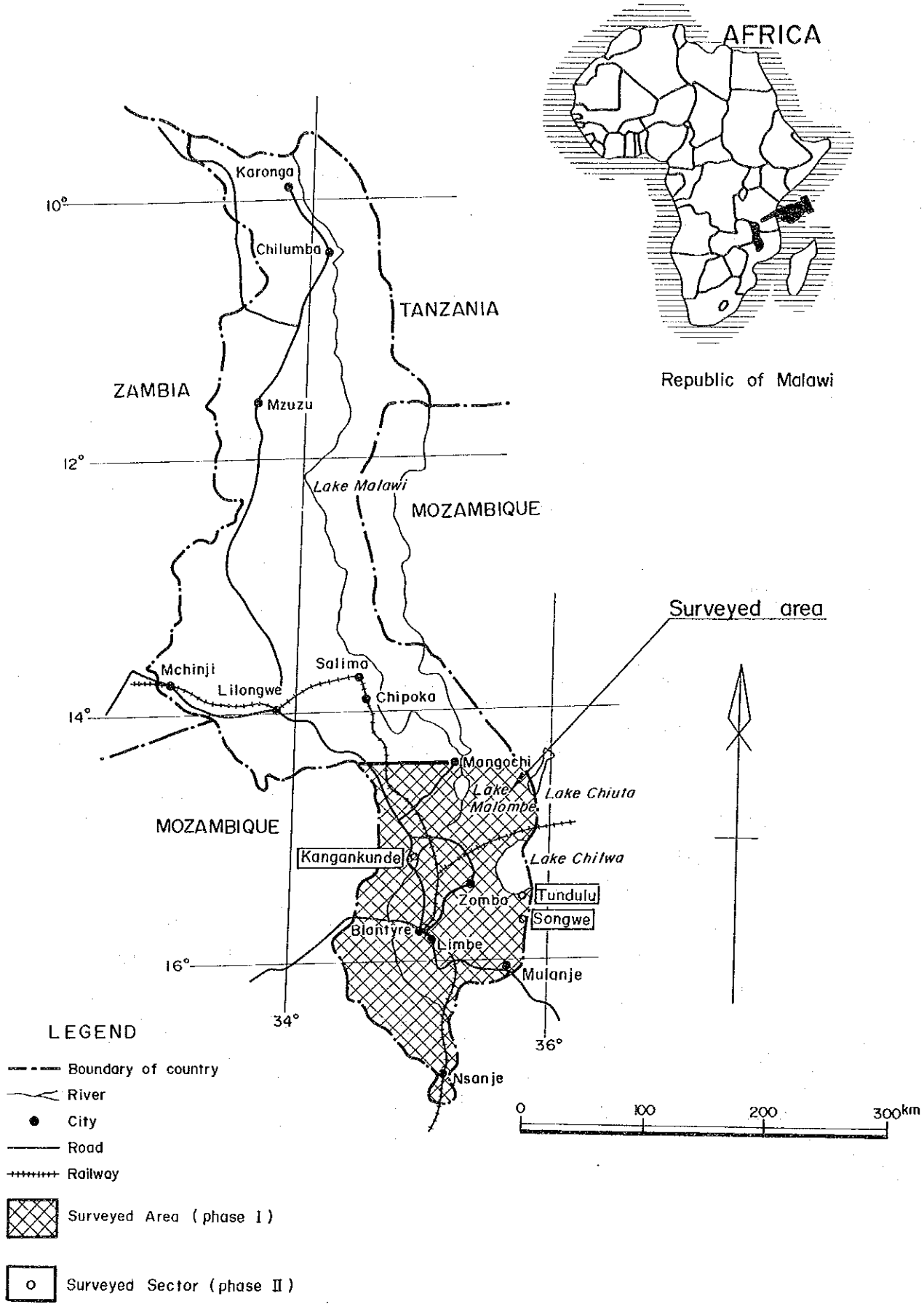


Fig. 1 Location map of survey area

Summary

This report discusses the results of the second phase cooperative mineral exploration in the Chilwa Alkaline area in the Republic of Malawi.

The aim of the survey is to investigate the geological setting of carbonatites, its characteristics of mineralization and potential for economic deposits using geological, geochemical and drilling data. The field survey was performed from July to December 1987.

Contents of the survey are as follows :

Methods and details of the survey							
Sector	Geological and geochemical survey				Drilling survey		
	Area	Route survey	Trench survey	Geochemical samples	No. of drill holes	Hole length	Ore samples
	km^2	km	m	pcs		m	pcs
Tundulu	7.5	16	500	152	24	1,204.8	243
Songwe	3.2	9	600	151	11	558.95	110
Kangankunde	0.8	6	500	102	0	0	0
Total	11.5	31	1,600	405	35	1,763.75	353

Outline of the survey results is as follows:

(1) Tundulu sector

Carbonatites are distributed in Tundulu, Nathace and Makhanga Hills. In this sector useful minerals rich in REE such as bastnaesite, synchysite, pyrochlore, apatite are found.

Results of geochemical survey revealed that carbonatites in Nathace Hill are anomalously rich in ten elements. These are La, Ce, Nd, Sm, Eu, Tb, Nb, Sr, Y and P. On the other hand, carbonatites on Tundulu Hill are not anomalous in any of the ten elements.

In Nathace Hill, rock samples from eleven drill holes, JMT-7, 14, 15, 16, 17, 18, 20, 21, 22, 23 and 24, indicate REE mineralization (total amount of La, Ce, Nd, Sm, Eu, Tb and Y oxides > 1.0%). Phosphorus mineralized zone (P > 2.2%, length > 2.0m) is recognized in the eastern slope of Nathace Hill.

(2) Songwe sector

Songwe Hill has carbonatites which contain useful minerals rich in REE such as bastnaesite, synchysite and pyrochlore. Geological survey discovered that the northern slope (lower than 850m asl) of the hill has anomalous values in REE.

All drill holes except JMS-8 indicate REE mineralization. REE contents of the samples from the above-mentioned holes are 2-4 times higher in Sm and Eu (medium REE) than those from Mountain Pass Mine (USA) which commecially produces bastnaesite.

(3) Kangankunde sector

Carbonatites in Kangankunde Hill contain useful minerals such as monazite, strontianite and apatite.

Geochemical survey on the hill revealed anomalous values in REE and phosphorus on the northern slope of the hill. This is also supported by previous works.

From the resutls of the first and second phase surveys, the following has been recommended:

1. Geological, geochemical and drilling surveys shall be carried out to confirm the extent and grade of carbonatite deposits in Chilwa Island sector.

2. Detailed geological and drilling surveys shall be carried out to confirm ore reserves and grade in Tundulu and Songwe sectors.

PART I GENERAL REMARKS

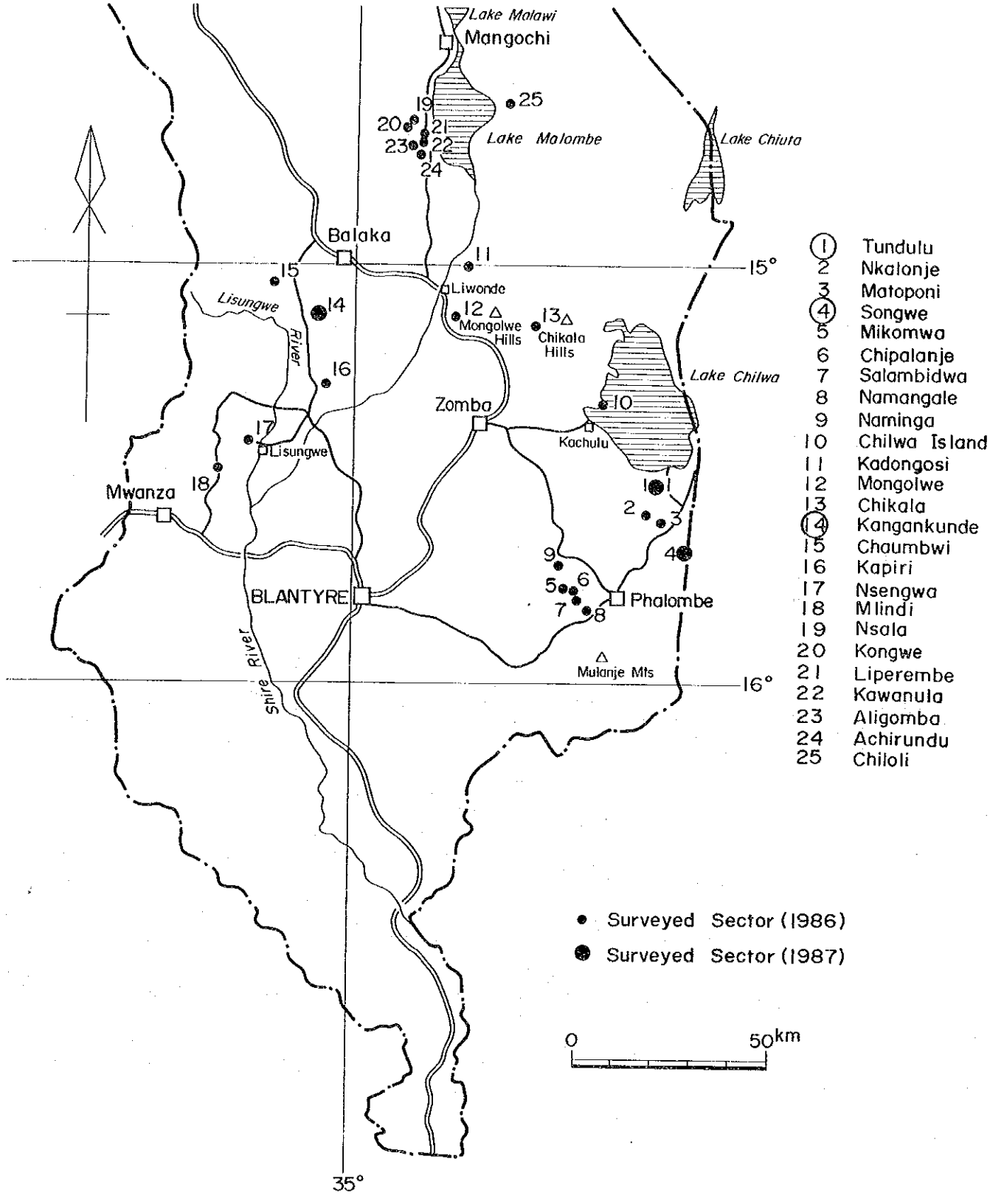


Fig. 2 Distribution of carbonatites of Chilwa Alkaline area

Chapter 1 Introduction

1-1 Origin of the survey

The Republic of Malawi occupies an area of about 119,000 km^2. It lies in the southern part of the Great African Rift Valley. It is underlain by various rocks ranging from Precambrian to Quaternary age. Thus the potential for minerals such as gold and rare earths is expected to be high. However, up to date the production of mineral commodities is very low.

The Department of Geological Survey is responsible for the discovery of and prospecting for all deposits in the country by exploration, detailed surveys, compilation of geological maps and publications of geological reports of interest in the country.

This survey was conducted by the Government of Japan in response to the request of the Government of the Republic of Malawi based on the Scope of Work (S/W) signed on the 4th August 1986.

During the first phase survey, an examination of previous work on the Chilwa Alkaline area (30,000 km^2) and the Landsat image interpretation were made. From the results obtained, 25 sectors expected to have carbonatite mineralization were selected.

Geological and geochemical field surveys were carried out in the selected sectors (25) (Fig. 2).

1-2 Conclusion and Recommendation

1-2-1 Conclusion of the first phase survey

From previous geological and geochemical surveys, the sectors have been evaluated or grouped as follows:

Sectors which are considered as having high potential of carbonatite deposit:-

Tundulu, Songwe, Chilwa Island and Kangankunde sectors

Sectors which are considered as having potential carbonatite deposit:-

Nkalonje, Matoponi and Kapiri sectors

Sectors where geochemical anomalies are recognized but no trace of carbonatite:-

Mikomwa, Chipalanije, Salambidwa, Namangale, Naminga, Kadongosi, Chaumbwi, Nsala, Kongwe, Aligomba, Achirundu and Chiloli sectors

1-2-2 Recommendation for the second phase survey

The following is recommended for the second phase survey in accordance with the results of the first phase survey.

It is desiable to conduct the geological and geochemical surveys which aim at confirming the dimensions and grades of carbonatites, and to conduct radiometric and trench survey, drilling survey in order to confirm the underground conditions of carbonatites in the potential sectors namely, Songwe, Chilwa Island, Kangankunde, Tundulu, Nkalonje, Matoponi and Kapiri sectors.

1-3 Outline of the second phase survey

1-3-1 Area of the survey

The Chilwa Alkaline area occupies one-fourth of Malawi. The area is presented in the maps at a scale of 1:250,000, published by the Government of Malawi, and occupies the southern half of Mangochi (Sheet 8), Blantyre (Sheet 9) and Nsanje (Sheet 10).

The following three sectors, on the map of Blantyre were selected for the second phase survey:

1. Tundulu sector (south of Lake Chilwa)
2. Songwe sector (south of Lake Chilwa)
3. Kangankunde sector (west of Shire River)

1-3-2 Purpose of the survey

The purpose of this phase survey is to elucidate the geological conditions of carbonatites in these above three sectors and to understand the mineralization related to carbonatites.

1-3-3 Method and area covered

Contents of the survey are shown in Tab. 1.

Tab. 1 Contents of the survey

Sector	Geological and geochemical survey				Drilling survey		
	Area	Route survey	Trench survey	Geochemical samples	No. of drill holes	Hole length	Ore samples
	km^2	km	m	pcs		m	pcs
Tundulu	7.5	16	500	152	24	1,204.8	243
Songwe	3.2	9	600	151	11	558.95	110
Kangankunde	0.8	6	500	102	0	0	0
Total	11.5	31	1,600	405	35	1,763.75	353

1-3-4 Organization of the survey team

Following is a list of coordinators, administrators and field survey team.

Coordinator and administrator

Japan side	Malawi side
Yoshiyuki KITA (JICA)	M.C. CHATUPA (GSD)
Kenji SAWADA (MMAJ)	A.T. MNDALA (GSD)

Field survey team

Japan side	Malawi side
Tsuyoshi YAMADA (MINDECO) Leader; Geol., Geoche.	G.W.P. MALUNGA (GSD) Leader
Tsutomu AOYAMA (MINDECO) Drilling	
Hiromi HORISHITA (MINDECO) Drilling	
Yukio CHIBA (MINDECO) Drilling	

JICA : Japan International Cooperation Agency

MMAJ : Metal Mining Agency of Japan

GSD : Geological Survey Department (Malawi)

MINDECO : Mitsui Mineral Development Engineering Co., Ltd.

1-3-5 Period of the survey

The progress of the survey is shown in Tab. 2.

Tab. 2 Process of the survey

	1987 July	Aug.	Sep.	Oct.	Nov.	Dec.	1988 Jan.	Feb.
Geological and Geochemical survey	29					6		
Drilling survey	31					6		
Data analysis, laboratory works and report making						7		10

Chapter 2 Physical features of the survey area

2-1 Landforms and drainage

The Chilwa Alkaline area occupies nearly Southern Region and some of adjoining central Region of Malawi.

In the survey area, the eastern part is occupied by Mulanje Mountains having 3,000m above sea level. In the north and northeastern parts, there are Lake Malombe and Lake Chilwa. Phalombe Plain with the elevation of 500m - 700m extends from Lake Chilwa to Mulanje Mountains. Tundulu and Songwe sectors are situated in Phalombe Plain and are mountainous area having 200m - 300m elevation.

The central and western parts of the survey area are valley running along Shire River, which starts from Lake Malawi and Kirk Mountains lying to the west of the valley. Kangankunde sector is located between Shire River valley and Kirk Mountains. It is rather mountainous having 200m elevation.

Shire River, with large discharge, gently meanders across the central part of the survey area from north to south.

The drainage system of tributaries of Shire River and creeks streaming into Lake Chilwa is dendritic.

2-2 Climate and vegetation

The survey area belongs to tropical savanna climate and it has two seasons, i.e., a dry season (April - October) and a rainy season (November - March). In Blantyre situated near the center of the survey area, the average annual rainfall is 1000mm and the average temperature is 15-20°C (Fig. 3).

During the dry season, diurnal variation of temperature is very large, i.e., the temperature rises up to 40°C in daytime and goes down to 25°C in nighttime.

Vegetation is characterized by grasses and small trees with sporadically towering trees.

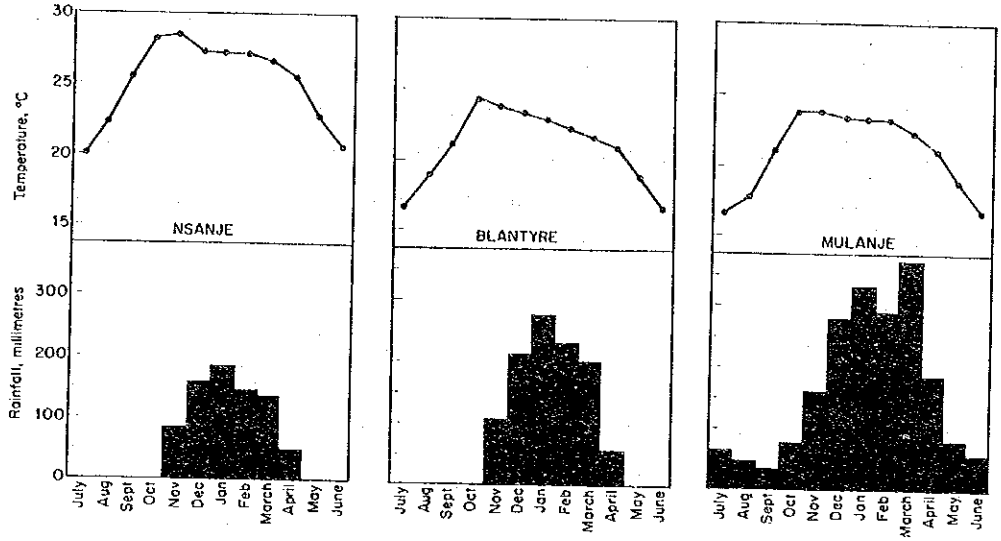


Fig. 3 Temperature and rain fall

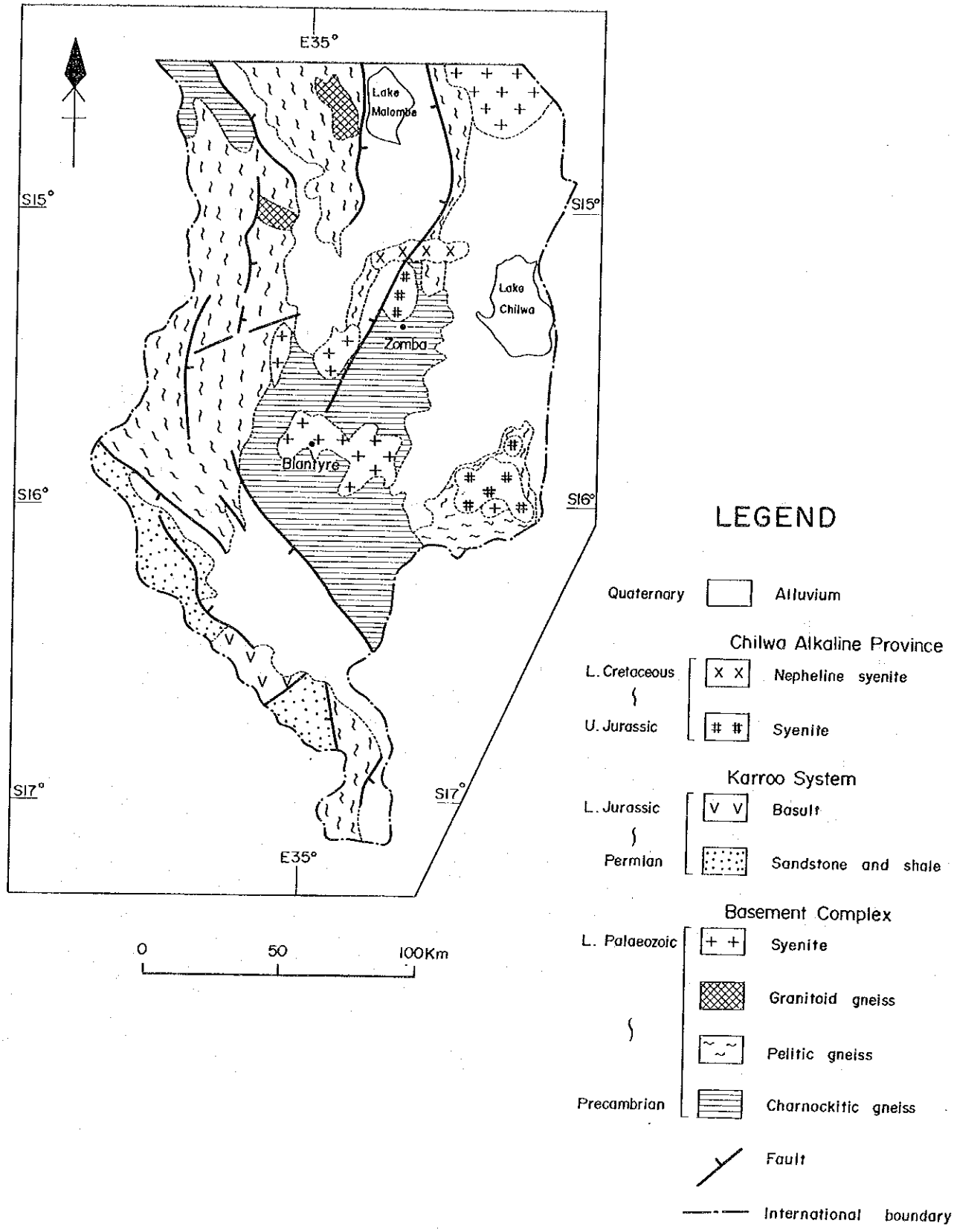


Fig. 4 Geological map of Chilwa Alkaline area

Chapter 3 Outline of geology

3-1 General geology of Chilwa Alkaline area

Most of Malawi is underlain by late Precambrian to early Paleozoic (650-400 Ma) metamorphic basement such as crystalline schists and gneisses of granulite or amphibolite facies which is a part of Mozambique Belt. Granulite facies rocks comprise hypersthene granitic gneiss and garnet-sillimanite-graphite siliceous schist. Amphibolite facies consist of biotite gneiss and amphibolite. The general trend of these basement rocks is north-south.

In the southern Malawi, the basement rocks are intruded by ultrabasic rocks (500 Ma), syenites and granites (450 Ma). These intrusive rocks are considered to be products of the latest phase of orogenic processes in Mozambique Belt.

During Jurassic to Cretaceous period, alkaline rocks and carbonatites were active to form volcanic necks and small intrusive bodies. These intrusive rocks constitute "Chilwa Alkaline Province".

Tundulu, songwe and Kangankunde sectors which are in the survey areas of this phase are located in "Chilwa Alkaline Province" (Fig. 4).

Although there are no metal mines under exploitation, some ore deposits of bauxite and alluvial gold as well as carbonatite are known in the area. Bauxite deposits are on the top of Mulanje Mountains with 2000 - 3000m above sea level. Ore reserve of 70 million tons containing 45% Al_2O_3 is known to be present.

3-2 General geology of the Each sector.

3-2-1 Tundulu sector

This sector is underlain by late Precambrian to early Paleozoic basement rocks of gneisses and syenites which are intruded by alkaline rocks and carbonatite of "Chilwa Alkaline Province".

Igneous rocks of "Chilwa Alkaline Province" are mainly composed of nepheline syenite, phonolite, agglomerate, feldspathic breccia and carbonatite.

Carbonatite can be classified into sövitic, ankeritic and sideritic. Useful minerals are apatite, bastnaesite, monazite, synchysite, pyrochlore, parisite and strontianite.

3-2-2 Songwe sector

This sector is underlain by late Precambrian to early Paleozoic basement gneisses which are intruded by alkaline rocks and carbonatite of "Chilwa Alkaline Province".

Igneous rocks in the sector are composed mainly of nepheline syenite, agglomerate, feldspathic breccia and carbonatite.

Carbonatite comprises mainly of sövitic and ankeritic. Bastnaesite, synchysite, monazite, pyrochlore and parisite are found in the carbonatite.

3-2-3 Kangankunde sector

This sector is underlain by basement gneisses and igneous rocks of "Chilwa Alkaline Province" such as feldspathic breccia, agglomerate and carbonatite. Gneisses are intensely fenitized.

Carbonatite is in this sector can be classified into sövitic, ankeritic, sideritic, dolomitic and manganitic. Useful minerals in the carbonatite are monazite, strontianite, apatite, pyrochlore and parisite.

Chapter 4 Comprehensive discussion

4-1 Tundulu Sector

4-1-1 Geological structure and characteristics of mineralization

Geological structure of the sector is characterized by superimposed ring structures of two phases (Fig. 5). The first ring structure has the center at Tundulu Hill with a diameter of 2000m. In the inside of the first ring structure develops the second one of 500 - 600m diameter centering Nathace Hill.

Carbonatite in his sector can be classified into sövitic, ankeritic and sideritic.

Sövitic carbonatite occurs mainly in the first ring structure, while ankeritic and sideritic in Nathace Hill in the second ring structure.

Minerals rich in REE, Nb, Sr and P are bastnaesite, synchysite, pyrochlore, strontianite, apatite. These useful minerals are considered to be products of middle to late stage of igneous activity associating carbonatite, and are concentrated in the eastern half of the second ring structure centering Nathace Hill.

4-1-2 Potential for economic deposit in carbonatite

Based upon the results of drilling at Tundulu Hill, a REE mineralized zone of 7.0m thick, 1.48% REO at JMT-10 is recognized (cutoff grade is 1.0% REO). Phosphorus mineralized zones are recognized at JMT-2, 3, 9 and 12. All of recognized every zones are either, small scale or low grade.

In Nathace Hill, REE mineralized zones are recognized at JMT-7, 14, 15, 16, 17, 18, 20, 21, 22, 23 and 24. Rock samples from eleven drill holes are 1.5-2 times higher in Sm and Eu than those from Mountain Pass Mine (USA) which produces bastnaesite (Tab. 7). Phosphorus mineralized zones are recognized at JMT-7, 14, 17, 18, 19, 20, 21 and 24 (Tab. 8).

It is inferred that the carbonatite body in the second ring structure centering Nathace Hill has the highest potential for economic resources.

4-1-3 Geochemical Anomaly

Mean value plus a standard deviation is defined as a threshold of geochemical anomaly.

It is recognized that Nathace Hill indicates the anomalous value of REE, Nb, Sr and P, suggesting to be consistent to the results of geological survey and drilling.

4-2 Songwe sector

4-2-1 Geological structure and characteristics of mineralization

The constituent rocks of this sector are the same as those of Tundulu sector (Fig. 11).

Igneous rocks of "Chilwa Alkaline Province" comprise of carbonatites, breccias, altered rocks, nepheline syenite and dykes.

Breccia associated with carbonatite is developed showing an elliptical

structure with a diameter of 900m centering Songwe Hill. A structure of breccia suggests the existence of a vent, which is produced by the magmatic activity of carbonatite intruding into the nepheline syenite.

Carbonatite occurs in breccia showing irregular, massive and dyke-like shapes. Dominating lithology is sövitic and ankeritic.

Useful minerals in carbonatite, include bastnaesite, synchysite, pyrochlore and strontianite.

4-2-2 Potential for Economic Deposit in Carbonatite

Based upon the results of drilling at Songwe Hill, REE mineralized zones are recognized at JMS-1, 2, 3, 4, 5, 6, 7, 9, 10 and 11. REE content indicates that the values of Sm and Eu are 2-3 times and 2-4 times higher than those ores from Mountain Pass Mine, respectively. Phosphorus mineralized zones are recognized at JMS-10 and 11, but are thin.

It is inferred that the carbonatite body on the northern slope of Songwe Hill (lower than 850m asl) has the highest potential for economic resources.

4-2-3 Geochemical Anomaly

It is felt that the northern slope of Songwe Hill is rich in REE oxides and Nb.

The area rich in REE is consistent to the site of drill holes where mineralized zones are recognized.

4-3 Kangankunde sector

4-3-1 Geological structure and characteristics of mineralization

Constituent rocks of this sector are the same as those of Tundulu and Songwe Sectors.

Igneous rocks of "Chilwa Alkaline Province" comprise carbonatite, breccia and altered rocks. Nepheline syenite is absence.

Geological structure is characterized by elliptic structure centering Kangankunde Hill. The diameters in N-S and E-W directions are 900m and 700m, respectively.

In the ellipse, the following rocks are zonally arranged from the center to the outer part; carbonatites, carbonatized breccias, breccias and basement rocks.

Carbonatites are dolomitic, sideritic and ankeritic. They are distributed widely on the northern and western slopes of the Kangankunde Hill. Manganese carbonatite is found at the top and on the eastern slope of the hill. Useful minerals in carbonatites include monazite, strontianite and apatite.

Geological difference of Kangankunde sector from Tundulu and Songwe sectors is the existence of carbonatized breccia and absence of nepheline syenite.

4-3-2 Potential for economic deposit in carbonatite

Based upon the results obtained from the survey as well as previous works, it is inferred that carbonatite body on the northern slope of Kangankunde Hill has the highest potential for economic resources.

4-3-3 Geochemical anomaly

It is recognized that the northern slope of Kangankunde Hill is rich in REE and phosphorus.

Chapter 5 Conclusion and recommendation for the third phase survey

5-1 Conclusion

(1) Tundulu sector

Carbonatites are distributed in Tundulu, Nathace, etc. Hills. Carbonatites in Tundulu Hill are mainly sövitic, while those in Nathace Hill are ankeritic and sideritic.

Based upon the geological data, it is concluded that the carbonatite body centering Nathace Hill has the highest potential for economic deposits. The conclusion is consistent to the results of geochemical survey and drilling.

(2) Songwe sector

Carbonatites are developed in Songwe Hill, and are composed mainly sövitic and ankeritic.

It is concluded that the carbonatite body on the northern slope of Songwe Hill (lower than 850m asl) has the highest potential for economic resources.

The conclusion is consistent to the results of geochemical survey and drilling.

(3) Kangankunde sector

Carbonatites developed in Kangankunde Hill are composed mainly dolomitic, sideritic and ankeritic.

It is inferred that the carbonatite body on the northern slope of Kangankunde Hill has the highest potential for economic resources.

5-2 Recommendation for the third phase survey

Integrated interpretation of the results of the second phase survey and the first phase survey recommends the follows to evaluate potential of REE resources in the survey area.

The similar survey as the second phase survey, geological, geochemical and drilling surveys, shall be carried out in Chilwa Island sector which was chosen as a highly potential sector for carbonatite deposits by the first phase survey together with Tundulu, Songwe and Kangankunde.

Detailed geological survey and drilling survey shall be carried out to define extent and grade of ore deposits in Nathace Hill of Tundulu sector and Songwe sector where REE mineralization and phosphorus mineralization were detected by the second phase survey.

Kangankunde sector is excluded from the third phase survey. Because BRGM of France has been given a licence for exclusive prospecting right in the sector.

PART Ⅱ PARTICULARS

Chapter 1 Tundulu sector

1-1 Method of the Survey

During the second phase, geological, geochemical and drilling surveys have been carried out.

The published topographic maps of 1/50,000 in scale were enlarged to make topographic maps of 1/5,000.

Route survey was carried out by the enlarged maps. The outcrops of mineralized zone were determined by using a tape and a pocket-compass. The results were put on the route maps of 1/2,000 in scale. Trench survey was done under the scale of 1/200. Results were drafted on the geological map of 1/5,000 in scale

Geochemical and geological surveys were performed at the same time. As a principle, samples were collected from carbonatites. In collecting samples, consideration was taken to elucidate the distribution of elements in carbonatites and the characteristics of the mineralization. Collected samples were analyzed by the ICP (Inductively Coupled Plasma) method. Analyzed elements were of 10 components as indicated in Tab. 3. The results of analyses were processed and analyzed statistically by computor.

Drilling survey was performed using two small drilling rigs to collect cores from the depth less than 50m. The results of core-observation were put on the geologic log of 1/200 in scale. Samples of carbonatites were collected for chemical analysis to determine REE contents, Nb, Sr and P.

Contents of the survey are shown in Tab. 3.

Tab. 3 Contents of survey, Tundulu

Geological and geochemical survey		Drilling servey	
Area	7.5 km²	No. of holes	24
Route survey	16 km	Total length	1204.8 m
Trench survey	500 m	Inclination	-90°
Assay of geochemical samples	152 pcs	Assay of ore samples	243 pcs
Microscopic observation (Thin section)	21 pcs	Assay element:	
Microscopic observation (Polished section)	23 pcs	La, Ce, Nd, Sm, Eu, Tb, Nb, Sr,	
X-ray diffractive analysis	25 pcs	Y, P (10 elements)	

1-2 Geology (Fig. 5)

Main constituent rocks of this sector are as follows:

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa Alkaline Province" Carbonatites (sövitic, ankeritic and sideritic) Apatite rocks Breccias (agglomerate and feldspathic breccia) Altered rocks (carbonate silicate rock) Nepheline syenite Dykes (phonolite, sölvsbergite, trachyte etc.)
Early Jurassic	Dolerite
Late Precambrian to early Cambrian	Gneisses and syenites

Late Precambrian to early Cambrian basement rocks of gneisses and syenites are distributed in the southern part (Chigwakwalu Hill), the western part (Makhanga Hill) and the northwestern part (Namuka and Namilembia Hills). Gneisses are biotite gneiss and granitic gneiss. Syenites has a few grayish white quartz crystals.

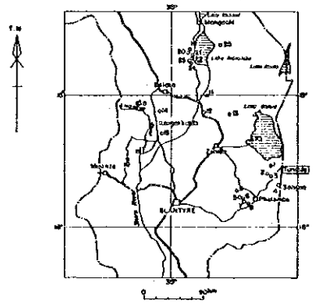
Dolerite is distributed in Namilembia Hill and intrudes into the basement rocks. Dykes of dolerite having N55°E strike and nearly vertical dip, range from 0.5m to 2m in width. Under the microscope, it has plagioclase and augite showing ophitic texture.

Igneous rocks of "Chilwa Alkaline Province" are developed showing a ring structure from the central part (Nathace Hill) through the eastern and the southern parts (the western slope of Chigwakwalu and the eastern and the northern slopes of Makhanga Hill, respectively) to the northern part (Kamilala Hill).

Nepheline syenite occurs in the eastern, the southern and the eastern parts of Nathace Hill. It is pale greenish in color, hard and compact showing medium grained equigranular texture. Under the microscope, it is composed of orthoclase, biotite, aegirine, nepheline, calcite, sphene and apatite. The result of K-Ar age determination shows 132.4-136.2 Ma and suggests that the time of intrusion is in early Cretaceous (JICA an MMAJ, 1987).

COOPERATIVE MINERAL EXPLORATION
IN
THE CHILWA ALKALINE AREA,
REPUBLIC OF MALAWI
(PHASE II)

GEOLOGICAL MAP AND PROFILE OF TUNDULU SECTOR



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FEBRUARY 1988

0m 250m 500m

LEGEND

- Drift
- Carbonatite
- Apatite rock
- Carbonatite bearing agglomerate / feldspathic rock
- Agglomerate / feldspathic rock
- Calc-silicate rock
- Dyke / plug
  - P : phonolite
  - S : solvsbergite
  - T : trachyte
  - J : juvite
  - B : beforsite
  - D : dolerite
- Nepheline syenite
- Gneiss
- Syenite
- Fault
- Drilling site (1987)
- Trench (1987)
- Profile line

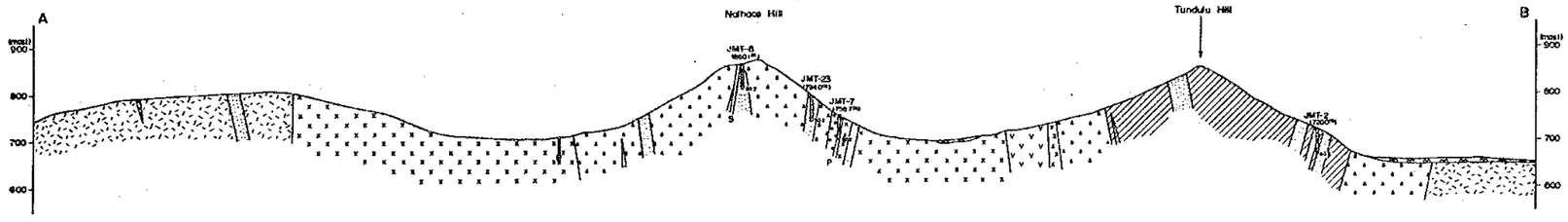


Fig. 5 Geological map and profile of Tundulu sector

Breccias have an extensive distribution in Nathace, Tundulu and Kamilala Hills. Breccias are classified into feldspathic breccia and agglomerate. The former is composed of rock fragments rich in feldspars with pale red to reddish brown in tint. The latter is composed of rock fragments of basement rocks, tuff, trachyte, phonolite and others. Breccias often contain rock frangments of carbonatite and are associated with interstitial carbonate. A diameter of each breccia range from several centimeters to several meters.

Apatite rock is distributed in Nathace Hill and the eastern part of Makhanga Hill. Apatite rock on the eastern slope of Nathace Hill has rather large dimension of 300m (N-S direction) x 50m (E-W direction). The rock is fine grained and whitish to pale reddish in tint. Phenocrysts of dark brownish siderite are scattered in some places. Under the microscope, main constituent minerals are apatite and quartz associated with alkali feldspar, limonite, rutile, zircon, synchysite, pyrochlore and others. Apatite is granular and usually around 0.1mm in size.

Carbonatites in this sector are classified into sövitic, ankeriticand sideritic. Sövitic carbonatite is around Tundulu, Kamilala Hills and the eastern part of Makhanga Hill. Ankeritic and sideritic carbonatites are distributed in the southern part of Tundulu and Nathace Hills.

Sövite is mainly composed of fine to medium grained whitish calcite. It is milky white in color, compact and rich in magnetite. Under the microscope, it is characterized by a mosaic texture constituted by calcite, dolomite, biotite, aegirine, apatite with lesser amounts of opaque minerals.

Ankeritic and sideritic carbonatites are dark gray to dark brown in color. Fine grained apatite and bastnaesite are visible while monazite and pyrochlore are recognized under the microscope.

Altered rocks are developed along boundaries between nepheline syenites and breccias on the western slope of Tundulu Hill. They are fine to medium grained, rich in biotite and magnetite. Most of rocks underwent carbonatized alteration but texture of nepheline syenite is observed in some places. These rocks are produced by contamination along boundary between nepheline syenite and carbonatite, when the latter have intruded into the former (Garson, 1965).

Dykes are phonolite, trachyte, sölvsbergite. These alkaline dykes are several meters in width and are developed in the area where basement rocks are.

The geological structure in this sector is characterized by superposed ring structures of two phases. The first ring structure has a diameter of about 2000m, developing from Tundulu Hill through Chigwakwalu Hill and the eastern part of Makhanga Hill to Kamilala Hill. The second ring structure has a diameter of 500~600m, centering Nathace Hill.

According to Garson (1962), he has assumed the underground sites of the center of igneous activities which have produced the ring structure as follows:

The first igneous activity is 1,200-1,300m below the ground surface around Tundulu Hill, the second igneous activity is 2,400-3,000m and 500-700m below the ground surface around Nathace Hill.

1-3 Results of geochemical survey

Geochemical samples collected were mostly carbonatites. 152 samples were collected and they were assayed for 10 elements. The elements assayed and their detectable limit of each element are shown in Tab. 4.

Tab. 4 Detectable limits

(ppm)

Element	La	Ce	Nd	Sm	Eu	Tb	Nb	Sr	Y	P
limit	1	2	5	0.1	0.1	0.1	10	1	10	10

The analyzed values of the geochemical samples show a lognormal distribution in general. When histograms of the analyzed values of this sector are examined, most of the elements show the lognormal distributions rather than the normal distributions. Therefore, the values are changed into logarithm to be statistically analyzed and processed by computer.

1-3-1 Statistical value

Statistical values of each element and REE oxide (REO) of this sector as well as the crustal abundance are shown in Tab. 5.

All elements analyzed in carbonatites here have over ten times higher than the crustal abundance.

It suggests that these 10 elements can be used effectively as pathfinder elements of carbonatites in Tundulu sector.

Tab. 5 Statistical values of geochemical survey, Tundulu

(ppm)

Element	Rock type	No. of Samples	Max.	Min.	Mean	M + 1S	Abundance (Earth Crust)
La	Carbonatite	108	22610	18	1429	5487	25
	Others	44	18698	<1	134	832	
Ce	Carbonatite	108	26527	21	2452	8892	81
	Others	44	24731	1	242	1458	
Nd	Carbonatite	108	6304	<5	649	2708	20
	Others	44	4973	<5	57	411	
Sm	Carbonatite	108	865.7	<0.1	93.8	564	4
	Others	44	657.9	<0.1	17.9	111	
Eu	Carbonatite	108	186.7	<0.1	22.0	117	0.8
	Others	44	71.7	<0.1	1.4	18	
Tb	Carbonatite	108	317.6	<0.1	2.7	47	0.5
	Others	44	112.2	<0.1	0.4	7	
Nb	Carbonatite	108	9467	<1	183	1257	20
	Others	44	1175	<1	74	444	
Sr	Carbonatite	108	139015	203	4651	18010	300
	Others	44	48820	64	555	2327	
Y	Carbonatite	108	1566	5	133	627	38
	Others	44	1962	5	25	124	
P	Carbonatite	108	145772	<5	6221	57181	900
	Others	44	124135	34	1603	9751	
REO	Carbonatite	108	64073	64	6080	22013	
	Others	44	59026	11	646	3515	

1-3-2 Correlation of the elements

Correlation coefficient of each element in this sector is shown in Tab. 6.

Correlation coefficient 0.8 and above : extremely strong correlation

0.8 - 0.6 : strong correlation

0.6 - 0.4 : weak correlation

11 pairs of elements, all of which are REE except P showing extremely strong correlation are (La, Ce), (La, Nd), (La, Sm), (La, Eu), (Ce, Nd), (Ce, Sm), (Ce, Eu), (Nd, Sm), (Nd, Eu), (Eu, Y), (P, Y).

It is considered that these elements exist in bastnaesite and synchysite.

Tab. 6 Correlation coefficients of elements, Tundule

AREA: T (N of cases: 152)

Correlations:	logLa	logCe	logNd	logSm	logEu	logTb	logNb	logSr	logY	logP
logLa	1.00									
logCe	.99	1.00								
logNd	.94	.96	1.00							
logSm	.83	.84	.82	1.00						
logEu	.84	.86	.91	.79	1.00					
logTb	.43	.45	.50	.49	.56	1.00				
logNb	.38	.38	.32	.45	.34	.32	1.00			
logSr	.61	.59	.58	.37	.58	.31	.08	1.00		
logY	.62	.64	.72	.65	.83	.57	.37	.42	1.00	
logP	.30	.31	.36	.38	.52	.46	.38	.27	.80	1.00

1-3-3 Distribution of anomalies

The following methods are used to select geochemical anomalous values.

The thresholds and anomalous values are defined as:

the thresholds = M + 1S

the anomalous values $\geqq$ M + 1S

where M : mean value

S : standard deviation

The thresholds and anomalous values are shown in Tab. 5 and their distribution is mapped in Fig. 6-1, 6-2, 6-3.

It is inferred that carbonatite body in Nathace Hill indicates anomalous values of REE, Nb, Sr and P. While, the body in Tundulu Hill indicates almost no sign of anomaly.

Therefore, it is concluded that the carbonatite body in Nathace Hill has higher potential for REE, Nb, Sr and P resources as compared with the body in Tundulu Hill.

1-4 Drilling survey

As a result of the first phase survey, Tundulu sector has been selected as a sector with higher potential for economic resources in carbonatites.

Drilling was performed to clarify how ore deposits occur in carbonatites.

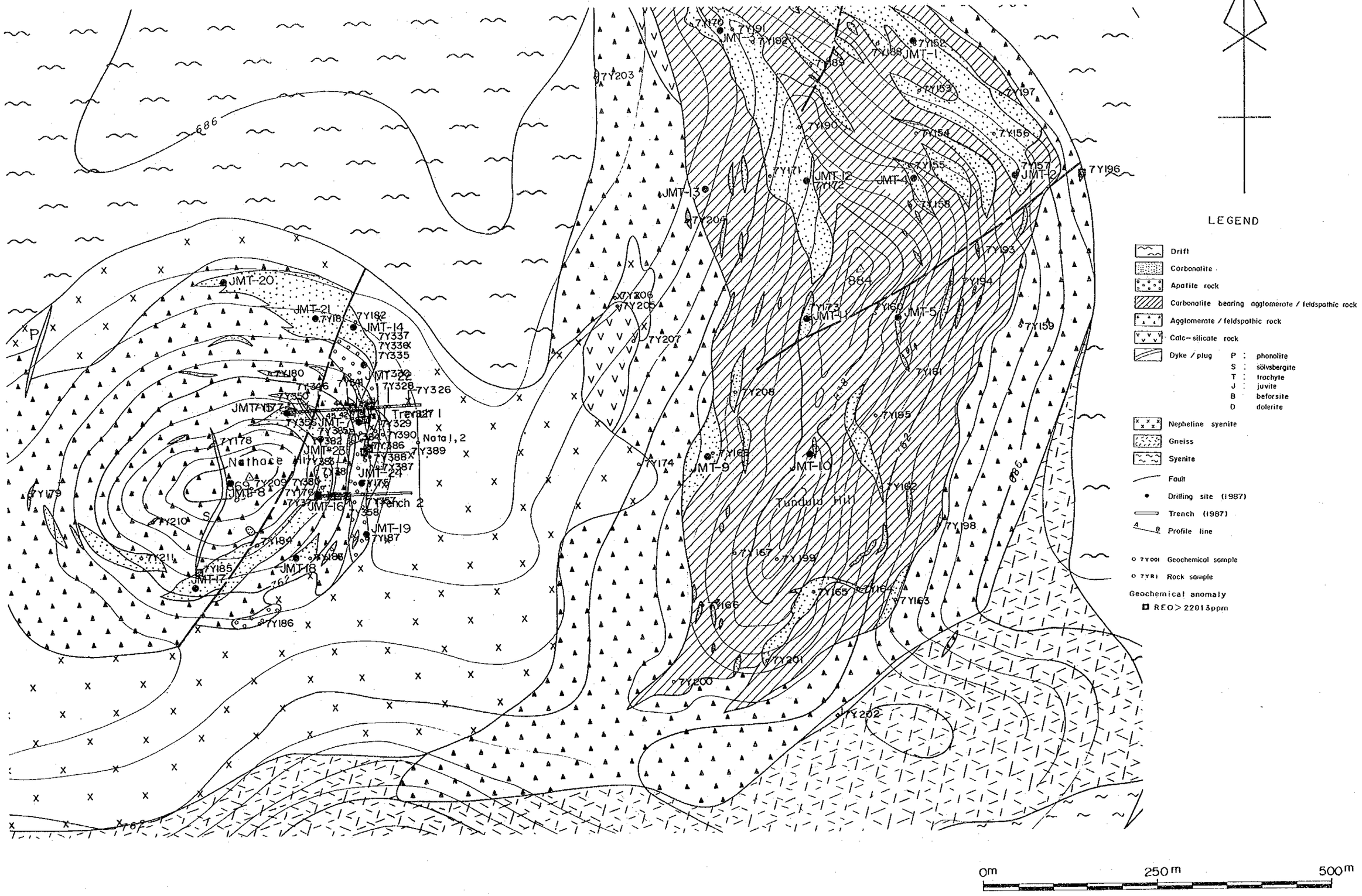


Fig. 6-1 Distribution of geochemical anomalies, Tundulu (REO)

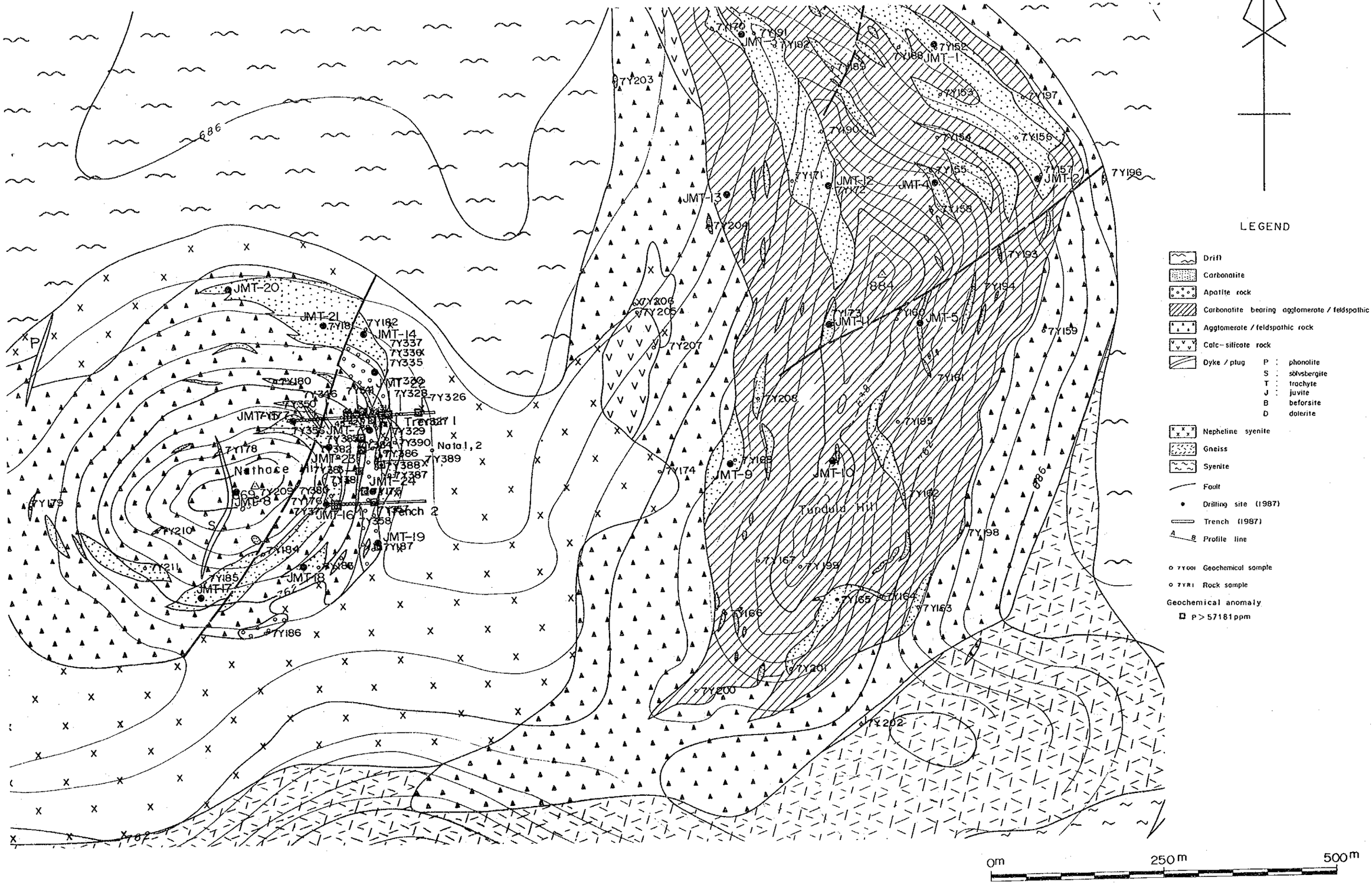


Fig. 6-2 Distribution of geochemical anomalies, Tundulu (P)

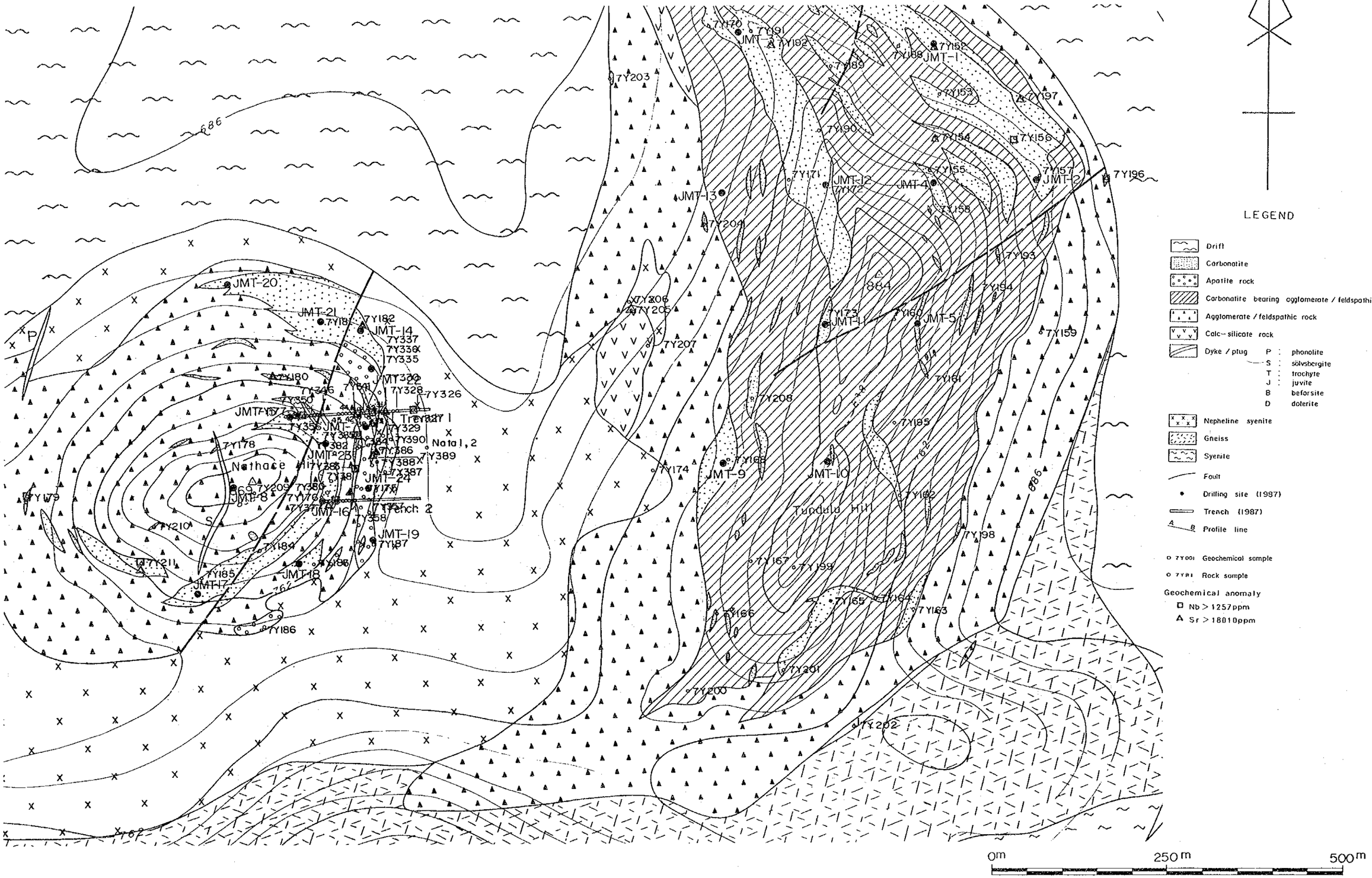


Fig. 6-3 Distribution of geochemical anomalies, Tundulu (Nb, Sr)

1-4-1 Outline of drilling

Drilling rigs are transported to the survey area by sea (up to Singapore), by air (to Malawi) and by a lorry to the drilling camp.

Drilling started on Songwe sector followed by Tundulu.

Two sets of rigs were used and both of them of model YBM-05DA with maximum capacity of up to 55m deep with 56mm in diameter.

Operations were conducted in two shifts of 12 hours each. The shifts aimed at getting as much core as possible with high operation efficiency. Water was transported from Lake Chilwa by land using a midget truck.

Core logging was done in order to know the mode of occurrence of ore deposits in carbonatites. The results were put on geologic logs of 1/200 in scale.

Core samples of carbonatite were cut in half and analyzed for elements such as La, Ce, Nd, Sm, Eu, Tb, Nb, Sr, Y and P.

Thin and polished section of rocks and mineralized ones were made and observed under the microscope. Some samples were analyzed by X-ray powder diffraction method.

Drilling covered 62 days, from September 23 to November 23.

1-4-2 Drilling procedure

Drilling was done after Songwe sector. The apparatus and materials for drilling were transported from Songwe to Tundulu sectors using four and eleven ton trucks.

The rig was set up at JMT-1 and drilling was excuted according to the following site numbers:-

JMT-1, 2, 4, 5, 3, 6, 12, 13, 11, 9 and 10.

One meter (wide) paths were cleared and levelled by human power from one drilling site to another. Total length of these paths reached 2,600m.

At Nathane Hill, drilling was excuted in the following order of site numbers:-

JMT-17, 18, 16, 15, 8, 7, 14, 19, 22, 24, 23, 21 and 20.

Paths cleared by human power in this sector totalled 2,800m (Fig. 7). Water was transported from Lake Chilwa to the camp using a midget truck, a distance of 5 km for Tundulu and 6 km for Nathace Hills. From the camp

to the drill site, water was supplied by two sets of pumps and hoses (1,500m long).

Drilling through surface soil was done using 73mm metal shoe but when hard rocks were encountered a diamond shoe (ϕ73mm) was used to set BW casing pipe. Diameter was 56mm at the buttom.

The progress of the operation at each drill hole is summarized in table of performance of drilling.

Rigs were withdrawn at the end of the operation on Nathace Hill. All materials, apparatus and cores were transported to the Geological Survey Department in Zomba, by the aid of trucks of four and eight ton trucks.

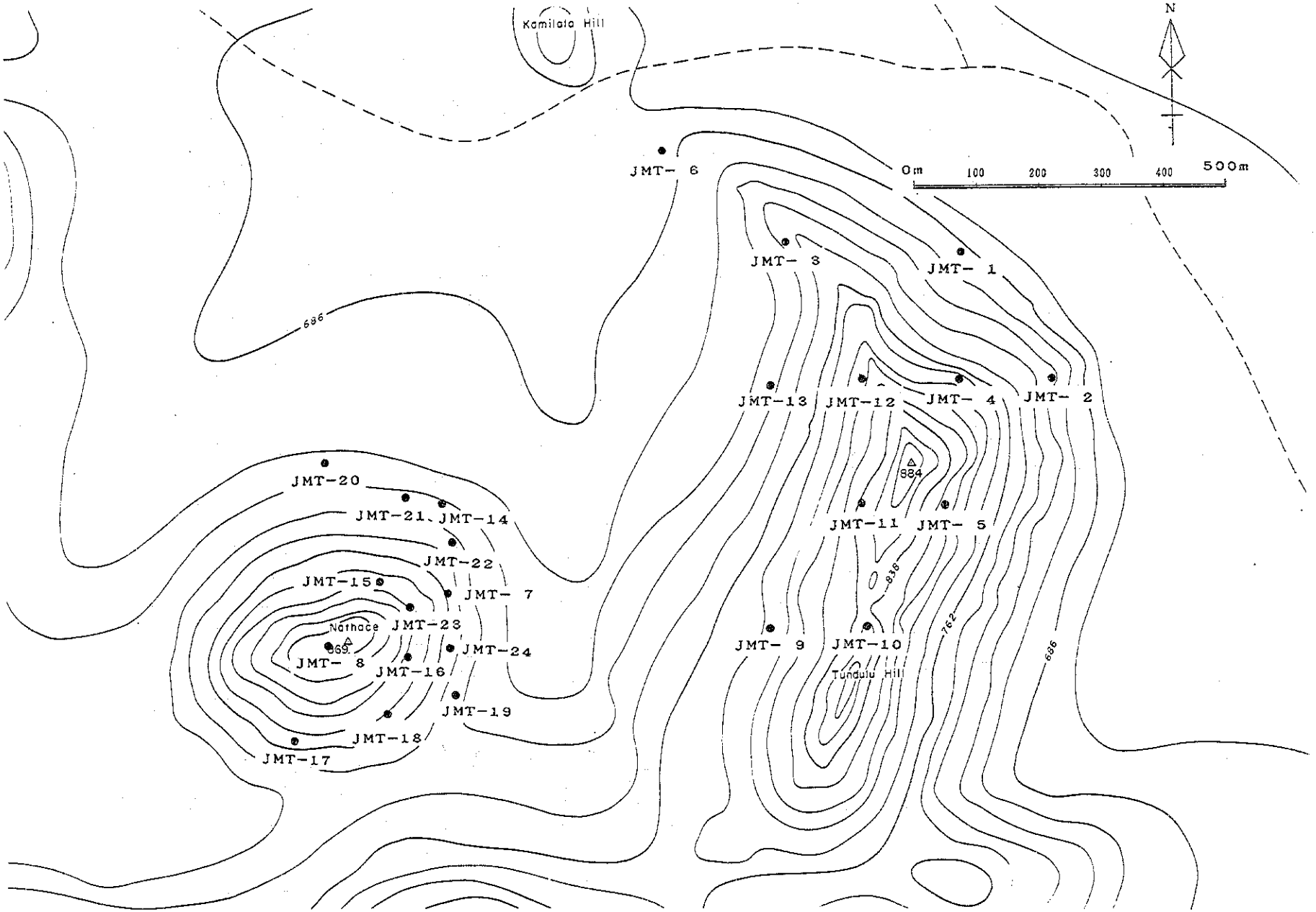


Fig. 7 Location map of drilling sites, Tundulu

Performance of the drilling, Tundulu(1)

Hole	Drilled length (m)	Core length (m)	Core recovery except soil(%)	Working period M.D.~M.D.	Bit size ø73mm		Bit size ø56mm	
					Depth(m)	Performance of the drilling	Depth(m)	Performance of the drilling
JMT- 1	50.3	46.4	100	9.23~ 9.25	3.9	Dry drilling with metal shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit, Using TK-60, 14.0m Escape of whole water
JMT- 2	50.3	49.4	100	9.26~ 9.28	1.8	0-0.9m Dry drilling with metal shoe, 0.9-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit,Using TK-60
JMT- 3	50.3	50.3	100	10. 3~10. 5	1.8	Drilling with diamond shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit, Using TK-60, 6.2m Escape of whole water
JMT- 4	50.3	47.9	98.2	9.28~ 9.30	1.8	0-1.5m Dry drilling with metal shoe, 1.5-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit, Using TK-60, 1.8-4.0m Reaming and installation of BW casing pipe
JMT- 5	50.3	49.0	99.4	10. 1~10. 3	1.8	0-1.3m Dry drilling with metal shoe, 1.3m-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit, Using TK-60, 1.8-3.0m Reaming and installation of BW casing pipe, 20.6m Escape of whole water
JMT- 6	50.4	49.0	99.6	10. 6~10. 8	1.8	0-1.2m Dry drilling with metal shoe, 1.2-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.4	Drilling with diamond bit, Using TK-60
JMT- 7	50.2	47.0	99.2	11. 3~11. 5	2.8	Dry drilling with metal shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60
JMT- 8	50.2	48.1	98.4	11. 1~11. 3	2.1	0-1.3m Dry drilling with metal shoe, 1.3-2.1m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 8.8m Escape of whole water
JMT- 9	50.1	48.1	98.6	10.14~10.16	1.8	0-1.3m Dry drilling with metal shoe, 1.3-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60
JMT-10	50.1	48.4	99.6	10.16~10.18	1.8	0-1.5m Dry drilling with metal shoe, 1.5-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60, 3.1m Escape of whole water
JMT-11	50.2	48.8	99.2	10.12~10.14	1.8	0-1.3m Dry drilling with metal shoe, 1.3-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 13.0m Escape of whole water
JMT-12	50.2	47.0	100	10. 8~10.10	3.8	0-3.2m Dry drilling with metal shoe, 3.2-3.8m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 3.8m Escape of whole water
JMT-13	50.3	49.0	100	10.10~10.12	1.8	0-1.3m Dry drilling with metal shoe, 1.3-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.3	Drilling with diamond bit, Using TK-60, 3.1m Escape of whole water
JMT-14	50.2	49.9	99.4	11. 6~11. 7	1.6	Drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 5.8m Escape of whole water
JMT-15	50.2	50.2	100.0	10.30~10.31	1.9	Drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 6.5m Escape of whole water
JMT-16	50.1	49.10	100.0	10.25~10.27	1.8	0-1.0m Dry drilling with metal shoe, 1.0-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60, 13.0m Escape of whole water

Performance of the drilling, Tundulu(2)

Hole	Drilled length (m)	Core length (m)	Core recovery except soil(%)	Working period M. D.~M. D.	Bit size ø73mm		Bit size ø56mm	
					Depth(m)	Performance of the drilling	Depth(m)	Performance of the drilling
JMT-17	50.1	47.4	97.7	10.20~10.22	1.8	0-0.6m Dry drilling with metal shoe, 1.6-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60
JMT-18	50.1	49.8	99.8	10.22~10.24	1.9	Drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60, 8.5m Escape of whole water
JMT-19	50.1	38.9	83.1	11. 8~11.11	3.3	Drilling with metal shoe, Using TK-60, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using high condenced TK-60
JMT-20	50.2	48.2	99.2	11.21~11.23	1.9	0-1.6m Dry drilling with metal shoe, 1.6-1.9m Drilling with diamond bit, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 5.6m Escape of whole water
JMT-21	50.1	49.3	98.4	11.19~11.21	2.0	Drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60, 6.0m Escape of whole water
JMT-22	50.2	41.8	86.4	11.12~11.14	2.0	0-1.8m Drilling with metal shoe, Using TK-60, 1.8-2.0m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60, 18.2m Drusy part, Escape of water
JMT-23	50.2	45.7	95.4	11.17~11.19	2.3	Drilling with metal shoe, Using TK-60, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60
JMT-24	50.1	44.7	91.6	11.14~11.16	1.8	0-1.3m Drilling with metal shoe, Using TK-60, 1.3-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60, 7.9m Escape of whole water

1-4-3 Geology and mineralization of drill holes

Drilling was performed aiming mainly at clarifying the geology and mode of carbonatite occurrence and useful minerals rich in REE.

Geology of each drill hole is shown in Fig. 8. Chemical compositions and REO of samples are shown in Appendix 2. REE mineralized zones defined as having over 1.0% REE oxides content, are listed in Tab. 7. In Tab. 8, shown are phosphorus mineralized zones where phosphorus content is over 2.2% (approximately 5% in P_2O_5 equivalent) and the length is over 2.0m.

As a result of the drilling in this sector, it is clarified that no useful elements, except P, seem to be concentrated in Tundulu Hill.

In Nathace Hill, REE mineralized zones are recognized at JMT-7, 14, 15, 16, 17, 18, 21, 22, 23 and 24. Main constituent minerals in the zones are bastnaesite, synchysite, strontianite and pyrochlore. Geological section through the drill holes of JMT-19, 24, 7, 22 and 14 and JMT-8, 16 and 24 are shown in Fig. 9.

Relatively large REE mineralized zones are found at a carbonatite body extending JMT-24, 7, 22 and 14 and a body at JMT-17. The longest core sample with continuous mineralization is 41.1m long between 8.7m and 49.8m of JMT-22. Its REO content is 3.68%. Mineral indications in JMT-17 are intermittent in 32.4m long between 17.7m and 50.1m, which is the bottom of the hole, and their REO content is between 1.90% and 4.11% (Fig. 9-1). REE contents in the mineralized zones indicate that the averaged values of Sm and Eu are 1.5 - 2 times higher than those of ores from Mountain Pass Mine (USA) where mainly bastnaesite is produced.

Phosphorus mineralized zones defined above are recognized at JMT-7, 14, 17, 18, 19, 20, 21 and 24. The longest core samples with continuous mineral indication is 14.4m long between 3.4m and 17.8m. Its phosphorus content is 7.3% (16.7% in P_2O_5 equivalent). Phosphorus mineral is mainly granular apatite.

1-5 Discussion

From the results of geological, geochemical and drilling surveys performed in Tundulu sector, the following facts have been clarified.

1. Carbonatites are developed showing a superinposed ring structure of two phases. Tundulu Hill is situated in the outer ring, while Nathace Hill in the inner one.
2. In areas where carbonatites are arranged in a ring, carbonatite intruding in an earlier stage, in general, tends to occupy the outer side of a ring and to have a lithology of sövite. Therefore, judged from the mode of occurrence and the lithology, carbonatite in Tundulu Hill is considered to intrude in the earlier stage of igneous activity.
3. Carbonatites in Nathace Hill which is considered to be produced in the later stage, are arranged in a half ring.
4. Carbonatites arranged in a half ring occupy mainly the eastern half of Nathace Hill, showing a zonal distribution of two layers.
5. REE mineralized zones are recognized in these two layers. The zone with a thickness of 41.1m and 3.68% REO is discovered at JMT-22 by drilling. Phosphorus mineralized zones are used to be found in carbonatite of the outer layer. Phosphorus mineralized zone is regognized at JMT-7. The zone is 7.3% P contents, 14.4m in length.
6. Among REE, Sm and Eu are densely concentrated to have 1.5 - 2 times higher values than those of carbonatites from Mountain Pass Mine.
7. REE pattern for each rock species suggests that carbonatite has the tendency to decrease chondrite normalized values from La to Tb (Fig. 10).

Tab. 7 Summary of the mineralized zone (REO>1.0%), Tundulu

(ppm)

Drill No.	Depth	Thick	La	Ce	Nd	Sm	Eu	Tb	Nb	Sr	Y	P	REO
JMT- 5	30.4-31.3	0.9	2406	4508	1436	208.5	35.3	103.3	459	735	99	5285	10560
	46.0-47.7	1.7	4485	7988	2260	334.9	57.4	9.2	470	912	251	9744	18490
JMT- 7	2.0- 3.0	1.0	2663	5802	1307	346.2	111.1	60.4	2048	4541	1478	131976	14249
	3.4- 9.0	5.6	2932	6366	1322	334.2	100.9	58.0	2851	7244	1318	131309	15043
	14.2-22.4	8.2	6434	8884	1010	200.5	38.0	12.6	1400	31871	276	17947	20276
JMT-10	16.8-23.8	7.0	2559	6353	2714	411.1	67.6	79.8	172	664	114	3954	14759
	27.9-29.8	1.9	2539	6260	2064	273.4	45.6	2.9	63	635	61	170	13523
JMT-14	0 -17.3	17.3	3441	5590	1273	264.6	68.2	23.0	2261	19984	416	22724	13719
	21.3-35.3	14.0	2433	3804	1433	237.3	61.1	18.6	2391	9161	363	18916	11028
	39.7-43.6	3.9	20623	23292	3442	461.0	50.1	<0.1	4360	55515	80	2462	57501
JMT-15	0 - 3.1	3.1	3666	5385	1152	152.3	20.7	7.8	297	30750	47	146	12526
	30.6-34.0	3.4	5711	8922	1972	290.9	43.3	<0.1	182	8965	72	465	20434
	37.3-41.4	4.1	3053	4508	965	138.5	21.2	1.5	244	8834	90	2836	10543
JMT-16	21.2-27.8	6.6	3990	5959	1266	195.1	27.3	<0.1	280	31891	58	1592	13804
	39.5-48.1	8.6	3663	4835	991	146.7	23.0	11.8	467	14011	70	1585	11702
JMT-17	17.7-29.0	11.3	7112	9251	1826	271.9	41.5	5.7	1500	34396	49	927	22264
	29.6-35.2	5.6	5503	8193	1758	261.4	41.0	12.0	2344	25270	43	551	18986
	36.2-50.1	13.9	13642	17316	2804	419.2	58.3	2.1	1880	50843	39	178	41141
JMT-18	48.4-50.1	1.7	7900	9198	2838	436.3	96.7	90.3	848	11623	810	46709	25622
JMT-20	26.2-28.4	2.2	2832	4821	1388	235.5	43.3	5.3	194	45964	141	6907	11369
JMT-21	38.0-42.2	4.2	2121	3532	1195	342.5	135.3	89.8	1930	4202	1147	61602	10337
JMT-22	8.7-49.8	41.1	12981	14988	2272	315.5	35.0	5.0	617	37510	76	2878	36791
JMT-23	39.7-44.7	5.0	5992	8524	1750	254.6	34.7	1.0	410	22377	103	2360	20004
JMT-24	1.0- 4.9	3.9	3833	5226	1280	238.5	59.9	22.9	746	5920	788	61679	13780
	8.2-12.9	4.7	4860	6891	1384	258.4	54.0	<0.1	1834	3372	640	43271	16952
Mountain Pass (USA)			7500	14000	3200	200	40	-	-	-	790	-	20000

Tab. 8 Summary of the mineralized zone (P>2.2%, Thick>2.0m), Tundulu

(ppm)

Drill No.	Depth	Thick	La	Ce	Nd	Sm	Eu	Tb	Nb	Sr	Y	P	REO
JMT- 2	16.1-22.1	6.0	853	1732	607	78.7	18.2	23.4	513	5949	107	37183	4108
	42.5-45.5	3.0	973	1819	652	79.0	20.2	5.1	420	8431	101	32087	4385
JMT- 3	32.6-34.7	2.1	550	1173	382	60.5	11.5	66.2	753	5205	64	30437	2772
JMT- 7	3.4-17.8	14.4	2779	4952	891	209.9	60.0	29.7	1442	10936	776	72931	11717
JMT- 9	1.3- 4.3	3.0	362	734	263	46.4	13.1	<0.1	465	1006	66	51913	1786
JMT-12	3.2-24.0	20.8	800	1532	579	78.7	18.0	15.2	1176	18383	90	29219	3739
	42.0-50.2	8.2	715	1356	508	74.4	16.6	11.8	2149	14863	90	33591	3330
JMT-14	10.4-14.0	3.6	1474	2877	1061	226.9	72.5	35.4	5354	5948	663	41912	7729
	21.3-25.3	4.0	2065	4297	1390	273.1	86.1	40.0	4603	20012	592	36120	10534
JMT-17	2.9- 5.2	2.3	1667	2258	665	170.1	50.8	35.5	447	2323	537	28908	6483
JMT-18	48.4-50.1	1.7	7900	9198	2838	436.3	96.7	90.3	848	11623	810	46709	25622
JMT-19	1.3- 4.8	3.5	879	1630	581	140.9	47.1	49.5	82	4460	1510	122165	5903
	12.4-14.6	2.2	708	1445	591	196.0	80.4	51.2	121	4457	1473	105549	5544
	17.7-24.7	7.0	491	854	266	59.2	16.2	25.6	124	2411	249	37067	2369
JMT-20	1.6- 4.6	3.0	1580	2602	802	198.5	75.3	20.2	390	3250	743	61020	7268
JMT-21	0 - 4.1	4.1	1836	3197	975	192.6	54.2	9.8	461	7282	582	48055	8253
	33.7-42.2	8.5	1785	2964	899	237.0	86.9	44.8	1384	7113	784	42991	8205
JMT-24	1.0- 4.9	3.9	3833	5226	1280	238.5	59.9	22.9	746	5920	788	61679	13780
	8.2-12.9	4.7	4860	6891	1384	258.4	54.0	<0.1	1834	3372	640	43271	16952

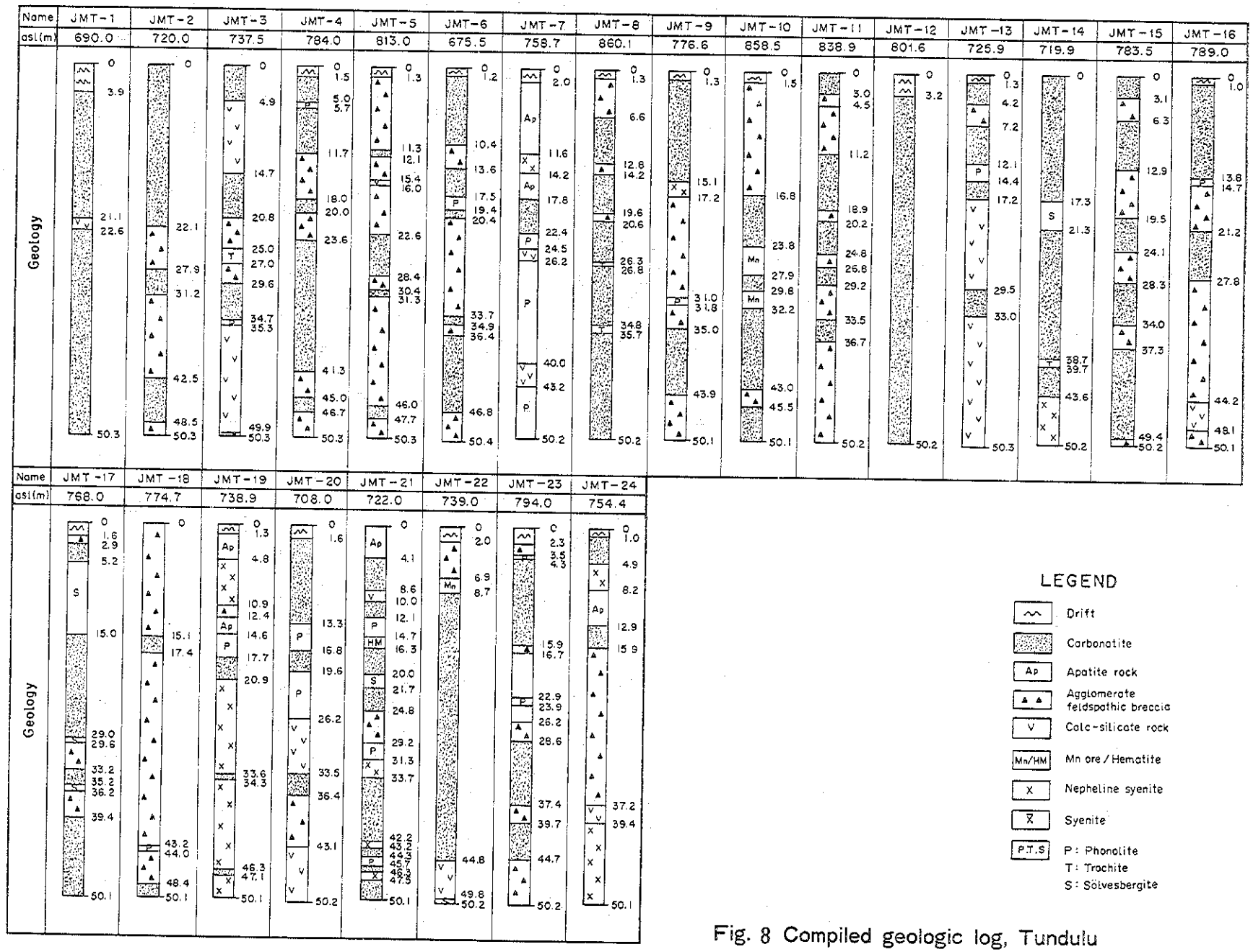
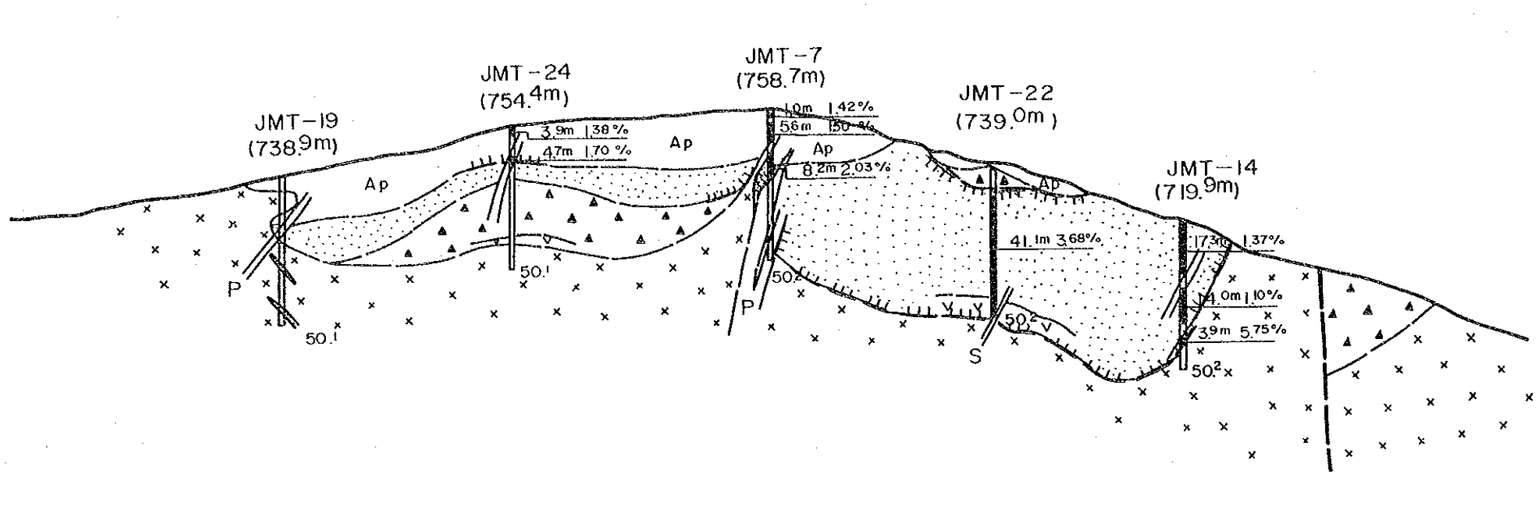


Fig. 8 Compiled geologic log, Tundulu

JMT-19 ~ JMT-14 Line



JMT-8 ~ JMT-24 Line

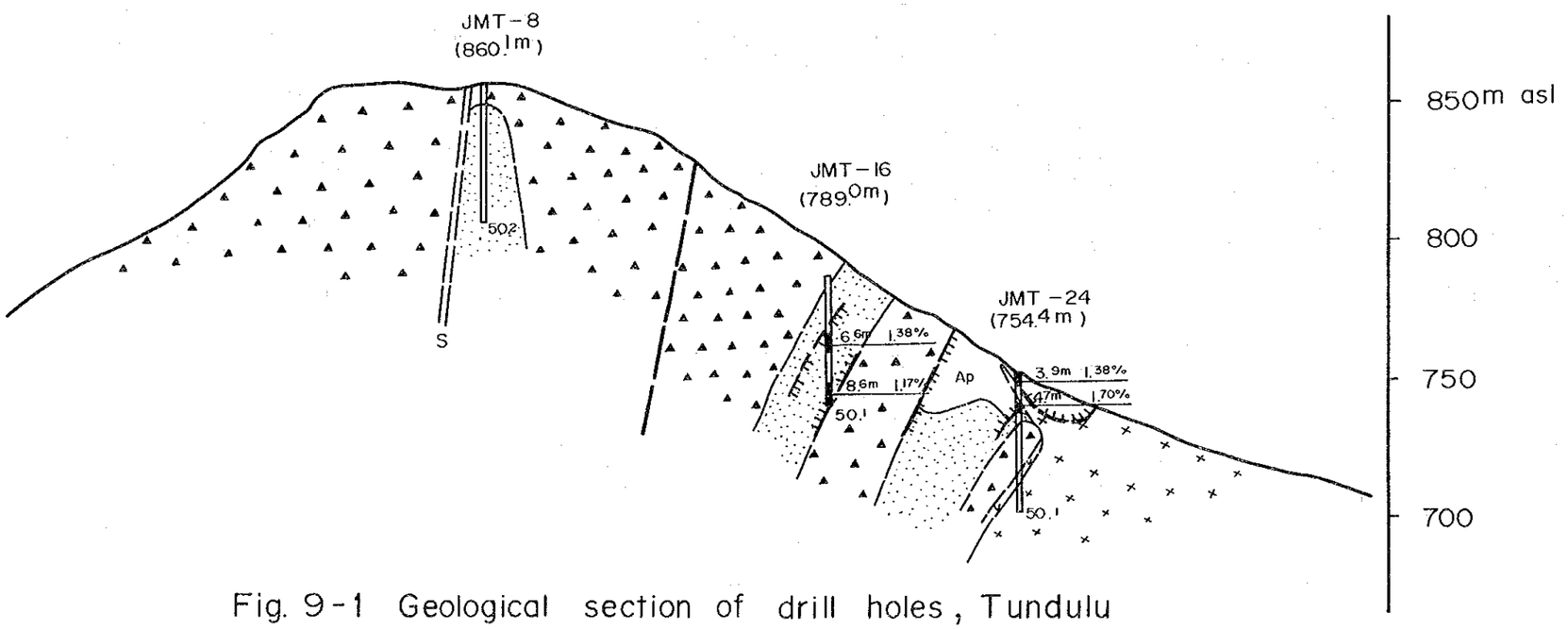


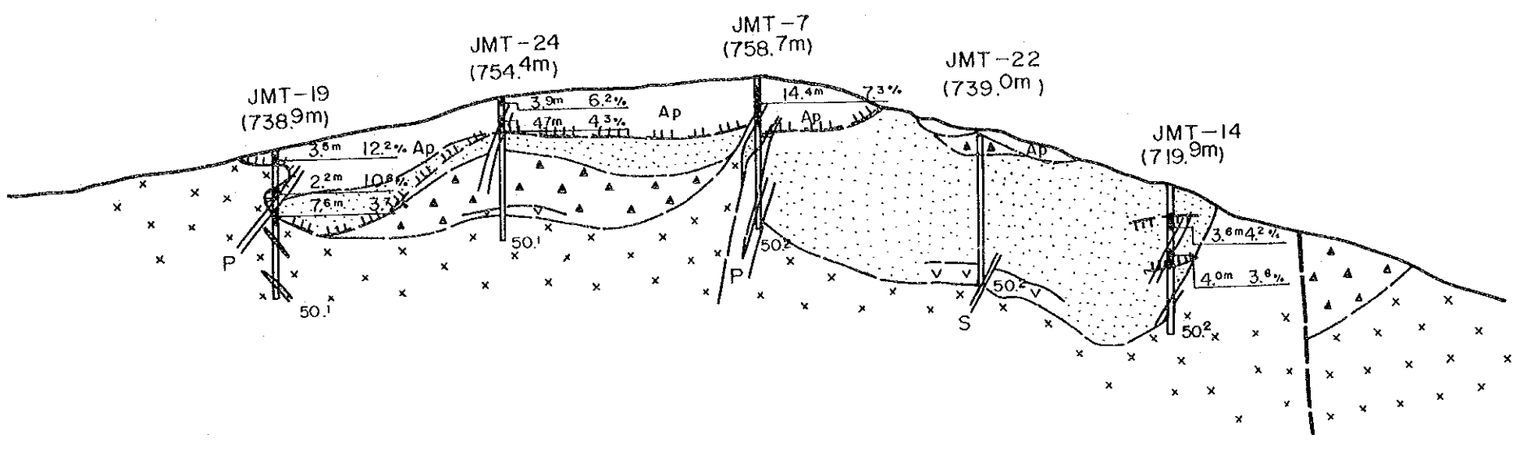
Fig. 9-1 Geological section of drill holes, Tundulu

LEGEND

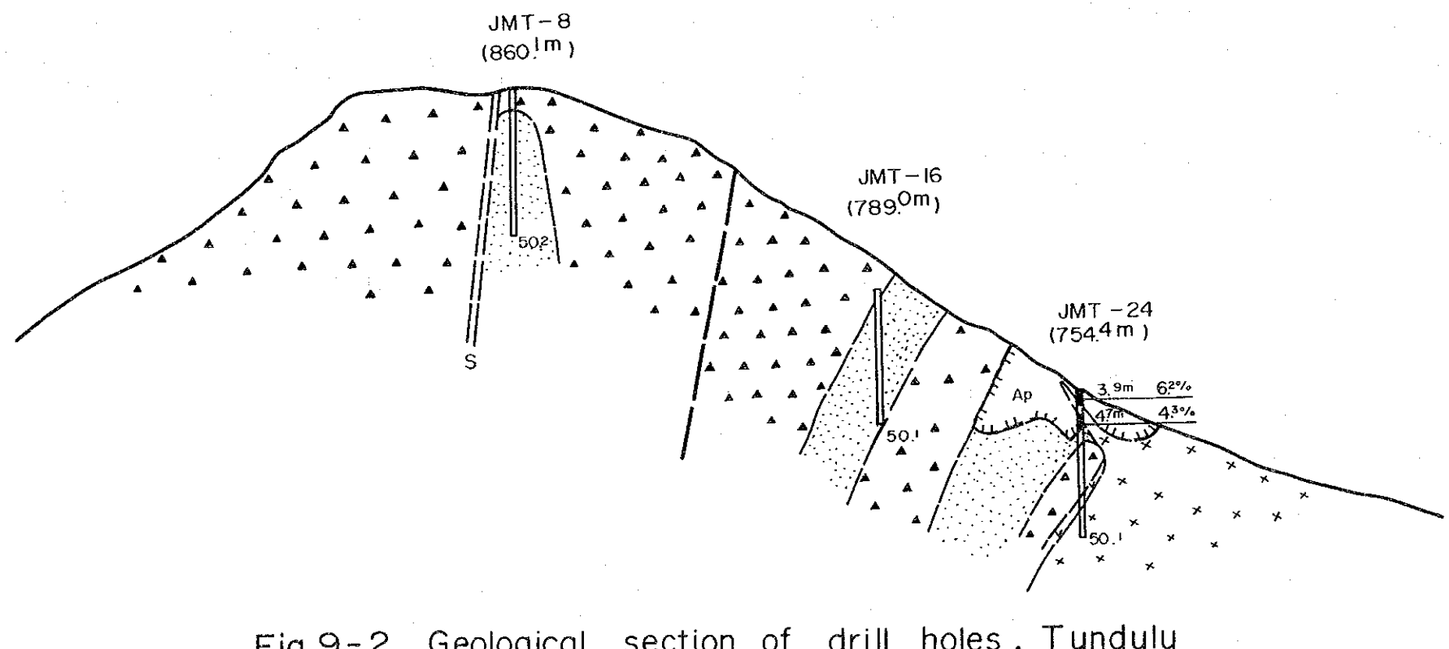
- Drift
- Carbonatite
- Ap: Apatite rock
- Agglomerate feldspathic breccia
- Calc-silicate rock
- Mn/HM: Mn ore / Hematite
- X: Nepheline syenite
- P.T.S: P: Phonolite, T: Trachite, S: Sölvsbergite
- Fault
- Expected mineralized zone (REO > 1%)

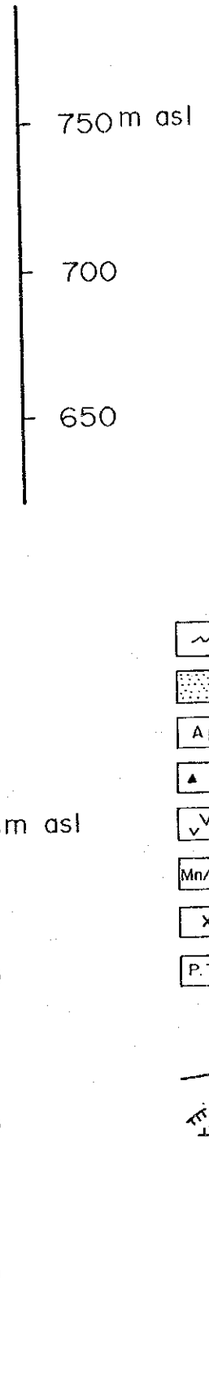
Thickness, m REO %
50.1 (Depth m)
(La, Ce, Nd, Sm, Eu, Tb, Y)

JMT-19 ~ JMT-14 Line



JMT-8 ~ JMT-24 Line



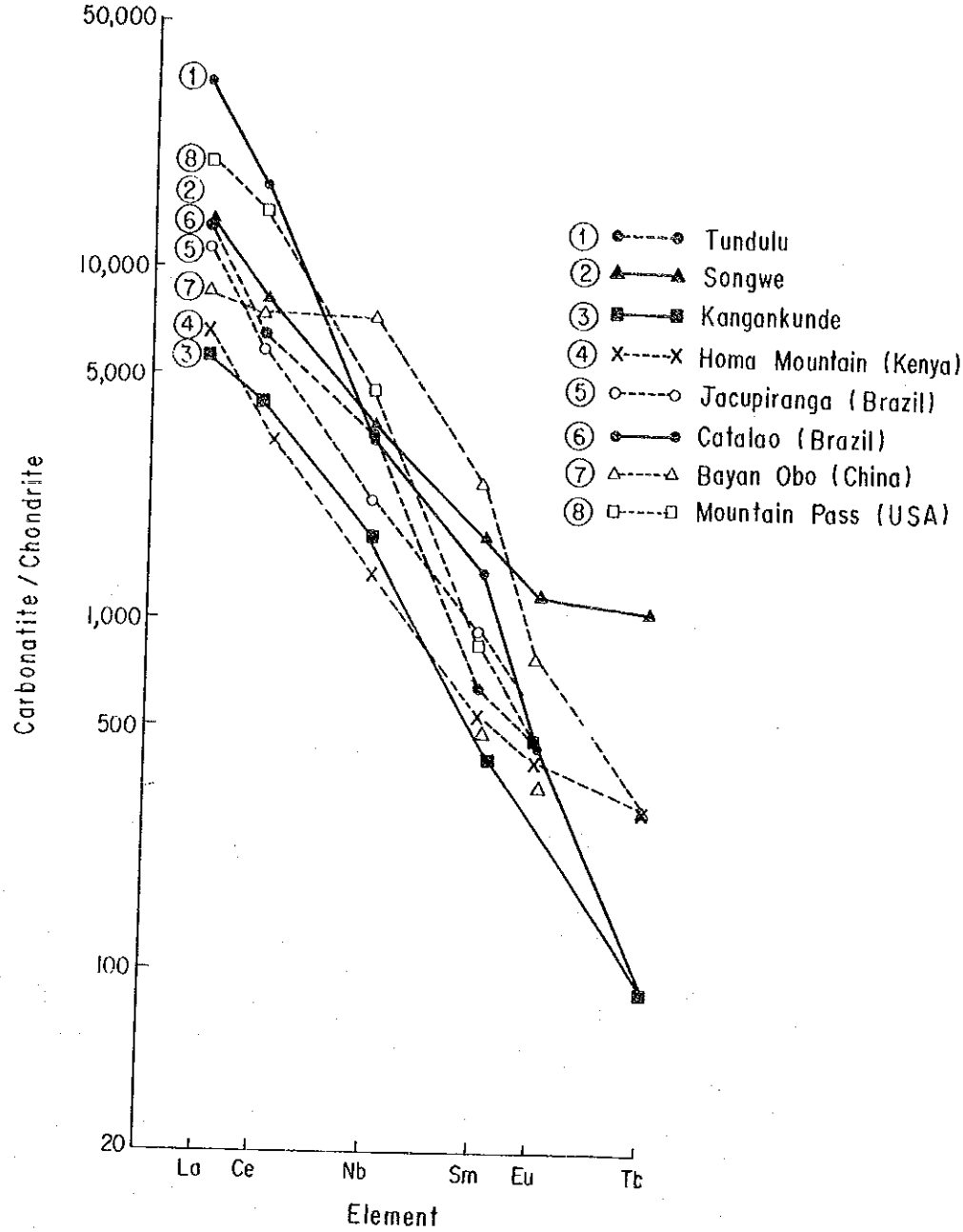


LEGEND

- Drift
- Carbonatite
- Ap — Apatite rock
- Agglomerate feldspathic breccia
- Calc-silicate rock
- Mn/HM — Mn ore / Hematite
- X — Nepheline syenite
- P.T.S — P : Phonolite, T : Trachite, S : Sölvsbergite
- Fault
- Expected mineralized zone (P>2.2 %)

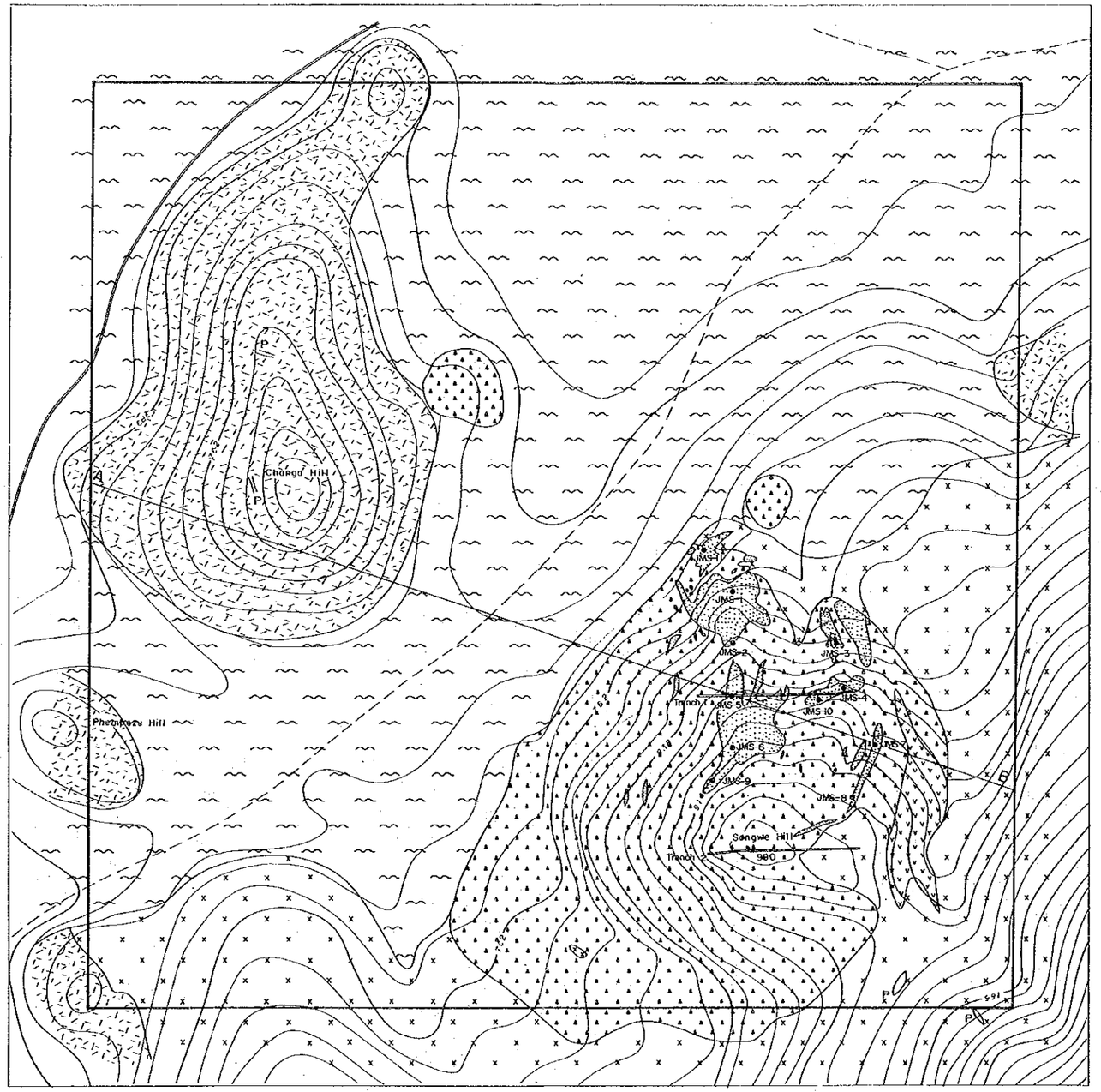
Thickness, m P%
50.1
(Depth m)

Fig 9-2 Geological section of drill holes, Tundulu



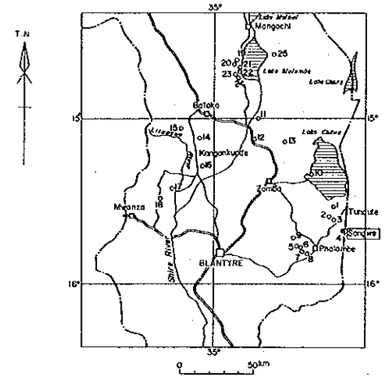
① JMT - 22, 8.7^{m}~49.8^{m} (41.1^{m})
② JMS - 4, 38.1^{m}~53.3^{m} (15.2^{m})
③ Geochemical Sample
④ Ohde et al. (1979)
⑤⑥ GSJ and DNPM (1987)
⑦ Kishimoto (1985)
⑧ Hida (1970)

Fig.10 Chondrite normalized rare eath concentration



COOPERATIVE MINERAL EXPLORATION
IN
THE CHILWA ALKALINE AREA,
REPUBLIC OF MALAWI
(PHASE II)

GEOLOGICAL MAP AND PROFILE OF SONGWE SECTOR



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1988

0m 250m 500m

LEGEND

- Drift
- Carbonatite
- Agglomerate / feldspathic rock
- Calc-silicate rock
- Dyke P phonolite
- Nepheline syenite
- Gneiss
- Drilling site (1987)
- Trench (1987)
- Profile line

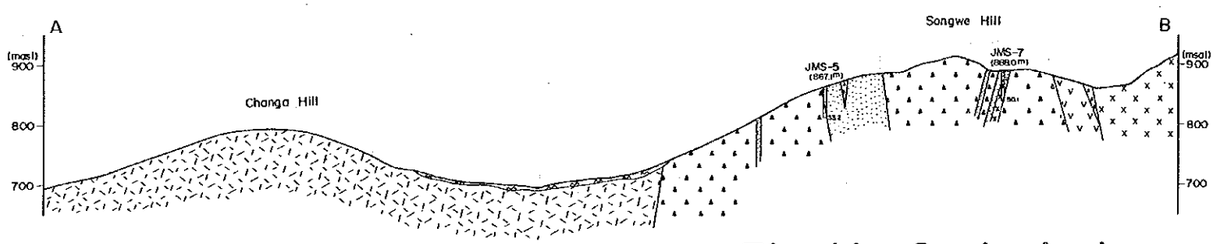


Fig. 11 Geological map and profile of Songwe sector

Chapter 2 Songwe sector

2-1 Method of the survey

During the second phase survey, geological, geochemical and drilling surveys have been done. Method of the survey is the same as that in Tundulu sector described before (1-1).

Contents of the survey are shown in Tab. 9.

Tab. 9 Contents of survey, Songwe

Geological and geochemical survey		Drilling servey	
Area	3.2 km²	No. of holes	11
Route survey	9 km	Total length	558.95 m
Trench survey	600 m	Inclination	-90°
Assay of geochemical samples	151 pcs	Assay of ore samples	110 pcs
Microscopic observation (Thin section)	13 pcs	Assay element:	
Microscopic observation (Polished section)	16 pcs	La, Ce, Nd, Sm, Eu, Tb, Nb, Sr,	
X-ray diffractive analysis	13 pcs	Y, P (10 elements)	

2-2 Geology (Fig. 11)

Constituent rocks of this sector are as follows:

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa Alkaline Province" Carbonatites (sövitic and ankeritic) Breccias (agglomerate and feldspathic breccia) Altered rocks (carbonate silicate rock) Nepheline syenite Dykes (phonolite, trachyte)
Late Precambrian to early Cambrian	Gneisses

Main constituent rocks of Songwe sector are almost the same as those of Tundulu sector described before.

Basement rocks of gneisess are distributed in the northeastern part (Changa Hill) and the western part (Phempezu Hill). They are composed mainly of granitic and biotite gneiss.

Igneous rocks of "Chilwa Alkaline Province" are developed from the eastern part of Changa Hill to Songwe Hill and to the south.

Nepheline syenite occurs widely in the southern part of Songwe Hill. It is gray colored, medium grained rock containing pink nepheline and dark green pyroxene. Under the microscope, nepheline syenite has microperthite, nepheline, cancrinite, aegirine, sphene, magnetite, sodalite and apatite.

Breccias are distributed in the area of 800m (E-W) x 1,000m (N-S). Carbonatites are found in breccias. Constituent rocks of breccias are feldspathic breccia and agglomerate.

Carbonatites in this sector are classified into sövitic and ankeritic. They are found in breccias on the northern slope of Songwe Hill, showing irregular, massive and dyke like shapes. The largest body is 350m (E-W) x 200m (N-S) in size.

Sövitic carbonatite is grayish white to dark brown, and fine grained. Under the microscope, it is characterized by a mosaic texture composed mainly of calcite and goethite with monazite, bastnae- site, synchysite and pyrochlore.

Ankeritic carbonatite is dark brown to black colored and fine grained rock. These carbonatites often contain manganese oxides and iron oxides. In a carbonatite body, veins of fluorite and barite are recognized.

Altered rocks are developed along boundary between nepheline syenite and breccias as well as in breccias on the eastern slope of Songwe Hill. They are dark gray colored, fine grained and massive rocks, and have undergone carbonatized alteration. Nepheline syenite is sometimes found as a xenolith in altered rocks in places. Under the microscope, altered rocks show porphyritic texture composed mainly of K-feldspar and goethite with apatite, chlorite, synchysite and parisite.

Phonolite and trachyte occur as dyke rocks. Phonolite shows various lithology ranging from porphyritic to fine grained compact one. It sometimes contains biotite in places.

Geological structure in this sector is elliptical with a diameter of about 700m and a height of about 300m. Carbonatites are usually distributed within this elliptical structure.

Lineation of the carbonatite is predominant in N-S and NE-SW directions, plunging steeply. The elliptical structure inferred to be a vent formed by intrusion of igneous rocks associating carbonatites into

nepheline syenite (Garson, 1965).

2-3 Results of Geochemical survey

Collected rock species, analysed elements, their detectable limit and procedure of statistical analyses are the same as those of the Tundulu sector.

151 samples are collected in this sector.

2-3-1 Statistical value

Statistical values of each element and REO of this sector as well as the crustal abundance are shown in Tab. 10.

All the elements analysed have over ten times higher content than the crustal abundance. An exception is Sr content in rocks.

Therefore, these elements can be used effectively as pathfinder elements of carbonatites in Songwe sector.

Tab. 10 Statistical values of geochemical survey, Songwe

(ppm)

Element	Rock type	No. of Samples	Max.	Min.	Mean	M + 1S	Abundance (Earth Crust)
La	Carbonatite	79	14949	103	1799	4974	25
	Others	72	7305	33	765	2095	
Ce	Carbonatite	79	18252	162	3515	9353	81
	Others	72	12723	53	1395	3856	
Nd	Carbonatite	79	5034	<5	1191	3769	20
	Others	72	6246	<5	507	1816	
Sm	Carbonatite	79	822.0	<0.1	160.2	759	4
	Others	72	944.0	1.4	108.7	345	
Eu	Carbonatite	79	235.4	<0.1	48.3	167	0.8
	Others	72	181.2	0.7	28.9	83	
Tb	Carbonatite	79	137.7	<0.1	25.1	83	0.5
	Others	72	173.4	<0.1	6.3	80	
Nb	Carbonatite	79	7001	45	594	1826	20
	Others	72	3851	<1	511	1757	
Sr	Carbonatite	79	43085	623	4181	10355	300
	Others	72	12513	200	955	2317	
Y	Carbonatite	79	2587	10	238	706	38
	Others	72	1316	5	171	466	
P	Carbonatite	79	107982	80	3344	14515	900
	Others	72	96765	<5	2753	12510	
REO	Carbonatite	79	45893	411	8679	23072	
	Others	72	33279	142	3773	10190	

2-3-2 Correlation of the elements

Correlation coefficient of each element in this sector is shown in Tab. 11.

The 10 pairs of elements, all of which are REE, showing extremely strong correlation with the correlation coefficient exceeding 0.8 are (La, Ce), (La, Nd), (La, Sm), (Le, Nd), (Ce, Sm), (Ce, Eu), (Nd, Sm), (Nd, Eu), (Sm, Eu) and (Y, Eu).

It is considered that these elements exist in bastnaesite and synchysite.

Tab. 11 Correlation coefficients of elements, Songwe

AREA: S (N of cases: 151)

Correlations:	logLa	logCe	logNd	logSm	logEu	logTb	logNb	logSr	logY	log P
logLa	1.00									
logCe	.97	1.00								
logNd	.90	.92	1.00							
logSm	.83	.85	.85	1.00						
logEu	.79	.82	.89	.83	1.00					
logTb	.62	.64	.68	.52	.63	1.00				
logNb	-.01	-.03	-.04	-.07	-.07	.03	1.00			
logSr	.44	.46	.41	.23	.32	.42	-.05	1.00		
logY	.62	.63	.66	.74	.81	.48	-.06	.36	1.00	
logP	.06	.08	.11	.12	.18	.26	.15	.27	.45	1.00

2-3-3 Distribution of anomalies

Anomalous values in this sector are calculated in the same manner as in the case of Tundulu sector.

The thresholds and distribution of anomalous values are shown in Tab. 10 and Fig. 12. It may be easily seen from the figure, that distribution of anomalous values of REE and Nb are restricted on the northern slope of Songwe Hill.

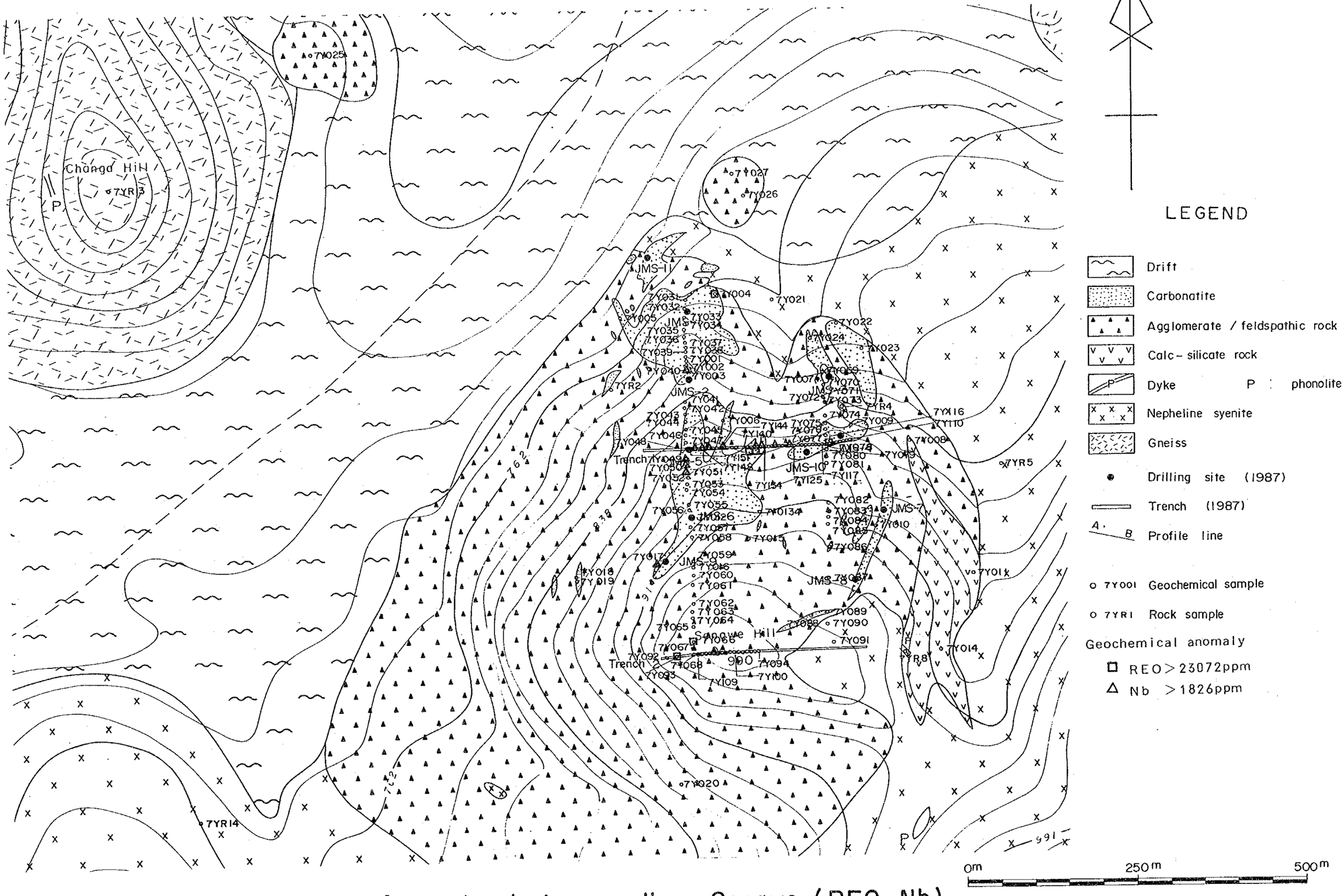


Fig. 12 Distribution map of geochemical anomalies, Songwe (REO, Nb)

2-4 Drilling survey

From first phase survey results, Songwe sector was selected as a sector that has high potential for economic resources in carbonatites.

Drilling was performed to clarify the mode of occurrence of ore deposits in carbonatites.

2-4-1 Outline of drilling

Transportation of the drilling rigs, operations and core observations were performed in the same way as in Tundulu sector.

Drilling covered 38 days, from August 13 to September 19.

2-4-2 Drilling procedure

Drilling rigs were transported from Kamuzu International Airport via Blantype to Changa in Songwe sector, using a truck of 11 tons burden. The rigs were transported from Changa to drilling camp using a truck of 4 tons burden.

Setting up of rigs was firstly made at JMS-1. Drilling in Songwe sector was performed in the following order of site number, JMT-1, 2, 3, 5, 6, 4, 9, 10, 8, 7 and 11. Location of drilling sites is shown in Fig. 13.

Transport routes of one meter wide were constructed from site to site, total length reached 2,200m. construction of the routes and land readjustment around each site was performed by human power.

Water was transported from naturally spouting pond, which was 5km from the sector by a truck of 3 tons burden with a $1.5m^3$ tank. Transported water was supplied to each drilling site by two sets of pump and hoses with total length of 1,500m.

Drilling through surface soil was performed using Metal shoe (ϕ73mm), and after reaching hard rock, diamond shoe (ϕ73mm) was used to set BW casing pipe. A diameter of diamond bit was 56mm at the bottom.

The progress of the operation at each drill hole is summarized in perfomance of the drilling.

After completion of the operation in Songwe sector, drilling rigs were transported to Tundulu sector in 4 days time.

Performance of the drilling, Songwe

Hole	Drilled length (m)	Core length (m)	Core recovery except soil(%)	Working period M. D.~M. D.	Bit size ø73mm		Bit size ø56mm	
					Depth(m)	Performance of the drilling	Depth(m)	Performance of the drilling
JMS- 1	50.45	48.95	95.0	8.13~ 8.16	1.8	0-0.4m Dry drilling with metal shoe, 0.4-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.45	Drilling with diamond bit, Using TK-60, 45.8m Escape of whole water
JMS- 2	50.1	47.50	97.5	8.17~ 8.22	1.9	0-1.4m Dry drilling with metal shoe, 1.4-1.9m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60. 1.9-12.9m Reaming and installation of BW casing pipe
JMS- 3	58.0	55.90	99.6	8.23~ 8.26	2.9	0-1.5m Dry drilling with metal shoe, 1.5-2.9m Drilling with diamond shoe, Installation of BW casing pipe	58.0	Drilling with diamond bit, Using TK-60. 2.9-16.2m Reaming and installation of BW casing pipe
JMS- 4	53.3	50.80	95.7	9. 3~ 9. 5	1.8	Dry drilling with metal shoe, Installation of BW casing pipe	53.3	Drilling with diamond bit, Using TK-60, 7.7m Escape of whole water
JMS- 5	53.2	51.30	100.0	8.27~ 8.29	1.9	Dry drilling with metal shoe, Installation of BW casing pipe	53.2	Drilling with diamond bit, Using TK-60, 7.7m Escape of whole water
JMS- 6	50.1	43.20	97.1	8.30~ 9. 2	5.6	Drilling with metal shoe, Using TK-60, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60. 6.0m Escape of whole water, 5.0-10.0m Reaming and installation of BW casing pipe
JMS- 7	50.1	40.90	84.3	9.14~ 9.16	2.0	0-1.6m Dry drilling with metal shoe, 1.6-2.0m Drilling with diamond shoe, Installation of BW casing pipe	50.1	Drilling with diamond bit, Using TK-60. 12.5-15.4m Drusy, escape of whole water
JMS- 8	42.2	38.35	94.5	9.11~ 9.13	2.0	0-1.7m Dry drilling with metal shoe, 1.7-2.0m Drilling with diamond shoe, Installation of BW casing pipe	42.2	Drilling with diamond bit, Using TK-60
JMS- 9	50.2	44.30	90.0	9. 6~ 9. 8	1.8	0-1.0m Dry drilling with metal shoe, 1.0-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60. 22.6-30.9m Drusy
JMS-10	51.0	47.10	91.9	9. 9~ 9.11	2.8	0-2.3m Drilling with metal shoe, Using TK-60, 2.3-2.8m Drilling with diamond shoe, Installation of BW casing pipe	51.0	Drilling with diamond bit, Using TK-60. 5.0m Escape of whole water
JMS-11	50.2	42.40	85.7	9.17~ 9.19	1.8	0-0.7m Dry drilling with metal shoe, 0.7-1.8m Drilling with diamond shoe, Installation of BW casing pipe	50.2	Drilling with diamond bit, Using TK-60. 2.2m Escape whole water, 1.8-5.3m Reaming and installation of BW casing pipe

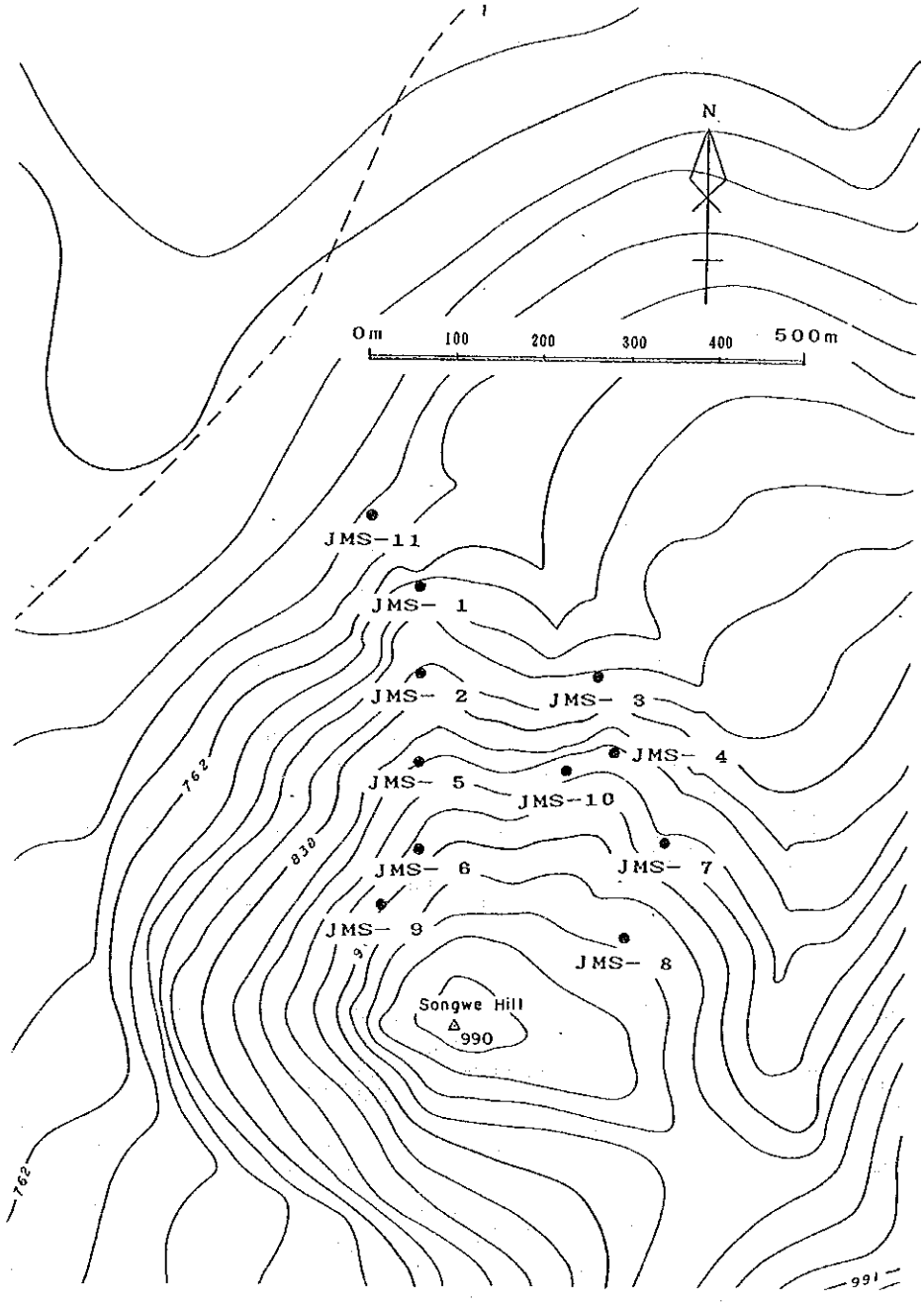


Fig 13 Location map of drilling sites, Songue

2-4-3 Geology and mineralization of drill holes

Drilling was performed, from outcop at the surface to about 50m in depth, aiming mainly at classifying. The geology, mode of occurrence of carbonatite and minerals rich in REE included in carbonatite.

Geology of each drill hole is shown in Fig. 14. Chemical compositions and REO of samples are shown in Appendix 2 .

REE mineralized zones are listed in Tab. 12. In Tab. 13, shown are phosphorus mineralized zones.

In Songwe sector, REE mineralized zones are recognized at JMS-1, 2, 3, 4, 5, 6, 7, 9 and 10. Main constituent minerals are bastnaesite, synchysite, pyrochlore and strontianite.

Geological section through the drill holes of JMS-5, 10 and 4 is shown in Fig. 15.

The longest core sample with continuous mineralization is 15.2m long between 38.1m and 53.3m of JMS-4. Its REO content is 2.10%.

REE content of this mineralized zone is 2-3 times higher in Sm and 2-4 times in Eu respectively than that of Mountain Pass Mine. However, La, Ce and Nd content of this mineralization indication is lower. Phosphorus content is over 2.2% in JMS-10 and its mineralized zone is over 2m long. Phosphorus mineral is mainly granular apatite.

2-5 Discussion

From the results of geological, geochemical and drilling surveys performed in Songwe sector, the following facts have been clarified.

1. Carbonatites are developed showing an elliptical structure centering Songwe Hill. Geological structure is inferred to be a vent formed by intrusion of carbonatites into nepheline syenite of "Chilwa Alkaline Province" rock.

2. Carbonatites in the vent are composed mainly of sövitic and ankeritic. REE mineralized zones in carbonatites are recognized on the northern slope of Songwe Hill (lower than 850m asl). The zone with a length of 15.2m and contents of 2.10% REO is discovered at JMS-4 by drilling. Phosphorus mineralized zones are recognized at JMS-10 and 11, the length of each zone being as thin as less than 3.6m.

3. Contents of Sm and Eu in the REE mineralized zones are 2-3 and 2-4 times higher respectively than those of ores from Mountain Pass Mine.

4. The rare earth pattern (Fig. 10) of chemical analysis from JMS-4 indicates that medium REE in Songwe sector is higher than those of Tundulu and Kangankunde sectors.

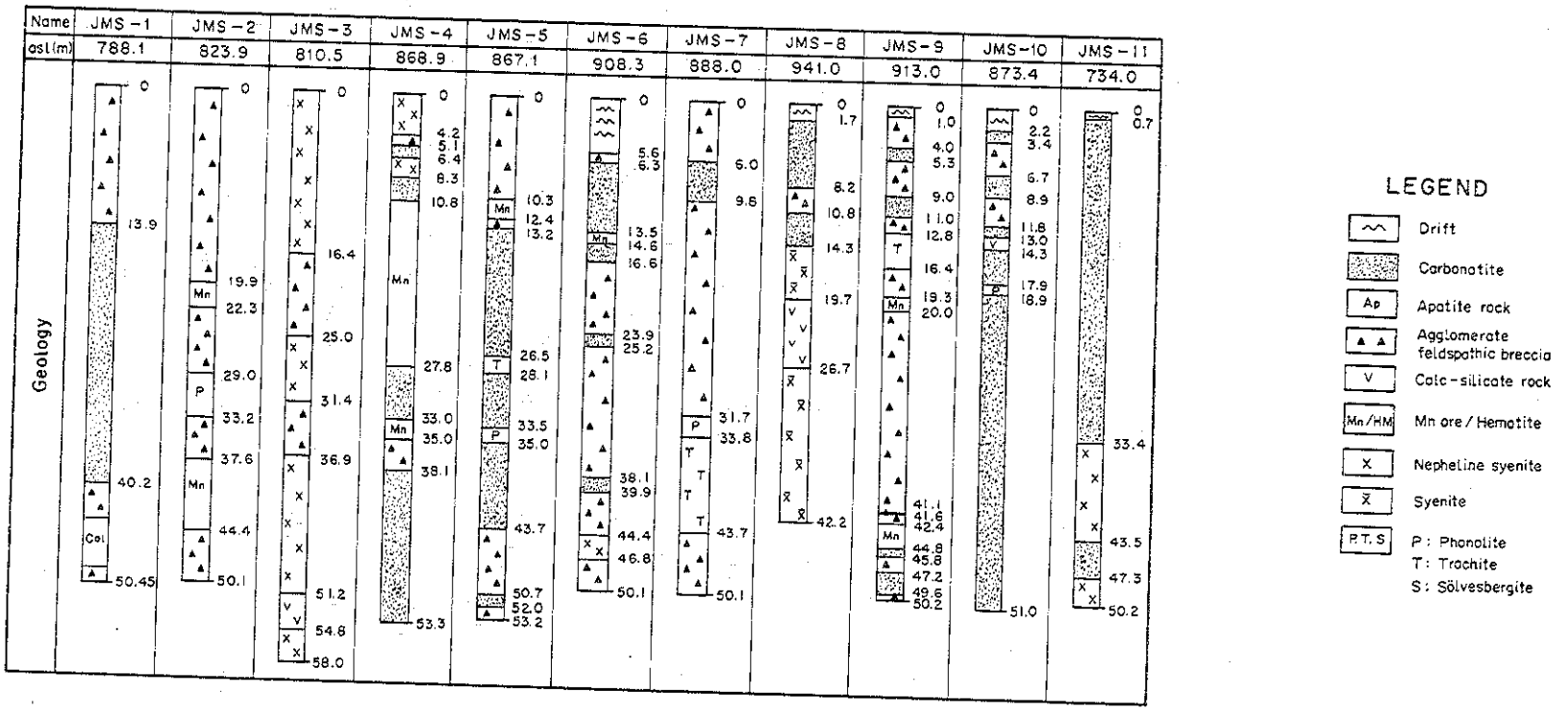


Fig. 14 Compiled geologic drill log, Songwe

Tab. 12 Summary of the mineralized zone (REO>1.0%), Songwe

(ppm)

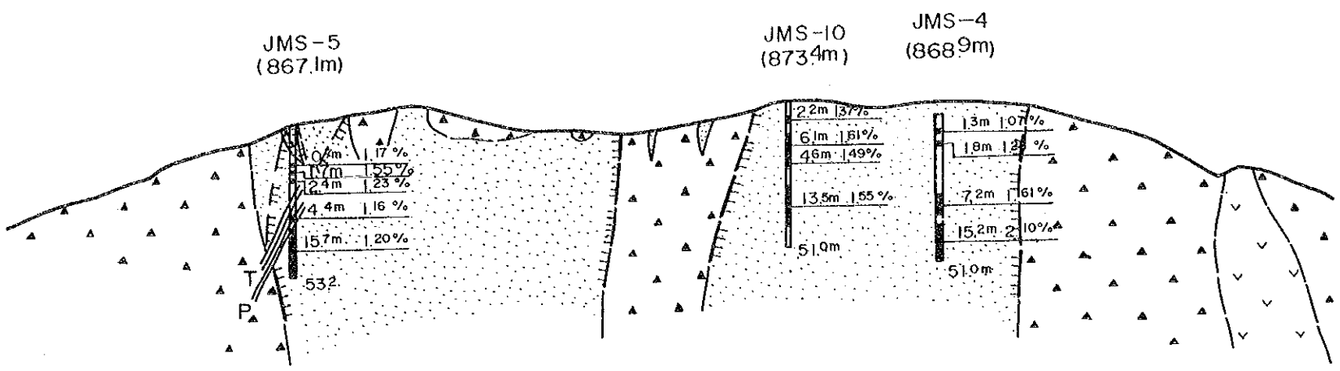
Drill No.	Depth	Thick	La	Ce	Nd	Sm	Eu	Tb	Nb	Sr	Y	P	REO
JMS- 1	19.9-26.7	6.8	3540	6763	2438	387.9	92.8	13.1	963	2705	358	1887	16327
	29.0-31.9	2.9	2256	4324	1442	228.1	57.6	13.9	914	2009	274	3014	10333
	38.1-40.9	2.8	1814	3800	1855	357.9	90.4	36.3	396	1885	673	8571	10374
JMS- 2	17.0-29.0	12.0	3027	5793	2026	353.1	93.4	25.9	1053	3129	446	6210	14140
	37.6-44.4	6.8	3609	6505	2219	370.3	91.1	37.8	750	2848	336	6757	15813
JMS- 3	3.1- 3.7	0.6	2298	4366	1602	395.6	110.1	36.9	1406	1337	298	6702	10932
	5.4- 5.9	0.5	6300	10302	3425	469.3	101.8	32.8	138	9376	203	1504	24992
	13.5-20.8	7.3	6710	10117	2624	388.7	92.5	24.4	1601	16283	393	13125	24439
JMS- 4	5.1- 6.4	1.3	1922	4264	1748	373.7	110.4	46.6	691	4563	431	1938	10691
	9.0-10.8	1.8	1983	4910	2365	551.5	158.5	89.8	35	10311	603	4253	12806
	27.8-35.0	7.2	2955	6278	2883	589.4	152.0	67.2	27	5440	516	2070	16130
	38.1-53.3	15.2	5189	8481	2613	398.3	97.3	61.8	1497	10272	638	7870	21004
JMS- 5	13.2-13.9	0.7	2111	4529	1855	351.2	98.9	84.8	2418	3756	670	15040	11671
	16.1-17.8	1.7	3197	6539	2414	395.5	86.1	38.5	1070	2773	276	4701	15548
	18.6-21.0	2.4	2527	4967	1933	314.3	78.0	54.1	1065	3120	395	10053	12336
	29.1-33.5	4.4	2310	4653	1863	299.6	77.4	70.8	1272	7834	408	15398	11633
	35.0-50.7	15.7	2491	4744	1940	308.3	83.1	68.2	1616	4222	376	10004	12020
JMS- 6	6.3- 7.4	1.1	2081	4416	2083	316.7	90.7	55.8	3369	2178	317	374	11232
	38.1-39.9	1.8	1798	3897	1853	432.4	118.8	61.6	520	2107	468	3881	10360
JMS- 7	6.0- 8.0	2.0	2265	4776	2045	319.2	88.2	41.9	800	12637	476	6120	12031
JMS- 9	9.8-11.0	1.2	2197	4012	1595	280.1	79.6	51.7	426	1937	453	3391	10416
	34.6-37.1	2.5	2087	4148	1686	303.4	76.0	32.7	1296	1784	434	5866	10536
	41.1-41.6	0.5	2387	4746	1935	347.0	87.3	62.8	119	2858	689	7609	12335
	44.8-45.8	1.0	2148	4204	1946	396.0	126.1	145.9	514	3827	1867	28993	13096
	47.2-49.6	2.4	2564	5207	2123	332.1	81.3	26.6	683	2105	352	1033	12834
JMS-10	6.7- 8.9	2.2	2776	5313	2354	298.9	84.4	63.1	2838	2482	510	10940	13690
	11.8-17.9	6.1	3178	6265	2402	385.9	98.9	137.7	750	19337	901	26647	16087
	18.9-23.5	4.6	2773	5977	2370	345.0	89.3	145.9	2328	11252	674	11558	14883
	29.4-42.9	13.5	4432	5864	1676	238.6	62.2	80.0	1264	8441	422	10039	15480
JMS-11	4.3-14.0	9.7	2125	4969	2087	260.9	65.8	25.8	1022	1684	327	12844	11852
	17.0-33.4	16.4	2348	5037	1730	265.3	66.6	28.8	1525	2173	333	5614	12164
Mountain Pass (USA)			7500	14000	3200	200	40	-	-	-	790	-	20000

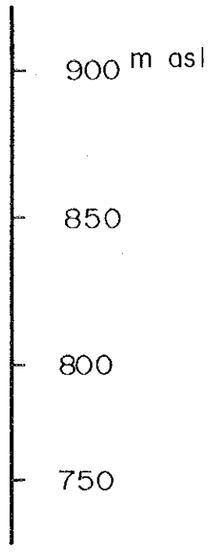
Tab. 13 Summary of the mineralized zone (P>2.2%, Thick>2.0m), Songwe

(ppm)

Drill No.	Depth	Thick	La	Ce	Nd	Sm	Eu	Tb	Nb	Sr	Y	P	REO
JMS-10	14.3-17.9	3.6	2704	5709	2298	403.8	105.2	192.0	966	15019	1082	33256	15047
JMS-11	4.3- 7.0	2.7	2506	5888	2371	221.0	73.8	32.3	455	2698	451	32545	13886

JMS-5 ~ JMS-4 Line





LEGEND

- Drift
- Carbonatite
- Ap — Apatite rock
- Agglomerate feldspathic breccia
- Calc-silicate rock
- Mn/HM — Mn ore / Hematite
- Nepheline syenite
- P.T.S — P: Phonolite, T: Trachite, S: Sölvsbergite
- Expected mineralized zone (REO > 1%)
- Thickness m, REO% (La, Ce, Nd, Sm, Eu, Tb, Y)
- 50.1 (Depth m)

JMS-1 ~ JMS-6 Line

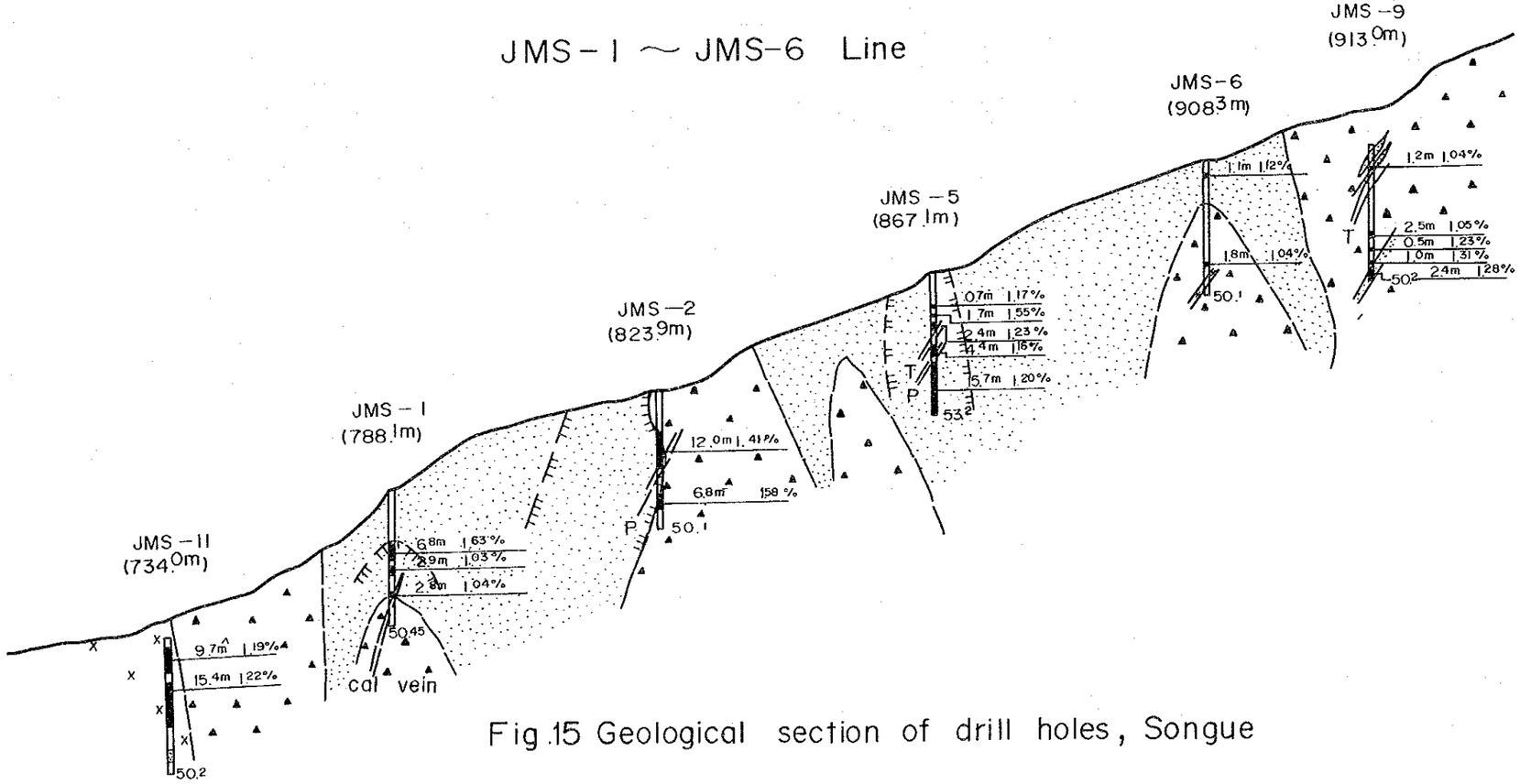
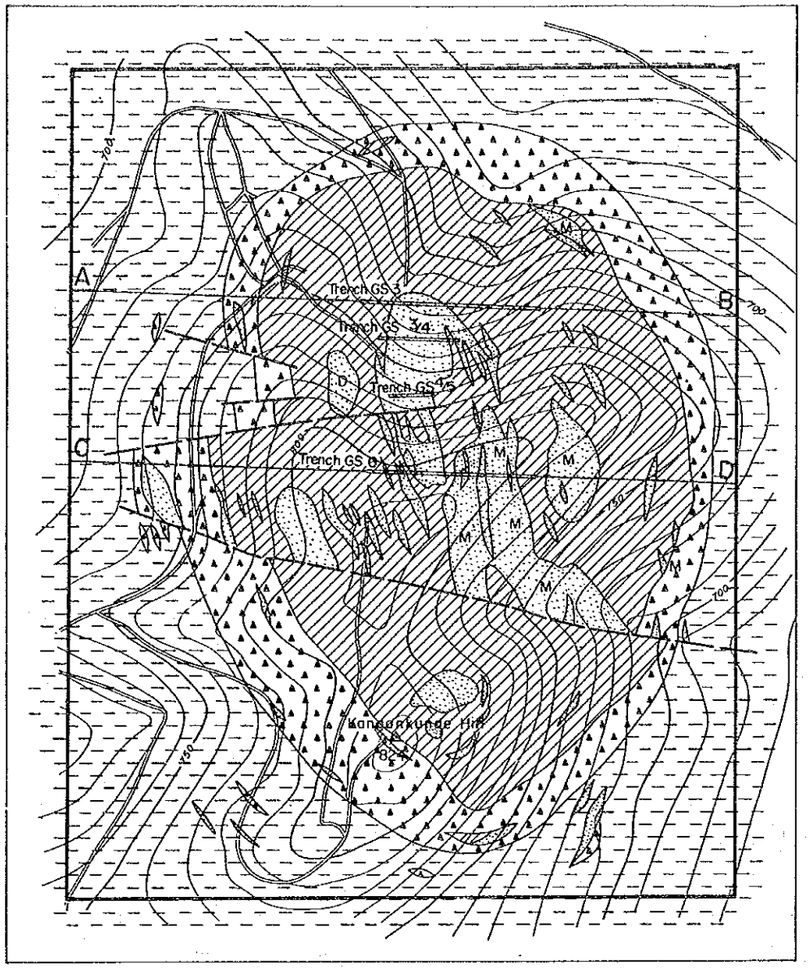
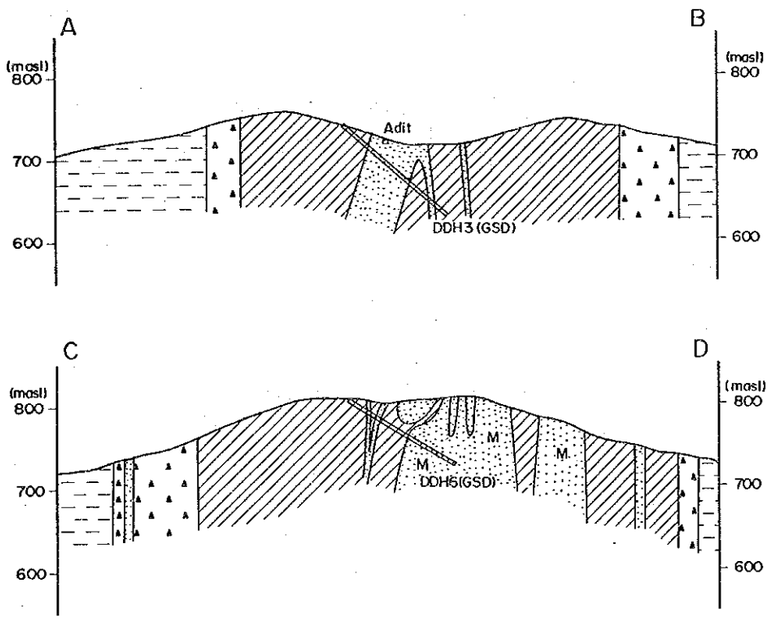


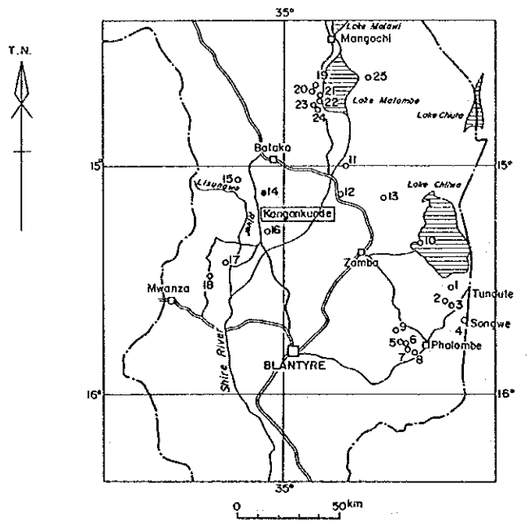
Fig.15 Geological section of drill holes, Songue





COOPERATIVE MINERAL EXPLORATION
IN
THE CHILWA ALKALINE AREA,
REPUBLIC OF MALAWI
(PHASE II)

GEOLOGICAL MAP AND PROFILES OF KANGANKUNDE SECTOR



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1988

LEGEND

- Drift
- Carbonatite
- M — Manganiferous carbonatite
- D — Dolomitic carbonatite
- Carbonatized feldspathic rock / agglomerate
- Agglomerate / feldspathic rock
- Fenitized syenite / gneiss
- Fault
- Trench (1987)
- A — B Profile line

0m 250m 500m

Fig. 16 Geological map and profiles of Kangankunde sector

Chapter 3 Kangankunde sector

3-1 Method of the survey

During the second phase survey, geological and geochemical servey have been done.

Route survey was done with a pocket compass. The results were put on a route map of 1/2,000 in scale.

Trench survey was done using of 1/200 scale. The results were put on a geological map of 1/5,000 in scale.

Geological and geochemical surveys were done at the same time. As a principle, samples were collected for chemical analyses from carbonatite bodies. Recognition of the geochemical anomaly was made by the use of chemical data which was analysed statistically by computor.

Contents of the survey are shown in Tab. 14.

Tab. 14 Contents of survey, Kangankunde

Geological and geochemical survey		
Area	0.8 km^2	
Route survey	6 km	
Trench survey	500 m	
Assay of geochemical samples	102 pcs	
Microscopic observation (Thin section)	6 pcs	Assay element:
Microscopic observation (Polished section)	1 pcs	La, Ce, Nd, Sm, Eu, Tb, Nb, Sr,
X-ray diffractive analysis	2 pcs	Y, P (10 elements)

3-2 Geology (Fig. 16)

Main constituent rocks of this sector are as follows:

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa Alkaline Province" Carbonatites (manganese, ankeritic, sideriteic and dolomitic) Breccias (agglomerate and feldspathic breccia)
Late Precambrian to early Cambrian	Gneisses

Late Precambrian to early Cambrian basement rocks of gneisses are distributed widely along the slope of Kangankunde Hill. They have undergone prints of fenitization showing igneous intrusion in "Chilwa Alkaline Province". Gneisses are leucocratic to pink colored and massive, including biotite and hornblende as colored minerals.

Igneous rocks of "Chilwa Alkaline Province" are mainly developed as an oval shaped complex, centering Kangankunde Hill, the size of which is approximately 900m (N-S) x 700m (E-W).

Breccias are composed of agglomerate and feldspathic breccia, as in the case of Tundulu and songwe sectors. Breccias in this sector are classified as carbonatized and are least altered ones. Least altered breccias are distributed along boundaries between igneous rocks of "Chilwa Alkaline Province" and the basement rocks, showing an elliptical form of 100m width. They are pink to reddish brown in color, compact and hard.

Carbonatized breccias are found along the inner boundary of the least altered breccias. In these rocks, fragments of feldspathized fenite are embeded in a matrix of dark brownish carbonate minerals. Under the microscope, characteristic is a mosaic structure constituted by dolomite, goethite and K-feldapar. Phenocrysts embeded in a matrix of carbonate minerals have undergone intense carbonitization. Apatite and strontianite are sometimes found in some places of the rocks.

Carbonatites in this sector are classified as dolomitic, sideritic, ankeritic and manganitic. Carbonatites are distributed mainly on the

northern, eastern and western slopes of Kangankunde Hill.

Dolomitic carbonatite is found on the northern slope of the hill. It appears as a small scaled body. Rock is gray in color and porphyritic. Granular apatite, magnetite and biotite are visible. Under the microscope, it is characterized by mosaic or porphyritic textures. Main constituent minerals are dolomite and apatite with quartz, K-feldspar, parisite, goethite and chlorite.

Sideritic and ankeritic carbonatites are found on the northern and western slopes of the hill. They tend to be mixed with each other. Sideritic carbonatite is dark brown to black in color and fine grained. Ankeritic carbonatite shows various colors such as black, dark brown, pale green and gray, being coarser-grained than sideritic carbonatite. In ankeritic carbonatite, such REE minerals as monazite, strontianite and others are visible. Under the microscope, it contains quartz, K-feldspar, dolomite, apatite, synchysite, monazite, pyrochlore and others.

Manganese carbonatite is developed at the top and on the eastern slope of the hill. It is melanocratic to dark brownish and massive, rich in iron and manganese oxides.

Geological structure is characterized by elliptic form centering Kangankunde Hill, whose diameters of N-S and E-W directions are approximately 900m and 700m, respectively.

In the ellipse, the following rocks are zonaly arranged from the center to the outer; carbonatite, carbonatized breccia, least altered breccia and basement rock.

Main fault of E-W trend is found in the central part of the sector. By the fault, carbonatites and breccias are displaced.

Intensive errosion in the area has revealed carbonatite body to a considerable depth as opposed to Tundulu sector.

3-3 Results of Geochemical survey

Collected rock species, analysed elements, their detectable limit and procedure of statistical analyses are the same as those of Tundulu and Songwe sectors.

102 samples are collected in this sector.

3-3-1 Statistical Value

Statistical values of each element and REO of this sector as well as the crustal abundance are shown in Tab. 15.

Elements having over ten times higher concentration than the crustal abundance are La, Ce, Nd, Sm, Eu (only in carbonatite), Nb, Sr and P.

Therefore, these 8 elements are used effectively as pathfinder elements of carbonatites in this sector.

Tab. 15 Statistical values of geochemical survey, Kangankunde

(ppm)

Element	Rock type	No. of Samples	Max.	Min.	Mean	M + 1S	Abundance (Earth Crust)
La	Carbonatite	96	25312	114	2132	7520	25
	Others	6	4069	153	545	1740	
Ce	Carbonatite	96	34763	133	3923	14233	81
	Others	6	8679	333	1197	3778	
Nd	Carbonatite	96	9478	18	1181	4468	20
	Others	6	3313	135	470	1439	
Sm	Carbonatite	96	910.5	<0.1	93.1	606	4
	Others	6	357.2	17.6	53.8	167	
Eu	Carbonatite	96	128.6	<0.1	14.0	85	0.8
	Others	6	59.1	5.5	11.6	29	
Tb	Carbonatite	96	127.8	<0.1	4.5	36	0.5
	Others	6	42.4	0.6	9.4	48	
Nb	Carbonatite	96	6322	<1	151	976	20
	Others	6	894	18	153	650	
Sr	Carbonatite	96	344408	3140	37007	97833	300
	Others	6	254639	1369	8157	54983	
Y	Carbonatite	96	273	5	12	32	38
	Others	6	50	5	12	34	
P	Carbonatite	96	90003	1468	12117	26058	900
	Others	6	36460	4988	15896	39379	
REO	Carbonatite	96	81491	326	8989	31958	
	Othersz	6	19841	845	2829	8582	

3-3-2 Correlation of the elements

Correlation coefficient of each element in this sector is shown in Tab 16.

The nine pairs of elements, all of which are REE, showing extremely strong correlation with the correlation coefficient exceeding 0.8 are (La, Ce), (La, Nd), (La, Sm), (Ce, Nd), (Ce, Sm), (Ce, Eu), (Nd, Sm), (Nd, Eu) and (Sm, Eu). It is considered that the elements exist in monazite.

Tab. 16 Correlation coefficients of elements, Kangankunde

AREA: K (N of cases: 102)

Correlations:	logLa	logCe	LogNd	logSm	logEu	logTb	logNb	logSr	logY	logP
logLa	1.00									
logCe	.99	1.00								
logNd	.96	.98	1.00							
logSm	.84	.88	.93	1.00						
logEu	.80	.85	.91	.93	1.00					
logTb	-.01	.02	.06	.09	.15	1.00				
logNb	.11	.14	.14	.14	.19	.04	1.00			
logSr	.42	.36	.30	.24	.18	.11	-.23	1.00		
logY	.43	.45	.46	.47	.54	.18	.09	.09	1.00	
logP	.11	.13	.15	.18	.20	.41	.24	.15	.44	1.00

3-3-3 Distribution of Anomalies

Anomalous values in this sector are calculated in the same manner as in Tundulu and Songwe sectors.

The thresholds and the distribution of anomalous values are shown in Tab. 15 and Fig. 17, respectively. It may be easily seen from the figure that the distribution of anomalous values of REE, Nb, Sr and P is confined in the northern and western slopes of Kangankunde Hill.

It is concluded that carbonatite bodies on the northern and western slopes of Kangankunde Hill have the highest potential for REE, Nb, Sr and P resources.