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

(PHASE II)

MARCH 1989

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 19 June to 13 November, 1988.

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.

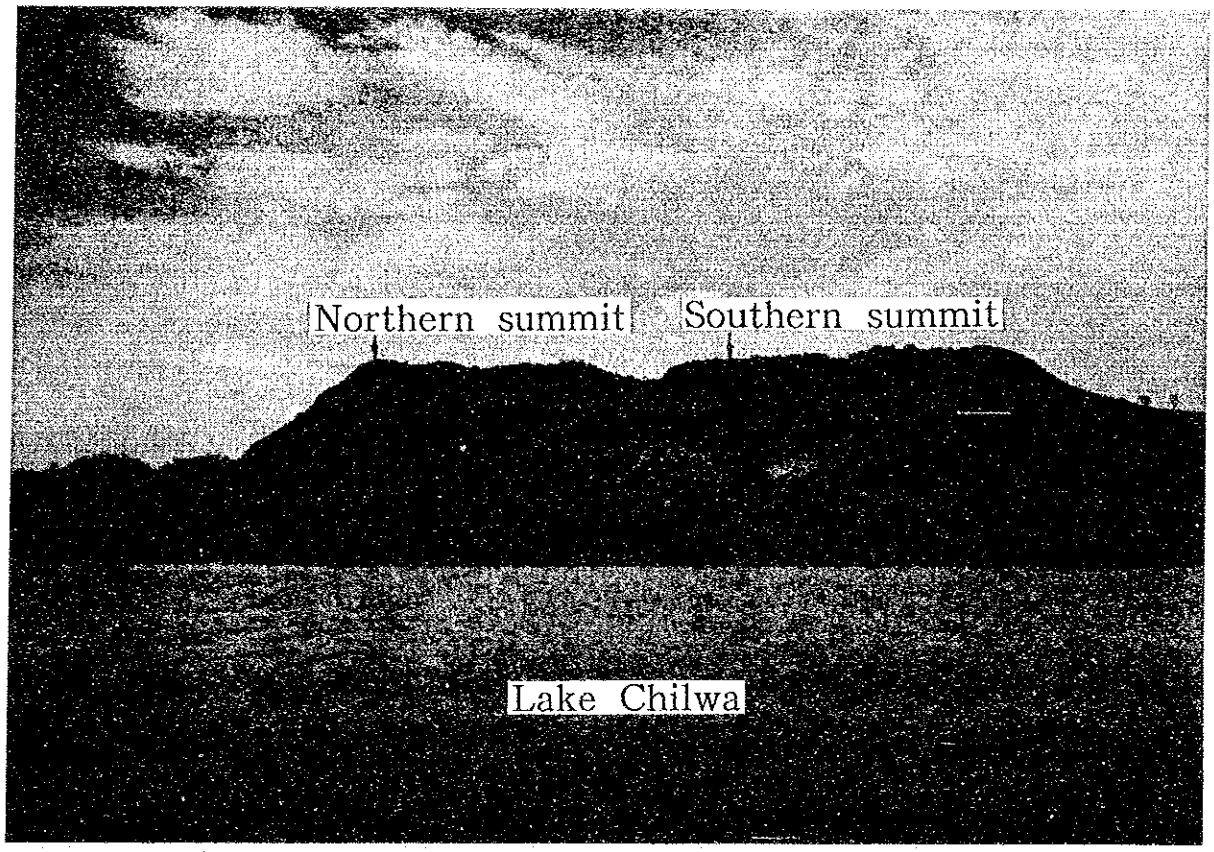
February, 1989

Kensuke Yanagiya

KENSUKE YANAGIYA
Presidente
Japan International Cooperation Agency

Junichiro Sato

JUNICHIRO SATO
Presidente
Metal Mining Agency of Japan



Chilwa carbonatite complex from the East (Lake Chilwa)

Contents

Part II Particulars

List of Figure

List of Tables

List of Appendices

List of Plates

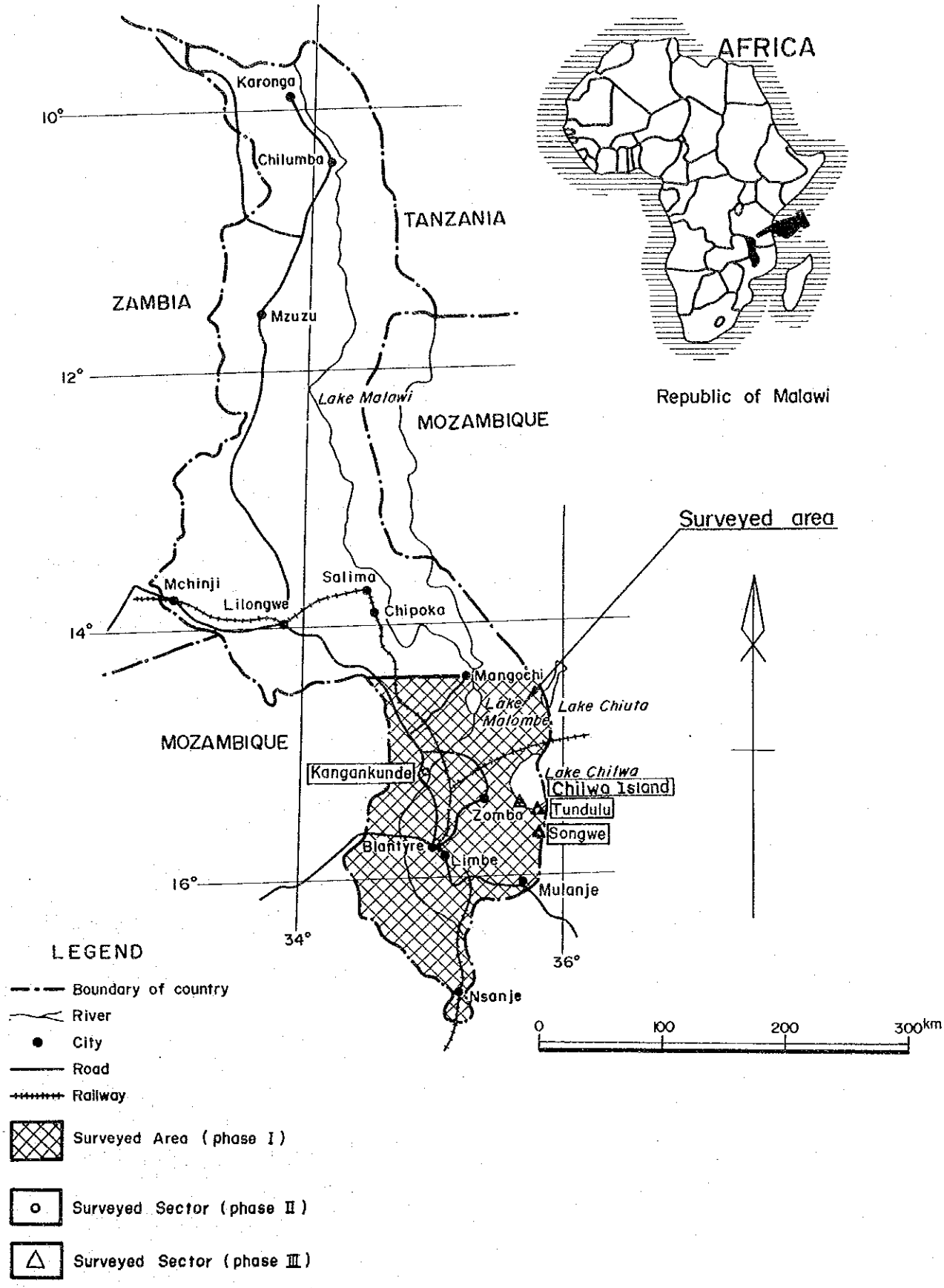


Fig. 1 Location map of survey area

SUMMARY

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

The aim of this phase survey is to elucidate the geological setting of carbonatites, its characteristics of mineralization and potential for economic resources using geological, geochemical and drilling data. The field survey was performed from June to November 1988.

Contents of the survey are as follows:

Sector	Geological and geochemical survey				Drilling survey		
	Area	Route survey	Trench survey	Geochemical samples	No. of drill holes	Hole length	Assay Samples
	Km^2	Km	m	pcs		m	pcs
Songwe	0	0	0	0	8	401.2	81
Tundulu	0	0	0	0	3	150.7	30
Chilwa Is.	6	20	600	151	32	1,606.4	322
Total	6	20	600	151	43	2,158.3	433

Outline of the survey results is as follows:

(1) Songwe sector

Carbonatites are developed mainly on Songwe Hill. A REE-mineralized zone, having total amount of such oxides analyzed here as La, Ce, Nd, Sm, Eu, Tb and Y more than 1.0%, is recognized on the northern slope of Songwe Hill (lower than 850m asl).

Useful minerals rich in REE in the mineralized zones are bastnaesite, synchysite and pyrochlore (total amount of REE oxides is shown as REO).

The ore reserve estimation has been made based upon the drilling survey. The result is that ore reserve is about 1.4 million tons and the grade of REO is 1.74%.

As the estimation of ore reserves is based on the assumption that mineralized zone extends 50m below the surface, it is impossible to compare the ore reserves of 1.4m million tons with those of other mines.

The contents of such medium REE as Eu and Tb are 1.4 and 2.1 times higher than those of Bayan Obo Mine, respectively.

It is inferred that, as the REO contents is not so high, it is not easy to exploit now. However, a REE-mineralized zone rich in medium REE has been recognized. Detailed survey shall be carried out, taking the market of medium REE into consideration, to define extent, reserve and grade of ore deposits in hitherto detected mineralized zones aiming at increasing the reserves.

(2) Tundulu sector

Carbonatites are mainly distributed in Tundulu and Nathace Hills.

REE-miniralized zone (REO 1.0%) and phosphorus-mineralized zones (having phosphorus content 2.2%, approximately 5% in P_2O_5 equivalent and the length over 2.0m) in carbonatite or apatite rock are recognized in Nathace Hill.

Useful REE-minerals in the mineralized zone are bastnaesite, synchysite and apatite.

The ore reserve estimation has been made based upon the drilling survey, which was performed in the mineralized zone to give the result that REE-ore reserve is about 0.6 million tons and the grade of REO is 2.09%. Phosphorus-ore reserve is about half a million tons and the grade of phosphorus (P_2O_5) is estimated to be 17.0%.

Although the estimation of surveyed areas is based on the assumption that mineralized zone extends 50m below the surface as in the case in Songwe sector, the grade of REO is not so high that it is not easy to make exploitation but the grade of phosphorus (P_2O_5) is estimated to be as high as 17.0%. It is inferred that the phosphorus resources of apatite rock in carbonatite can be useful for the production of fused magnesium phosphate by the aid of domestic resources of ultrabasic rocks or dolomitic rocks as well as electric power.

Further detailed drilling survey shall be carried out to define extent, reserve and grade of ore deposits in hitherto detected mineralized zones in carbonatites associating apatite rock at Nathace Hill.

(3) Chilwa Island sector

The carbonatite body shows distinct ring structure, having concentric arrangement, i.e., from outside to inside, are arranged sovitic carbonatite, ankeritic carbonatite and mixed rocks of ankeritic and sideritic carbonatites.

Useful REE-minerals in the area are bastnaesite, synchysite and strontianite and pyrochlore.

The result of geochemical survey suggests that ankeritic carbonatite and its mixed zone with sideritic carbonatite has higher anomaly for REE and sovitic carbonatite has higher anomaly for Nb and P.

As a result of drilling, a REE-mineralized zone has been recognized at a drill-hole where geochemical anomalous values were concentrated. As compared to the values of Bayan Obo Mine, REE contents are nearly the same or lower, and medium REE contents are the same or 1.9 times higher.

Based upon the results of geological, geochemical and drilling surveys, it is inferred that ankeritic carbonatite and its mixed zone with sideritic carbonatite have the highest potential for economic resources of REE rich in medium REE.

Up to now, the outline of REE-mineralized zones in carbonatites has been clarified, and REE-mineralized zone rich in medium REE has been recognized. Detailed geological and drilling surveys shall be carried out, as in the case of Songwe sector, to define extent, reserve and grade of ore deposits in hitherto detected mineralized zones aiming at increasing the reserves.

Part 1 General remarks

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 East African Rift Valley. It is underlain mainly by various rocks ranging from Precambrian to early Paleozoic ages and also by Quaternary rocks. Thus the potential for resources of rare metals and rare earth is expected to be high. Such useful minerals are expected to occur as bauxite, strontianite, pyrochlore, monazite, zircon, corundum, apatite and so on. However, up to date the production of mineral commodities is very low.

The Department of Geological Survey is responsible for the discovery of carbonatite deposits in Kangankunde, Chilwa Island etc. and the prospecting for coal in North Rukuru, Nthalire etc., through the compilation of map survey and continuous efforts on mineral exploration.

This survey of mineral resources in the Chilwa-Alkaline area (Fig. 1) 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 August 14, 1986.

During the first phase survey, an examination of previous works on the Chilwa-Alkaline area (30,000 km^2) and the LANDSAT image interpretation were made. Depending upon the results obtained, 25 sectors expected to have carbonatite mineralization were selected. Geological survey and geochemical prospecting were carried out in these 25 sectors (Fig. 2). It is concluded that four sectors of Tundulu, Songwe, Kangankunde and Chilwa Island are expected to have high potential for economic deposits of carbonatites.

During the second phase survey, geological survey and geochemical prospecting were caried out in the former three sectors among the above mentioned four. Drilling has been performed in the former two sectors.

1-2 Conclusion and recommendation of the first phase survey

1-2-1 Conclusion of the first phase survey

From the results of previous works, the LANDSAT image interpretation and geological survey and geochemical prospecting, 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 of carbonatite deposit:-

Nkalonje, Matoponi and Kapiri sectors

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

Mikomwa, Chipalanje, 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.

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

1-3 Conclusion and recommendation of the second phase survey

1-3-1 Conclusion of the second phase survey

(1) Tundulu Sector

Carbonatites are distributed in Tundulu, Nathace etc. Hills. Carbonatites in Tundulu Hill are mainly sovitic, 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.

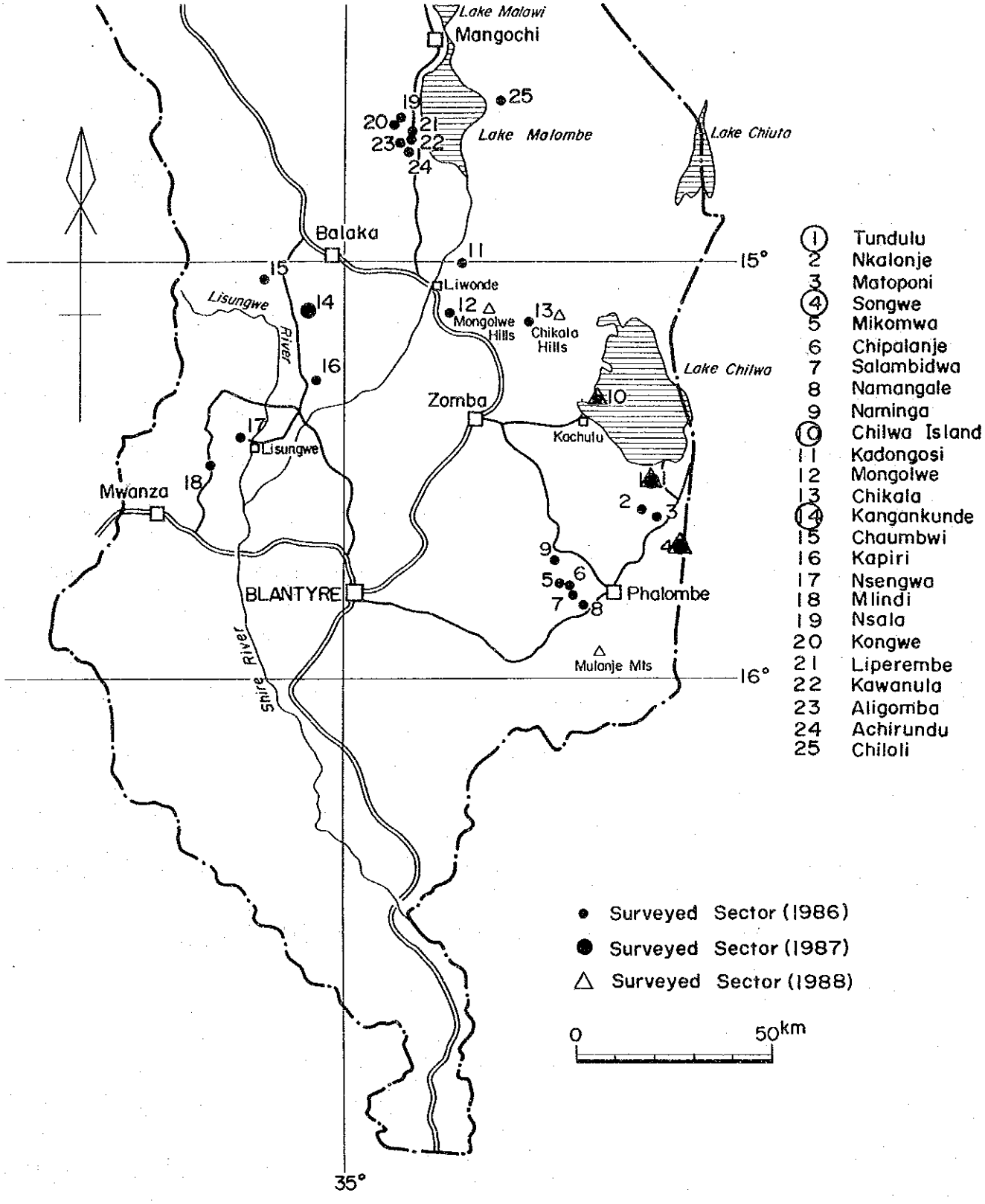


Fig. 2 Distribution of carbonatites of Chilwa Alkaline area

(2) Songwe Sector

Carbonatites are developed in Songwe Hill and are mainly of sovitic and ankeritic.

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

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

(3) Kangankunde Sector

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

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

1-3-2 Recommendation for the third phase survey

Integrated interpretation of the results of the second phase survey and 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 license for exclusive prospecting right in the sector.

1-4 Outline of the third phase survey

1-4-1 Area of the Survey

The Chilwa-Alkaline area is situated in the southern part of the Republic 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 surveyed area is 30,000 km^2 and occupies one-fourth of Malawi.

The following three sectors, on the map of Blantyre, were selected for the third phase survey.

1. Tundulu sector (south of Lake Chilwa)
2. Songwe sector (south of Lake Chilwa)
3. Chilwa Island (in Lake Chilwa)

1-4-2 Purpose of the Survey

The purpose of this phase survey was to elucidate the geological conditions of carbonatites in the Chilwa-Alkaline area and to understand the mineralization related to carbonatites.

In Songwe and Tundulu sectors, it was aimed to evaluate potential of REE and phosphorus resources.

In Chilwa Island sector, it was aimed to define extent of REE deposits in carbonatite body.

1-4-3 Method and area covered

During the third phase, geological, geochemical and drilling surveys were conducted.

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	Assay Samples
	Km^2	Km	m	pcs		m	pcs
Songwe	0	0	0	0	8	401.2	81
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Chilwa Is.	6	20	600	151	32	1,606.4	322
Total	6	20	600	151	43	2,158.3	433

1-4-4 Organization of the survey team

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

Coordinator and administrator

	Japan side	Malawi side
	Name	Name
(Phase III)	Toshihiko Hayashi (MMAJ) Kenji Sawada (MMAJ)	J.C. Chatupa (Geological Survey Department) A.T. Mndala (Geological Survey Department) F.R. Phiri (Geological Survey Department) R.S. Mshali (Geological Survey Department)

Field survey team

	Japan side	Malawi side
	Name	Name
(Phase III)	Tsuyoshi Yamada (MINDECO) Leader, Geology and Geochemi. Tsutomu Aoyama (MINDECO) Drilling Yukio Chiba (MINDECO) Drilling Shinji Tanaka (MINDECO) Drilling	D.H.Z. Mhango (Geological Survey Department)

MITI : Ministry of International Trade and Industry
JICA : Japan International Cooperation Agency
MMAJ : Metal Mining Agency of Japan
MINDECO : Mitsui Mineral Development Engneering Co., Ltd.

1-4-5 Period of the survey

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

Tab. 2 Process of the survey

	1988							1989		
	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Geological and geochemical survey	19					13				
Drilling survey	20					13				
Data analysis, laboratory works and report making						14			20	

Chapter 2 Physical features of the survey area

2-1 Landforms and drainage

The Chilwa-Alkaline area occupies nearly the whole Southern Region and some of adjoining Central Region of Malawi.

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

The central and western parts of the surveyed area are occupied, from east to west, by highlands of Zomba and Blantyre etc., by valley running along Shire River and by Kirk Range.

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 the Shire River and creeks streaming into Lake Chilwa is meandering and dendritic.

Tundulu and Songwe sectors of the survey areas of the third phase are situated in Phalombe Plain and are mountainous areas having 200m-300m elevation. Chilwa Island sector is located in Lake Chilwa. It is rather steep having 400-500m elevation above the surface of the lake.

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 temperatue is 17°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 of October and goes down to 10°C in night time of July to August.

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

In lowland area around Lake Chilwa, 'Marsh', a kind of aquatic plant,

grows thick. Mountainous areas of Mulange and Zomba are covered by such afforested needle as pine and cedar etc,.

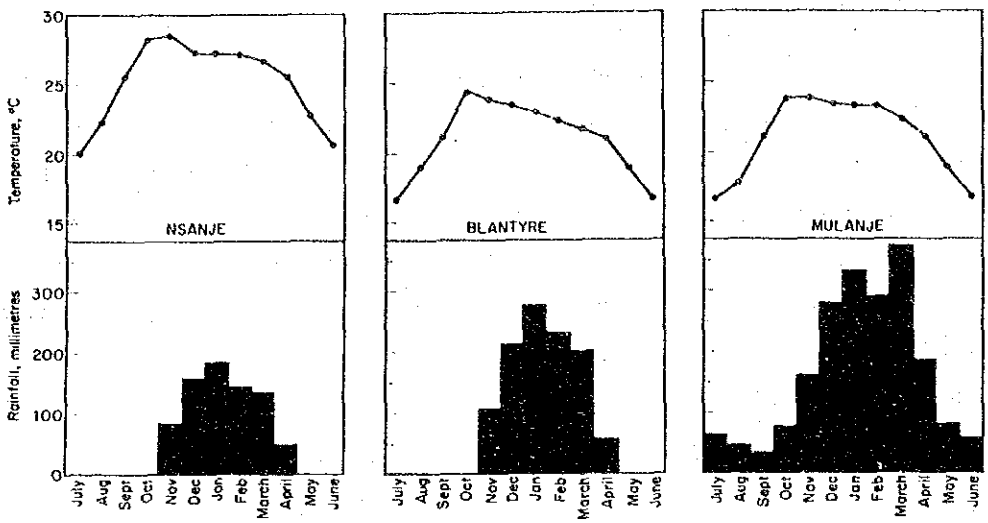


Fig. 3 Temperature and rain fall

Chapter 3 Outline of geology

3-1 General geology of Chilwa-Alkaline Area

Most of Malawi is underlain by late Precambrian to early Paleozoic metamorphic basement, which is a part of Mozambique Belt. The metamorphic rocks are known as the Malawi basement complex.

In the southern Malawi, the basement complex is 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, such alkaline rocks as carbonatites, agglomerate, alkaline dykes, nepheline syenite and syenite etc. were active. These intrusive rocks constitute "Chilwa-Alkaline Province" and form volcanic necks, dykes and small intrusive bodies.

Carbonatite bodies in Tundulu, Songwe and Chilwa Island sectors which are in the survey areas of the present phase belong to "Chilwa-Alkaline Province".

Geology younger than Tertiary period is characterized by the development of conglomerate and mudstone along Shire River and of sand and mud in the lowland area.

Although there are no metal mines now under exploitation in Malawi, some ore deposits of bauxite and alluvial gold as well as REE resources in carbonatite are known in the area (Fig. 4).

3-2 General geology of each sector

3-2-1 Songwe Sector

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

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

Carbonatite comprises mainly of sovitic and ankeritic ones with lesser

amount of highly-manganese one. Bastnaesite, synchysite, monazite, pyrochlore, parisite and apatite are found in the carbonatite.

3-2-2 Tundulu Sector

This sector is underlain by late Precambrian to early Paleozoic basement rocks of gneisses and syenites and by alkaline rocks and carbonatite of the "Chilwa-Alkaline Province". Igneous rocks of "Chilwa-Alkaline Province" are composed mainly of nepheline syenite, phonolite, agglomerate, feldspathic breccia and carbonatite.

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

3-2-3 Chilwa Island sector

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

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

Carbonatite are arranged concentrically and change from sovitic through ankeritic to sideritic inward. Useful minerals are bastnaesite, strontianite, synchysite, pyrochlore, apatite and fluorite.

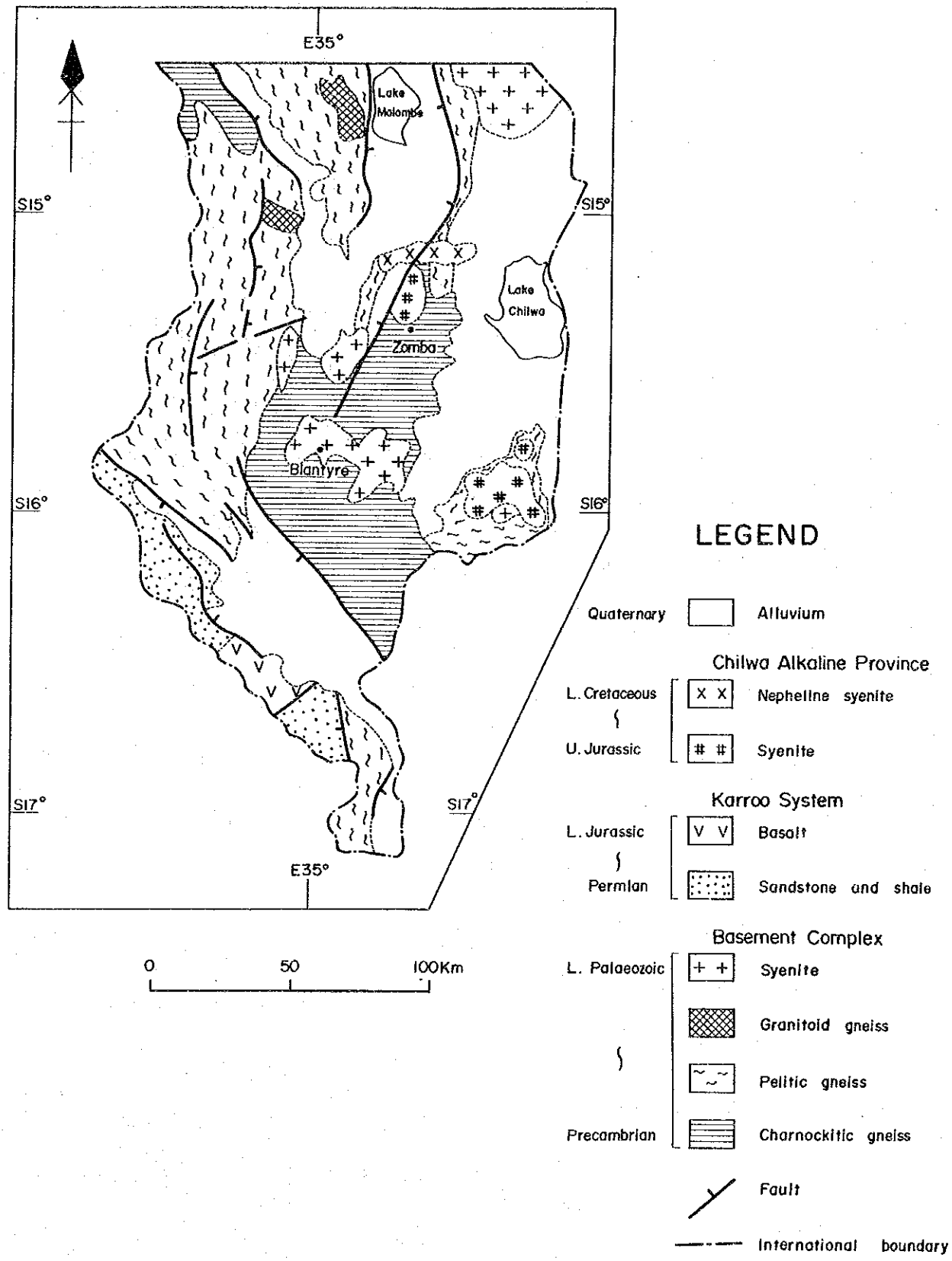


Fig. 4 Geological map of Chilwa Alkaline area

Chapter 4 Comprehensive discussion

4-1 Songwe Sector

By the previous phases survey, it is concluded that the carbonatite body on the northern slope of the Songwe Hill (lower than 850 m asl) has the highest potential for economic resources.

Drilling survey has been conducted to the body mentioned above to aim at confirming the dimensions and grades of ore deposits in carbonatite. Based upon the results of drilling, REE-mineralized zones in carbonatite and breccia are recognized at JMS-13, 14, 15, 16 18 and 19.

A preliminary estimation of ore reserve has been made for the mineralized zones assuming the following:

cutoff grade; REO more than 1.0% (REO represents total amount of 7 oxides of La, Ce, Nd, Sm, Eu, Tb and Y)

thickness; arithmetic mean of zones which are assumed to extend more than 10m

area; area of carbonatite cropped out on the surface and limitation is mainly 25m from bore holes,

density of ore; 3.0 (calcite; 2.7, ankerite; 3.0-3.1, siderite; 3.7-3.9 and taking the porosity into consideration)

The estimation discriminates six ore bodies in the present sector.

The following is a list of dimension, ore reserve and grade of each body.

Calculation of ore reserves (REO), Songwe

Block No.	J M S	Area (m^2)	Average Hight (m)	Ore Reserves (t)	Grade (ppm)			
					REO	Sm	Eu	Tb
1	1	1400	16.4	68,880	12,164	265.3	66.6	28.8
2	19	760	12.0	27,360	14,140	353.1	93.4	25.9
3	18	720	15.6	33,700	10,902	217.3	60.8	13.9
4	2	2250	49.6	334,800	30,691	529.5	114.6	31.1
5	5,13,14,15,16	9400	28.3	798,060	13,174	373.5	95.8	34.2
6	4, 10	2350	14.6	102,930	13,620	276.1	73.4	23.7
Total				1,365,730	17,414	394.6	96.3	35.4
Bayan Obo (China)				——	20,000	567	67	17

As the estimation is based on the assumption that mineralized zone extends 50m beneath the surface, it is impossible to compare the ore reserve with those of other mines.

Ore bodies in the area are 0.7, 1.4 and 2.1 times higher in Sm, Eu and Tb than those from Bayan Obo Mine (China) which produces bastnaesite.

4-2 Tundulu sector

By the previous phases survey, it is inferred that bodies of carbonatite and apatite rocks of Nathace Hill has the highest potential for economic resources of REE and phosphorus.

Drilling survey has been conducted to these bodies mentioned above to aim at confirming the dimensions and grades of ore deposits of REE and phosphorus. Based upon the results of drilling, REE- or phosphorus-mineralized zones in carbonatite or apatite rock are recognized at JMT-25, 26 and 27.

A preliminary estimation of ore reserve has been made for the REE mineralized zones.

The following is a list of dimension, ore reserve and grade of each REE-mineralized body.

Caluclation of ore reserves (REO), Tundulu

Block No.	JMT	(m^2) Area	(m) Average Hight	Ore (t) Reserves	Grade (ppm)			
					REO	Sm	Eu	Tb
R1	14, 22, 26, 27	5,480	26.4	434,020	22,414	272.5	53.8	16.9
R2	25	1,760	25.4	134,110	11,912	256.4	88.4	29.9
R3	17	1,880	10.3	58,090	30,187	336.5	49.0	5.2
Total				626,220	20,886	275.0	60.8	16.6
Bayan Obo (China)				——	20,000	567	67	17

In comparison with those from Bayan Obo Mine (China), the grade of Sm in ore bodies of Nathace Hill in Tundulu sector is about half times and of

Eu and Tb is nearly the same.

A preliminary estimation of ore reserve has been made for the phosphorus-mineralized zones assuming the following:

Cutoff grade; P more than 2.2%

Thickness; arithmetic mean of zones which are assumed to extend more than 10m

area; area of apatite rock cropped our on the surface

density of ore; 3.0 (REO; 3.0, apatite; 3.1)

The following is a list of dimension, ore reserve and grade of a phosphorus-mineralized body.

Culaulation of ore reserves (P), Tundulu

Block No.	JMT	(m^2) Area	(m) Average Hight	(t) Ore Reserves	Grade (%)		
					P	P_2O_5	REO
P1	7, 25, 26, 27	5,560	28.6	477,050	7.4	17.0	1.1

The grade of phosphorus (P_2O_5) is estimated to be 17.0%. The value is higher than those of ores from Araxa Mine (Brazil) and Sukulu Mine (Uganda), which are 15.0% and 13.0%, respectively.

Carbon and oxygen isotopic ratios are analyzed for carbonatite and apatite rock from Nathace Hill in order to elucidate the petrogenesis of these rocks.

Analyzed results for apatite rock and sideritic carbonatite are $\delta^{13}C$=-7.4‰ to -5.4‰ and $\delta^{18}O$=+5.4‰ to +8.7‰, which suggest that these rocks are igneous in origin. The result for carbonatite composed of kutnahorite and calcite, which is called sideritic carbonatite in the field, is $\delta^{13}C$=5.0‰ to -2.3‰ and $\delta^{18}O$=+20.7‰ to +22.0‰. Thus the rock is inferred to have undergone alteration through contaminated by meteoric water.

4-3 Chilwa Island sector

4-3-1 Geological structure and characteristics of mineralization

In this sector igneous rocks of "Chilwa-Alkaline Province" associated with carbonatite are developed throughout the island. Carbonatite is from the top of half-ring structure to the inner lowland. The carbonatite body shows distinct zonal arrangement, i.e., from outside to inside, are arranged breccia, sovitic carbonatite, ankeritic carbonatite and mixed rocks of ankeritic and sideritic carbonatites. The diameter of the body is about 2 km.

Ore minerals rich in REE etc. are pyrochlore, synchysite, strontianite, apatite and fluorite. REE minerals are common in ankeritic and sideritic carbonatites, while apatite and pyrochlore are in sovitic carbonatite.

Carbon and oxygen isotopic ratios are analyzed for carbonatite in order to elucidate the petrogenesis. Analyzed results for sovitic and ankeritic carbonatites are $\delta^{13}C$=-4.5‰ to -2.4‰ and $\delta^{18}O$=+8.2‰ to +12.1‰, which suggest that these rocks are igneous in origin. The result for sideritic carbonatite is $\delta^{13}C$=-6.6‰ to -6.7‰ and $\delta^{18}O$=+18.3‰ to +20.3‰. Thus the rock is inferred to have undergone secondary alteration.

4-3-2 Potential for economic deposit in carbonatite

Based upon the results of drilling of the third phase, REE-mineralized zones with more than 1.0% REO are recognized at 14 holes out of 32 holes. Among the 14 holes, thickness more than 10m are obtained from JMC-3, 10, 11, 12, 19, 20, 21, 26 and 29. Mineralized core samples from these holes are ankeritic carbonatite or its mixed zone with sideritic carbonatite.

Core from JMC-12 is the thickest, in which the mineralized zone is associated with ankeritic carbonatite, having 1.48% REO.

4-3-3 Geochemical anomaly

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

The area rich in REE is consistent to the site of drill holes where mineralized zones are recognized. The area indicating the anomalous value of Nb and P is in sovitic carbonatite field.

Chapter 5 Conclusion and recommendation for the future

5-1 Conclusion

During the third phase, drilling survey have been done in Songwe and Tundulu sectors, geological, geochemical and drilling surveys in Chilwa Island sector.

The following are the results of the surveys.

(1) Songwe sector

1. Carbonatites in this sector are classified into sovitic, ankeritic and breccias.

2. Useful minerals enriched in REE, Nb, Sr and P are bastnaesite, synchysite, parisite, strontianite, monazite, pyrochlore and apatite.

3. Carbonatites are developed showing an elliptical structure centering Songwe Hill, lining up in two files of N-S trend. Dip is as steep as 70° to vertical.

4. A REE-mineralized zone rich in medium REE is recognized on the northern slope of Songwe Hill (lower than 850m asl).

5. Based upon the results of drilling, six REE-mineralized zones, which are more than 10m thick in core showing the grade of REO more than 1.0%, are discriminated. The ore reserve estimation has been made based upon the assumption that mineralized zone extends 50m beneath the surface. The results are that the ore reserves are about 1.4 million tons and the grade of REO is 1.7%.

6. REE content of the mineralized zones indicate that the averaged values of such medium REE as Eu and Tb are 1.4 to 2 times higher than those of ores from Bayan Obo Mine (China).

From the results of the surveys, it is inferred that mineralized zones with comparatively high contents in medium REE are recognized on the northern slope of Songwe Hill.

As the underground extent of ore deposits has not yet been defined, it is impossible to compare the ore reserves with those of other mines.

As compared with the grade of ores from Bayan Obo Mine, REO content is

rather lower, but the content of medium REE is higher.

It is inferred that, of course depending on the market condition of REE, this sector is possible to be exploited.

(2) Tundulu sector

1. Carbonatites in this sector are classified into sovitic, ankeritic, sideritic, apatite rock and breccias.

2. Useful minerals enriched in REE, Nb, Sr and P are bastnaesite, synchysite, strontianite, pyrochlore and apatite.

3. Carbonatites are developed showing superposed double ring structure centering Nathace Hill. The outer ring is composed of sovitic, and the inner one of ankeritic, sideritic and apatite rock.

4. REE- or phosphorus-mineralized zones in carbonatite or apatite rock are recognized in the inner ring at Nathace Hill.

5. Based upon the results of drilling, three REE-mineralized zones, which are more than 10m thick in core showing the grade of REO more than 1.0%, are discriminated. One phosphorus-mineralized zone is recognized, which is more than 10m thick in core showing more than 2.2% P content.

6. The ore reserve estimation has been made based upon the assumption that mineralized zone extends 50m beneath the surface. The results are that REE-ore reserve is about 0.6 million tons and the grade of REO is 1.7%. Phosphorus-ore reserve is about half a million tons and the grade of phosphorus (P_2O_5) is estimated to be 17.0%.

From the results of the surveys, it is inferred that mineralized zones of carbonatites with comparatively high contents in REE and phosphorus are recognized on the eastern and southern slope of Nathace Hill. Carbonatites associating apatite rock is highly enriched in phosphorus.

Because REE minerals are closely associated with phosphorus minerals and the grades of REO as well as medium REE are not so high as compared with those of other mines, it is not advantageous to make exploitation now.

The grade of phosphorus (P_2O_5) is estimated to be as high as 17.0%. It is inferred that the phosphorus resources can be useful for the production of fused magnesium phosphate by the aid of domestic resources of ultrabasic rocks or dolomitic rocks as well as electric power.

(3) Chilwa Island sector

Geological survey

Carbonatites are developed on and around the top of the Island from Mbirikwi, Michulu and Chinyobi Hills through Northern and Southern summits to Mulinde Hill.

The carbonatite body occurs in a ring structure of 2km diameter, showing distinct zonal arrangement, i.e., from outside to inside, are arranged sovitic carbonatite, ankeritic carbonatite and its mixed rocks with sideritic carbonatite.

Useful minerals enriched in REE, Nb, Sr and P are pyrochlore, synchysite, strontianite, apatite and fluorite.

Geochemical survey

It is concluded that the central part occupied by ankeritic carbonatite and its mixed zone with sideritic carbonatite have higher anomaly for REE and Sr, while outer part occupied by sovitic and ankeritic carbonatites have higher anomaly for Nb and P, respectively.

Drilling survey

In Chilwa Island sector, REE-mineralized zones having more than 1.0% of REO are recognized at JMC-3, 7, 10, 11, 12, 14, 19, 20, 21, 22, 25, 26, 28 and 29. Among them, at JMC-3, 10, 11, 12, 19, 20, 21, 26 and 29, the thickness of mineralized zones are over ten meters.

These mineralized zones are usually found in ankeritic and its mixed zone with sideritic carbonatites.

The largest-scaled mineralized zone is recognized in ankeritic carbonatite at JMC-12, which is 48.0m thick in core having the REO grade of 1.48%.

From the results of the surveys, it is inferred that the central and the adjoining ankeritic carbonatite or its mixed zone with sideritic

carbonatite have the highest potential for REE resources, especially for medium REE. While, the outer part occupied by sovitic carbonatite have the highest potential for P- and Sr- resources.

5-2 Recommendation for the future

Integrated interpretation of the results of the third phase survey and the previous works recommends the follows to evaluate potential of REE and phosphorous resources to estimate ore reserve and grade as well as expected profits in Songwe, Tundulu and Chilwa Island sectors.

(1) Songwe Sector

A REE-mineralized zone rich in medium REE has been recognized as deep as 50m beneath the surface.

Up to now, it is rather disadvantageous to exploit the sector as REE resources, but taking the higher content of medium REE into consideration detailed survey shall be carried out to define extent, reserve and grade of ore deposits in hitherto detected mineralized zones aiming at increasing the reserves for the future.

Based upon the results, the effect of exploitation shall be discussed on the view point of economy.

(2) Tundulu sector

REE- or phosphorus-mineralized zones in carbonatite or apatite rock are recognized at Nathace Hill.

The estimated grade of phosphorus (17% in P_2O_5 equivalent) is high enough to be exploited for the production of fused magnesium phosphate.

Further detailed drilling survey shall be carried out to define extent, reserve and grade of ore deposits in hitherto detected mineralized zones with geochemical anomaly aiming at increasing the reserves.

Based upon the results, the effect of exploitation shall be discussed on the view point of economy.

(3) Chilwa Island sector

Through the third phase survey, it is recognized that ankeritic carbonatite or its mixed zone with sideritic carbonatite have the highest potential for medium REE-economic resources.

Detailed geological and drilling surveys in the same way as Songwe sector shall be carried out to define extent and grade of ore deposits in the detected mineralized zones for the future.

Part II Particulars

Chapter 1 Songwe sector

1-1 Method of the survey

During the third phase, geological 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.

Geological survey was carried out by the enlarged maps as well as by route maps of 1/2,000 in scale drafted in the second phase. Results were drafted on the geological map of 1/2,000 in scale.

Drilling survey was performed using 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 mineralized zones were collected for chemical analysis to determine REE contents in order to evaluate potential of resources.

Contents of the survey are shown in Tab. 3.

Tab. 3 Contents of survey, Songwe

Geological and geochemical survey			Drilling survey	
Area	0	km^2	No. of holes	8
Route survey	0	km	Total length	401.2 m
Trench survey	0	m	Inclination	- 90°
Assay of geochemical samples	0	pcs	Assay of ore samples	81 pcs
Microscopic observation (Polished thin section)	4	pcs	Assay element:	
X-ray diffractive analysis	1	pc		
EPMA	1	pc	La, Ce, Nd, Sm, Eu, Tb, Nb, Sr,	
Whole rock analysis	0	pc	Y, P (10 elements)	
Isotope analysis	0	pc		

1-2 Geology (Fig. 5)

Constituent rocks of this sector are as follows:

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

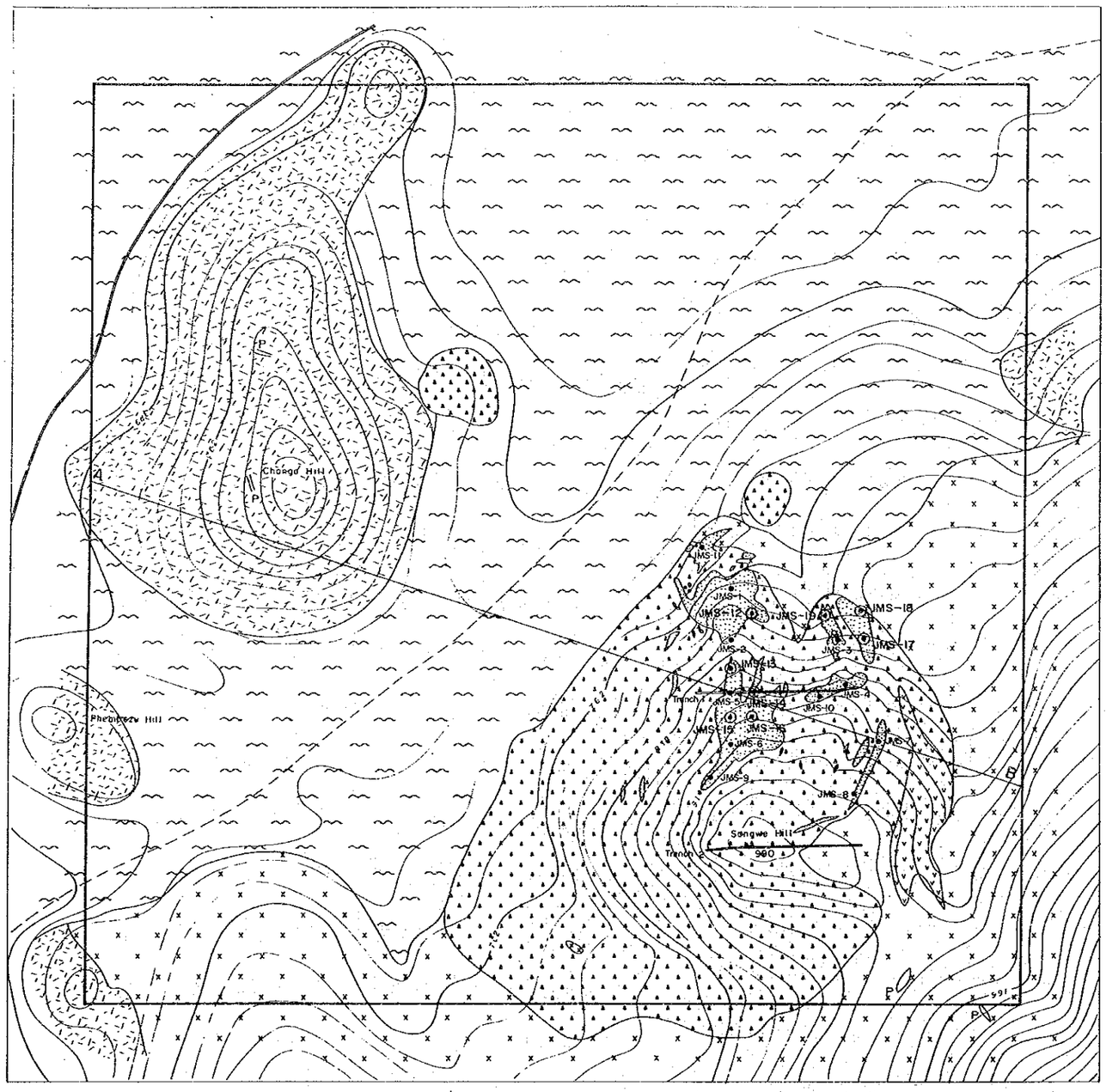
Late Precambrian to early Cambrian basement rocks of gneisses are distributed in the northwestern part (Chenga Hill) and the western part (Phempezu Hill). They are composed mainly of granitic and biotite gneisses.

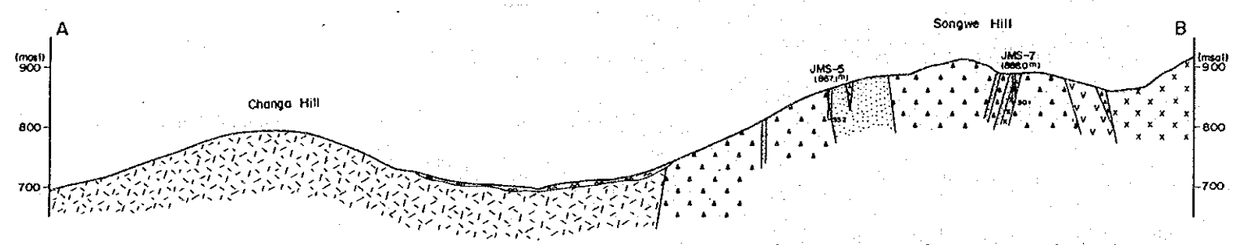
Igneous rocks of "Chilwa-Alkaline Province" are developed from the eastern part of Chenga Hill to Songwe Hill and to the south.

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.

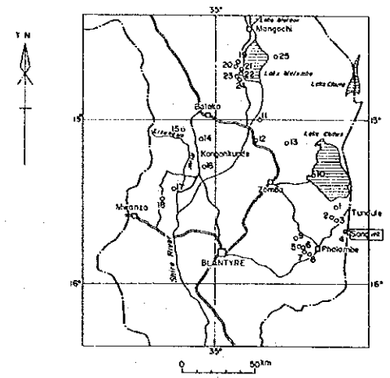
Carbonatites* in this sector are classified into calcitic (sovitic) and ankeritic. They are found in breccias on the northern slope of Songwe Hill, showing irregular, massive and dyke like shapes. The largest body is 350m (E-W) X 200m (N-S) in size.





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

GEOLOGICAL MAP AND PROFILE OF SONGWE SECTOR



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FEBRUARY 1988

0m 250m 500m

LEGEND

- Drift
- Carbonatite
- Agglomerate / feldspathic rock
- Calc-silicate rock
- Dyke P phonolite
- Nepheline syenite
- Gneiss
- Drilling site (1987)
- Drilling site (1988)
- Trench (1987)
- Profile line

Fig. 5 Geological map and profile of Songwe sector

Sovitic 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, bastnaesite, synchysite and pyrochlore.

Ankeritic carbonatite is dark brown to black colored and fine-grained rock. These carbonatites often contain manganese minerals and iron oxides. Syentysite, parisite, pyrochlore and apatite are recognized under the microscope.

In a carbonatite body, veins of fluorite and barite are recognized. Altered rocks are developed along the 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 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 is inferred to be a vent formed by igneous rocks associating carbonatites into nepheline syenite (Garson, 1965).

---

* Classification of carbonatite (by naked-eye)

sovitic carbonatite : white to gray colored, composed mainly of fine- to medium-grained calcite and violently resicating by the addition of dilute HCl (1:10)

ankeritic carbonatite: brown to dark brown colored, fine-grained, calcite-bearing

sideritic carbonatie : brown to dark, coarse-grained siderite occurs or leached

Comparison of results between of the naked-eye observation and of Laboratory analyses will be shown later.

1-3 Drilling survey

As a result of the first phase survey, Songwe sector has been selected as a sector with higher potential for economic resources in carbonatites. Through the second phase survey, geological geochemical and drilling surveys were conducted in this sector to conclude that REE mineralized zone exists in the carbonatite body on the northern slope of Songwe Hill (lower than 850m asl).

Drilling of the third phase survey was performed to define extent and grade of ore deposits.

1-3-1 Outline of drilling

Main apparatus and materials for drilling were transported from the Geological Survey Department in Zomba to Songwe, by the aid of trucks of four and eleven tons burden.

Extra sets of rigs and water pumps were transported to the survey area by sea (up to Singapore), by air (to Malawi) and by a lorry to the drilling camp.

Two set 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 naturally spouting pond to the camp by a midget truck.

Contents of the drilling are as follows:

No. of drill holes	Hole length	Core length	Core Recovery except soils	No. of analyzed samples
8	401.2m	360.3m	95%	81

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

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

Drilling covers 24 days, from June 30 to July 22.

1-3-2 Drilling procedure

Drilling rigs were transported from the Geological Survey Department in Zomba and extra rigs were from Lilongwe Airport, via Blantyre to Chenga in Songwe sector.

Setting up of rigs was firstly made at JMS-12. Drilling in Songwe sector was performed in the following order of site number, JMS-12, 13, 14, 15, 16, 17, 18 and 19. Location of drilling sites is shown in Fig. 6.

Transport routes of one meter wide were constructed from site to site, total length reached 1,700m. 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 1,000m.

Drilling through surface soil was performed using Metal shoe (73mm in diameter), and after reaching hard rock, diamond shoe (73mm in diameter) 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 performance of the drilling.

After completion of the operation in Songwe sector, drilling rigs were transported to Tundulu sector in 2 days time.

1-3-3 Geology and mineralization of drill holes

Drilling was performed, from outcrop at the surface to about 50m in depth, mainly aiming at clarifying mode of occurrence of useful minerals

rich in REE to evaluate the potential as carbonatite ore deposits.

Geology of each drill hole is shown in Fig. 7. Chemical compositions and REO of core samples are shown in Appendix 2.

REE-mineralized zones defined as having over 1.0% REE oxides content are listed in Tab. 4. In Tab. 5, 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.

In Songwe sector, REE-mineralized zones are recognized at JMS-13, 14, 15, 16, 17, 18 and 19.

Main constituent minerals in the zones are bastnaesite, synchysite and strontianite.

Among the holes drilled in the third phase, the following three holes have relatively large REE-mineralized zones. Namely, a zone is recognized at JMS-14 in manganese ankeritic carbonatite, 46.1m long between 0.6m and 46.7m. Its REO content is 1.26%. At JMS-16 manganese sovitic carbonatite is mineralized in 49.8m long between 0.3m and 50.1m, which is the bottom of the hole, and its REO content is 1.50%. At JMS-18, manganese carbonatite is mineralized in 49.6m long between 0.6m and 50.2m, which is the bottom of the hole, and its REO content is 3.07%. Near the surface of JMS-17, the zone extends in 7.0m long between 0m and 7.0m, and its REO and Eu contents are 3.45% and 204.5 ppm, respectively.

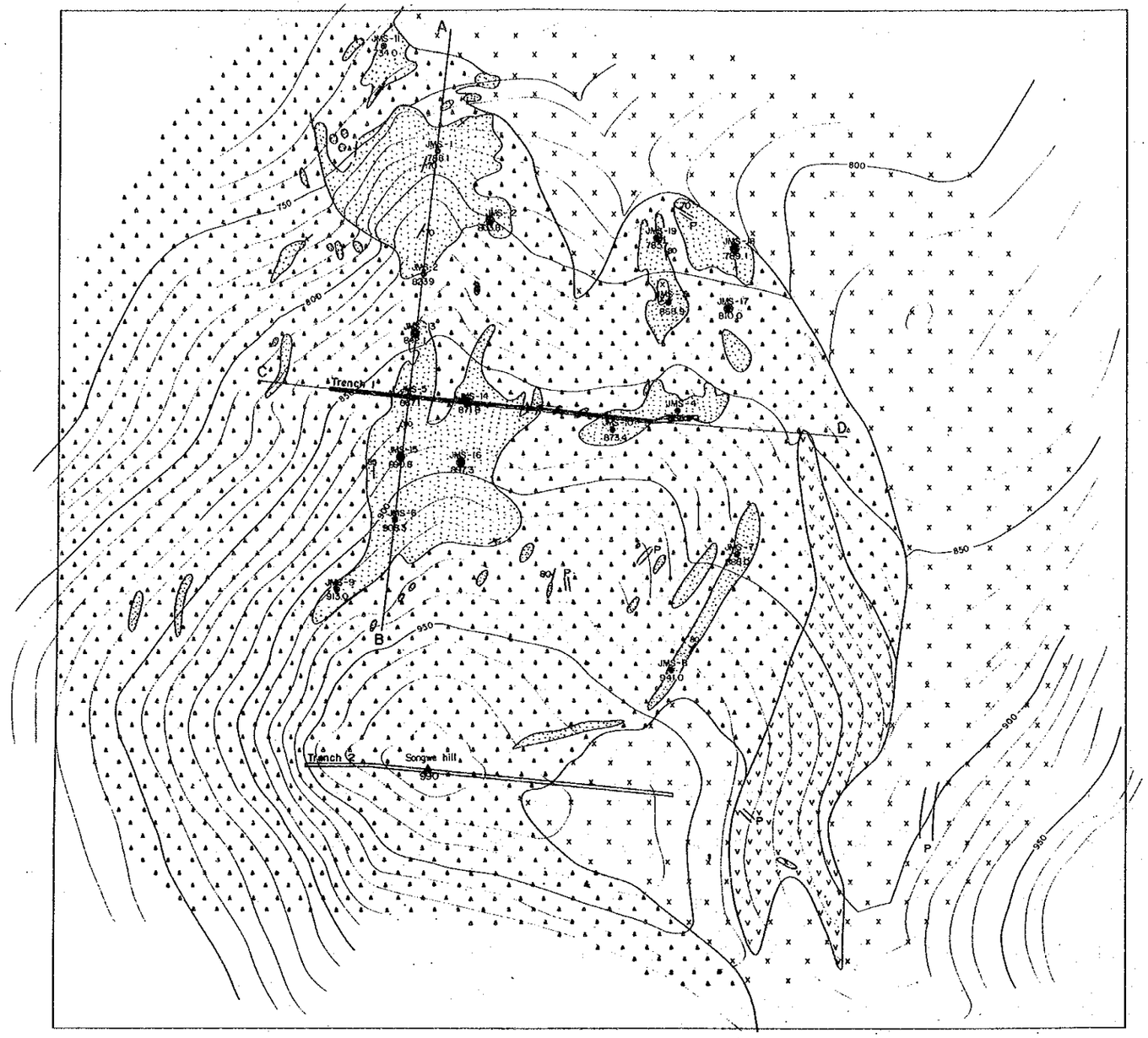
REE contents of these mineralized zones indicate that the averaged values of light REE are nearly equal or lower, and such medium REE as Eu and Tb are higher than those of ores from Bayan Obo Mine (China).

Phosphorus- mineralized zone is recognized at JMS-18. The core samples with continuous mineral indication are from 14.4m long zone between 35.8m and 50.2m. Its phosphorus content is 2.45% (approximately 5.6% in P_2O_5 equivalent). Phosphorus mineral is apatite.

1-4 Discussion

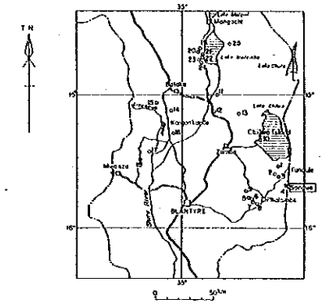
From the results of geological, geochemical and drilling surveys performed in Songwe sector through the first and second phases, the following facts have been clarified.

Carbonatites are developed showing an elliptical structure centering



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

DETAILED GEOLOGICAL MAP AND PROFILES OF SONGWE SECTOR



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FEBRUARY 1989

0m 100m 200m

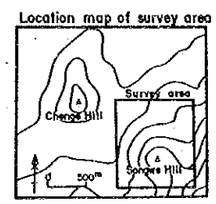
LEGEND

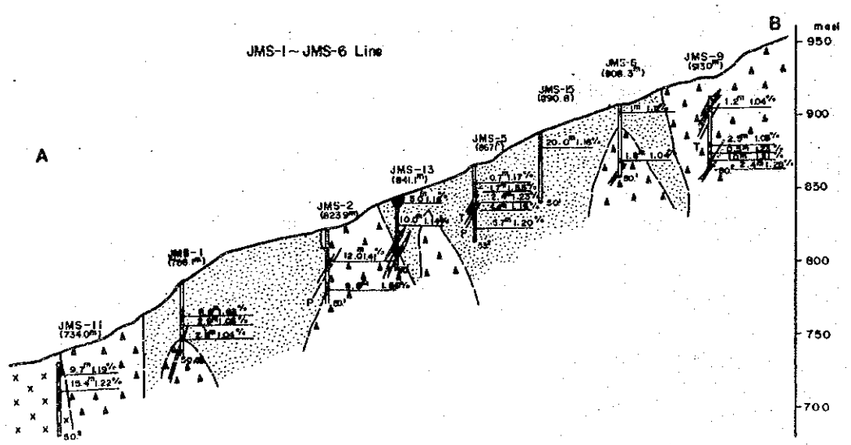
Chilwa Alkaline Complex

- Dyke — P : phonolite
- Carbonatite
- Agglomerate feldspathic rock
- Calc-silicate rock
- Nepheline syanite

- Drilling site (1987)
- Drilling site (1988)
- Thickness(m) REO% (La,Ce,Nd,Sm,Eu Tb,Y)
- 50.1 (Depth(m))
- Trench
- Profile line

Location map of survey area





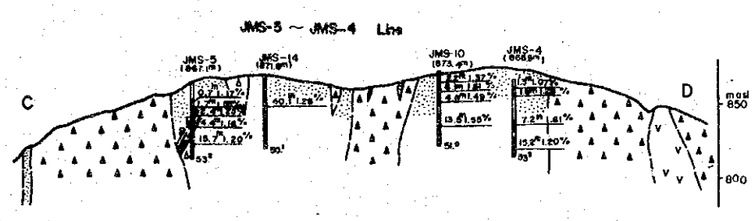


Fig. 8 Detailed geological map and profiles of Songwe sector

Songwe Hill. The elliptical structure is inferred to be a vent formed by the intrusion of carbonatites into the basement rocks. Carbonatites in the vent are mainly of sovitic and ankeritic.

Carbonatites are found in breccias as irregular and massive shaped bodies, main of which line up in two files with N-S trend. The largest body, situated in the western part of the two files, is 100m in width. Lineation of the carbonatite has rather random azimuth with a plunging angle ranging from 70° to 90° (Fig. 8).

REE-mineralized zones are recognized on the northern slope of Songwe Hill, lower than 850m asl, at JMS-4 and -10 etc,. REE contents of these mineralized zones indicate that the averaged values of such medium REE as Eu and Tb are higher than those of ores from Bayan Obo Mine (China). Ores from Bayan Obo Mine is considered to be more than 2 times higher in such middle REE as Sm and Eu than those from Mountain Pass Mine (U.S.A.) (Kishimoto, 1985).

Drilling survey has been conducted to the zones mentioned above to aim at confirming the dimensions and grades of ore deposits in carbonatite. Based upon the results of drilling as well as upon of the second phase survey, a preliminary estimation of ore reserve has been made for the mineralized zones assuming the following:

cutoff grade; REO more than 1.0% (REO repesents total amount of 7 oxides of La, Ce, Nd, Sm, Eu, Tb and Y)

thickness; arithmetic mean of zones which are assumed to extend more than 10m

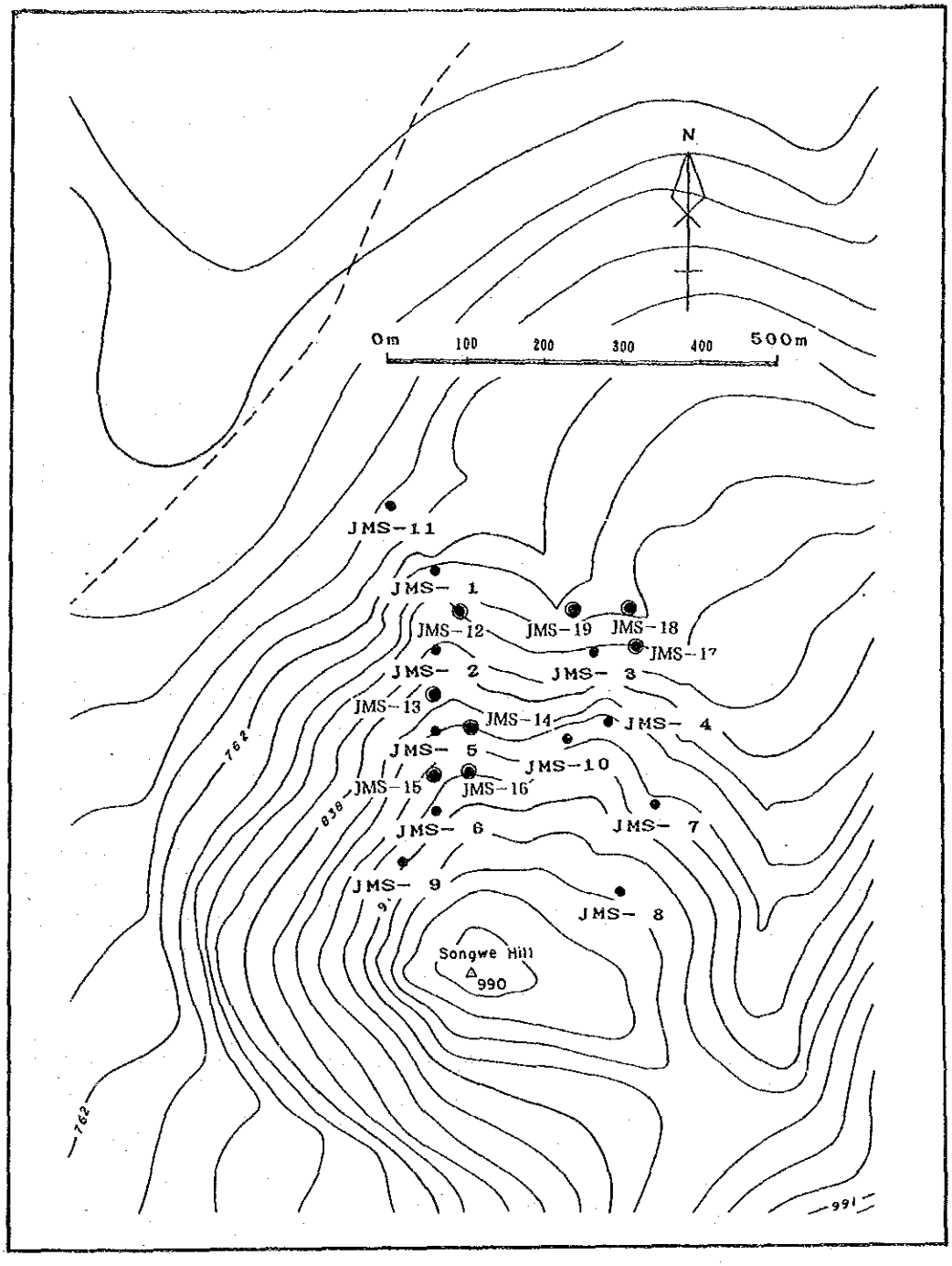
area; area of carbonatite cropped out on the surface and limitation is mainly 25m from bore holes

density of ore; 3.0 (calcite; 2.7, ankerite; 3.0-3.1, siderite; 3.7-3.9 and taking the porosity into consideration)

Based upon the results of estimation, six ore bodies were recognized in this sector. In table 6, are shown ore reserves and contents of REO, Sm, Eu and Tb for each body (Fig. 9).

As the estimation of ore reserves is based on the assumption that mineralized zone extends 50m below the surface, it is impossible to compare the ore reserves of 1.4 million tons with those of other mines.

REO content of 1.7% is rather lower as compared with that of Bayan Obo



LEGEND

• Drilling site (1987)

◉ Drilling site (1988)

Fig. 6 Location map of drilling sites, Songwe

Performance of the drilling, Songwe

Hole	Drilled length (m)	Core length (m)	Core recovery except soil(%)	Working period M.D. ~M.D.	Bit size φ 73㎜		Bit size φ 56㎜	
					Depth(m)	Performance of the drilling	Depth(m)	Performnce of the drilling
JMS-12	50.20	46.10	99.2	6. 30 ~ 7. 3	1.70	0~1.7m drilling with diamond shoe, Installation of BW casing pipe	46.10	Drilling with diamond bit, Using TK-60, 3.2m Escape of whole water
JMS-13	50.10	47.70	99.8	7. 3 ~ 7. 5	2.30	0~2.3m drilling with metal shoe, Installation of BW casing pipe	47.70	Drilling with diamond bit, Using TK-60, 11.5m Escape of whole water
JMS-14	50.10	48.00	97.0	7. 7 ~ 7. 9	0.60	0~0.6m drilling with metal shoe, 0.6~1.6m drilling with diamond shoe, Installation of BW casing pipe,	48.00	Drilling with diamond bit, Using TK-60, 25.0m Escape of whole water
JMS-15	50.10	49.70	99.2	7. 9 ~ 7. 12	1.50	0~1.5m drilling with metal shoe, Installation of BW casing pipe,	49.70	Drilling with diamonnd bit, Using TK-60, 19.8m Escape of whole water
JMS-16	50.10	49.50	99.4	7. 13 ~ 7. 14	1.80	0~1.8m drilling with diamond shoe, Installation of BW casing pipe	49.50	Drilling with diamond bit, Using TK-60, 11.9m Escape of whole water
JMS-17	50.10	28.40	86.6	7. 15 ~ 7. 17	17.30	0~17.3m drilling with metal shoe, Using TK-60, Installation of BW casing pipe	28.40	Drilling with diamond bit, Using TK-60, 15.3m Escape of whole water
JMS-18	50.20	42.70	86.1	7. 18 ~ 7. 20	1.50	0~0.6m drilling with metal shoe, 0.6~1.5m drilling with diamond shoe, Installation of BW casing pipe	42.70	Drilling with diamond, bit, Using TK-60, 4.5m Escape of whole water
JMS-19	50.30	48.20	99.8	7. 20 ~ 7. 22	2.60	0~2.0m drilling with metal shoe, 2.0~2.6m drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	48.20	Drilling with diamond bit, Using TK-60, 34.6m Escape of whole water

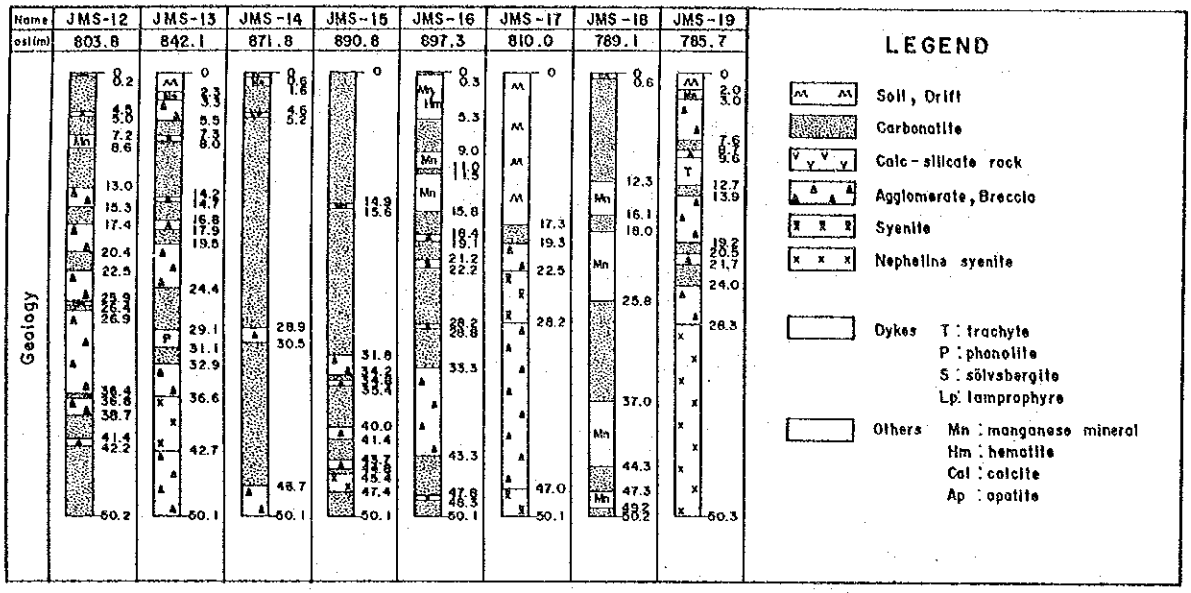


Fig. 7 Compiled geologic log, Songwe

Tab. 4 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-13	2.3 - 7.3	5.0	2440	4574	1715	298.90	74.30	16.40	1130.0	1988	496	7197.0	11560.2
	12.3 - 22.3	10.0	2302	4611	1726	330.50	81.90	24.40	1014.0	4098	399	4104.5	11386.3
JMS-14	0.6 - 46.7	46.1	2650	5122	1849	360.09	90.45	24.71	1671.2	2308	405	8116.7	12619.8
JMS-15	0.0 - 20.0	20.0	2068	4559	1989	352.65	93.20	27.18	1019.0	11071	593	12916.5	11645.1
JMS-16	0.3 - 50.1	49.8	3120	6056	2272	423.53	105.69	37.04	2235.0	5217	491	6663.9	15024.4
JMS-17	0.0 - 7.0	7.0	6958	13755	5002	865.50	204.50	77.70	5390.0	3039	1799	38023.0	34500.2
	17.3 - 19.3	2.0	2295	4642	1745	269.20	68.90	15.50	1417.0	25807	576	12902.0	11568.5
	35.7 - 40.7	5.0	2734	4176	1197	192.40	44.70	21.90	677.0	2599	201	5035.0	10286.2
JMS-18	0.6 - 50.2	49.6	8207	12493	3702	529.54	114.61	31.15	1407.5	22031	491	17837.0	30690.8
JMS-19	2.0 - 9.6	7.6	4619	7606	2532	376.92	82.28	19.54	1398.3	10278	368	4717.6	18733.5
	12.7 - 28.3	15.6	2747	4369	1326	217.32	60.78	13.88	780.6	2639	340	6738.9	10902.4
Bayan Obo (China)			2171	7166	5061	567	67	17	-	-	134		20000

Tab. 5 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-17	0.0 - 7.0	7.0	6958	13755	5002	865.50	204.50	77.70	5390.0	3039	1799	38023.0	34500.2
JMS-18	0.6 - 5.6	5.0	4663	8299	2935	413.60	101.90	30.50	3909.0	15394	623	31068.0	20507.2
	35.8 - 50.2	14.4	9252	14216	4267	622.23	132.43	41.98	1014.6	27263	586	24487.7	34953.4

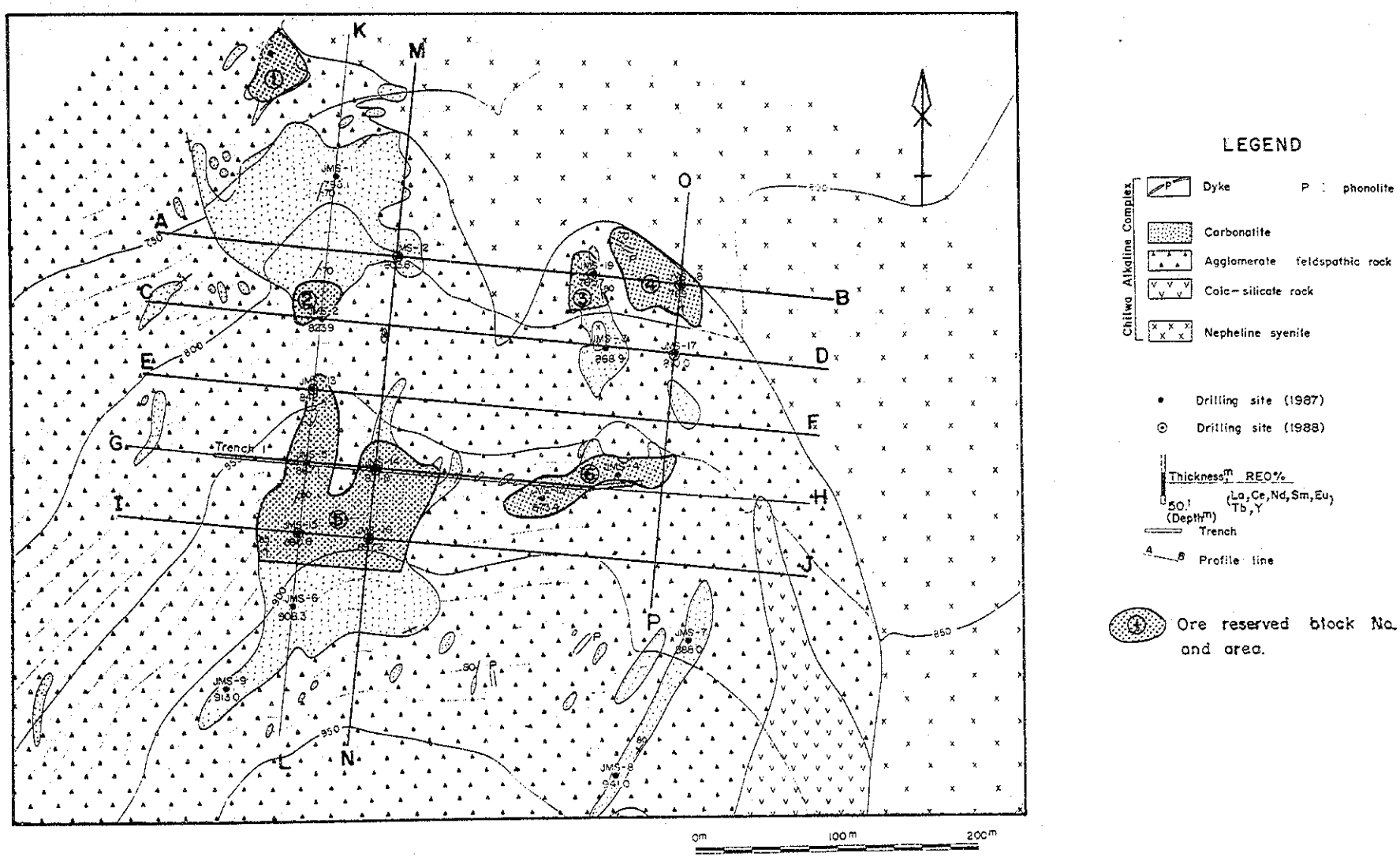


Fig. 9 - 1 Geological section of drill holes and map of ore reserves (REO), Songwe

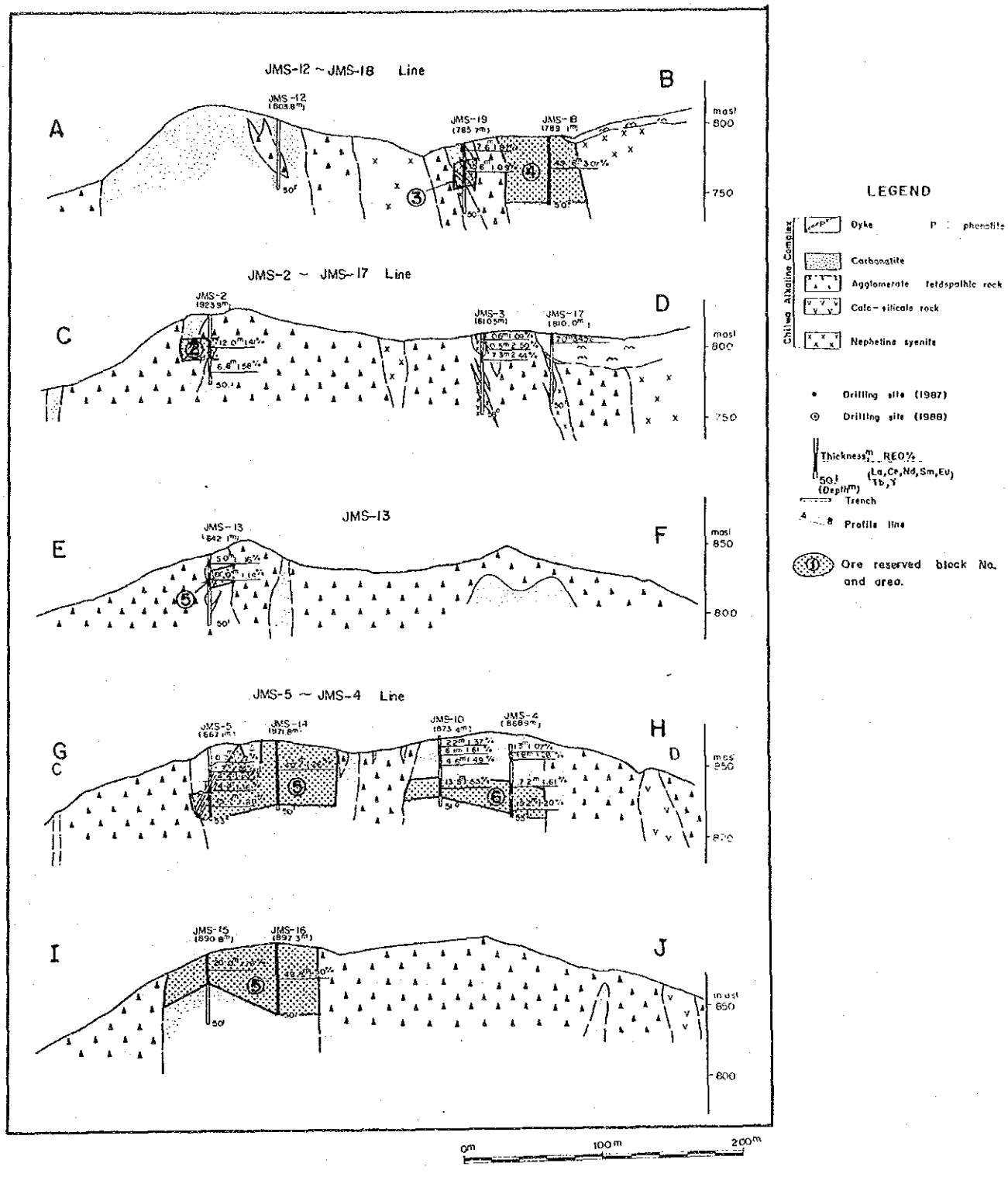


Fig. 9-2 Geological section of drill holes and map of ore reserves (REO), Songwe

-W·E section-

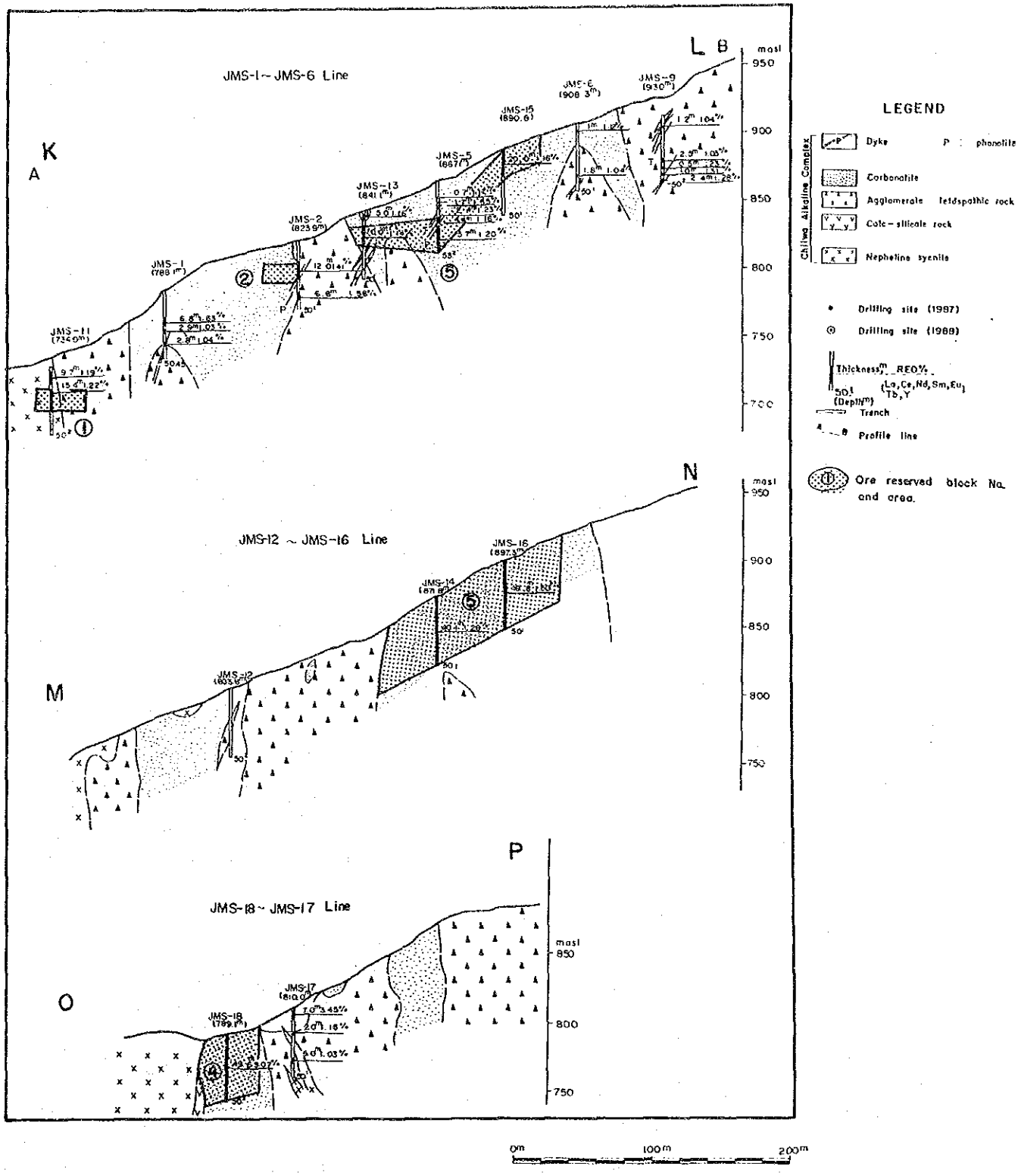


Fig. 9 - 3 Geological section of drill holes and map of ore reserves (REO), Songwe
- N·S section -

Mine, but the contents of such medium REE as Eu and Tb are 1.5 and 2 times higher than those of Bayan Obo Mine, respectively.

Tab. 6 Calculation of ore reserves (REO), Songwe

Block No.	J M S	Area (m^2)	Average Hight (m)	Ore Reserves (t)	Grade (ppm)			
					REO	Sm	Eu	Tb
1	1	1400	16.4	68,880	12,164	265.3	66.6	28.8
2	19	760	12.0	27,360	14,140	353.1	93.4	25.9
3	18	720	15.6	33,700	10,902	217.3	60.8	13.9
4	2	2250	49.6	334,800	30,691	529.5	114.6	31.1
5	5,13,14,15,16	9400	28.3	798,060	13,174	373.5	95.8	34.2
6	4, 10	2350	14.6	102,930	13,620	276.1	73.4	23.7
Total				1,365,730	17,414	394.6	96.3	35.4
Bayan Obo (China)				——	20,000	567	67	17

Chapter 2 Tundulu sector

2-1 Method of the survey

During the third phase, geological and drilling surveys have been done. Method of the survey is the same as that in Songwe sector described befoe (1-1).

Contents of the survey are shown in Tab. 7.

Tab. 7 Contents of survey, Tundulu

Geological and geochemical survey		Drilling servey	
Area	0 km^2	No. of holes	3
Route survey	0 km	Total length	150.7 m
Treach survey	0 m	Inclination	-90°
Assay of geochemical samples	0 pcs	Assay of ore samples	30 pcs
Microscopic observation (Polished thin section)	4 pcs	Assay element:	
X-ray diffractive analysis	6 pcs	La, Ce, Nd, Sm, Eu, Tb, Nb, Sr,	
EPMA	4 pcs	Y, P (10 elements)	
Whole rock analysis	5 pcs		
Isotope analysis	5 pcs		

2-2 Geology (Fig. 10)

Constituent rocks of this sector are as follows.

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa-Alkaline Province" Carbonatites (sovitic, ankeritic, and sideritic) Apatite rocks Breccias (agglomerate, feldspathic breccia) Altered rocks (carbonate-silicate rock) Nepheline syenite Dykes (phonolite, solvsbergite, 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 and granitic gneisses. 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 central part (Nathace Hill) through the eastern parts (Tundulu Hill) and the southern parts (the western slope of Chigwakwalu Hill 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 western 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 results of K-Ar age determination shows 132.4-136.2 Ma and suggests that the age of intrusion is in early Cretaceous (JICA and MMAJ, 1987).

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 fragments 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 sovitic, ankeritic and sideritic. Sovitic carbonatite is developed 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.

Sovite 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 igneous 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).

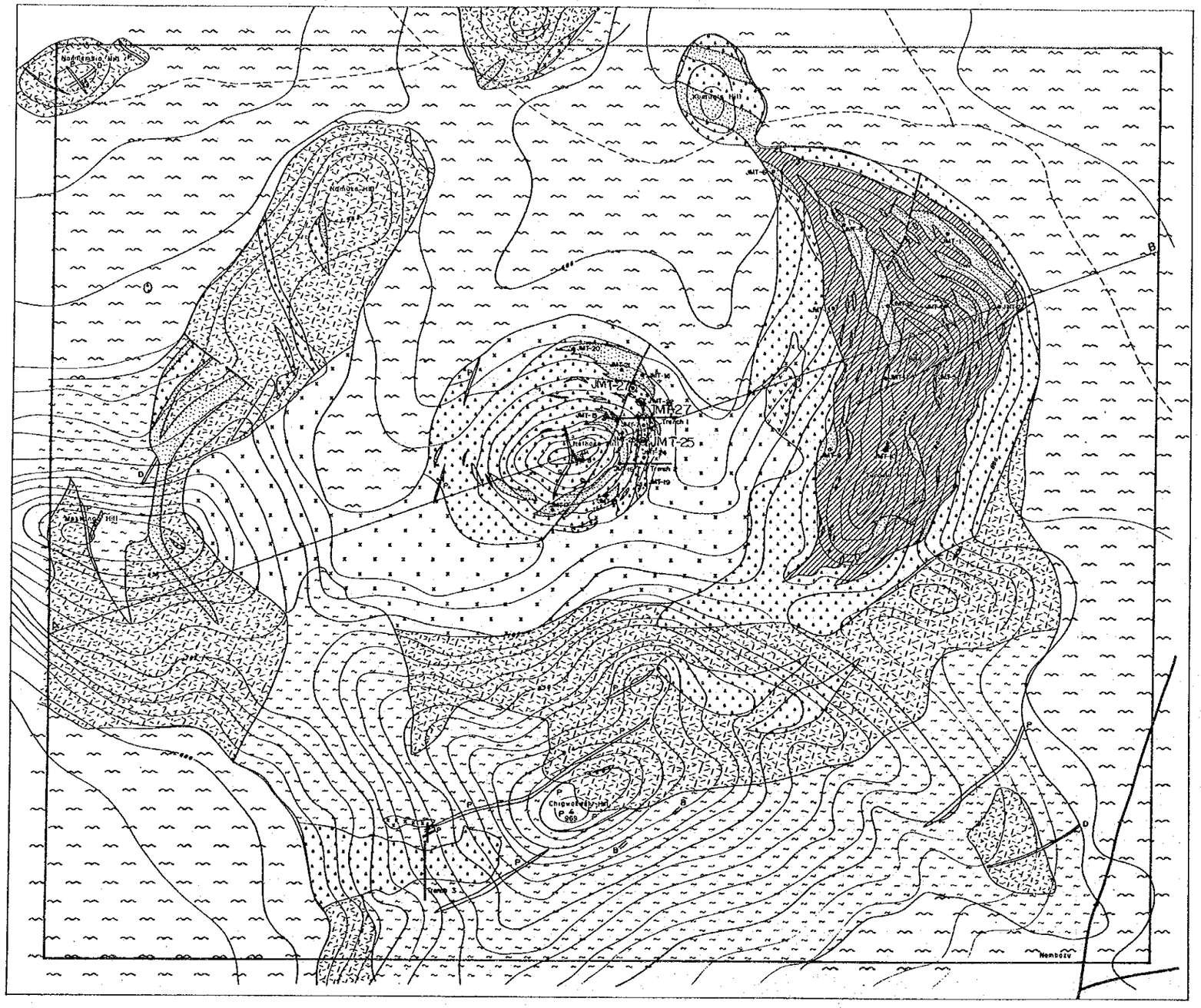
Dykes are phonolite, trachyte and solvsbergite. These alkaline dykes are several meters in width and are developed in the basement rocks area.

The geological structure of rocks of "Chilwa-Alkaline Province" is characterized by superposed ring structures of two phases. The first ring structure has a diameter of about 2,000m, 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.

Based upon the analysis of distribution pattern of stress, Garson (1962) has clarified that the first igneous activity occurred around 1,200-1,300m below the ground surface while the second activity around 2,400-3,000m and 500-700m below the surface.

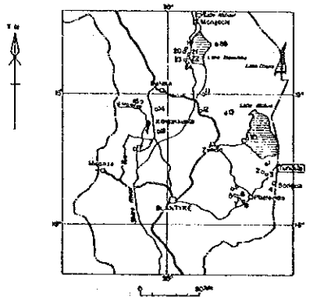
2-3 Drilling survey

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



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

GEOLOGICAL MAP AND PROFILE OF TUNDULU SECTOR



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
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 : sölvsbergite; T : trachyte; J : juvite; B : beforsite; D : dolerite
- Nepheline syanite
- Gneiss
- Syanite
- Fault
- Drilling site (1987) ⊙ Drilling site (1988)
- Trench (1987)
- A — B Profile line

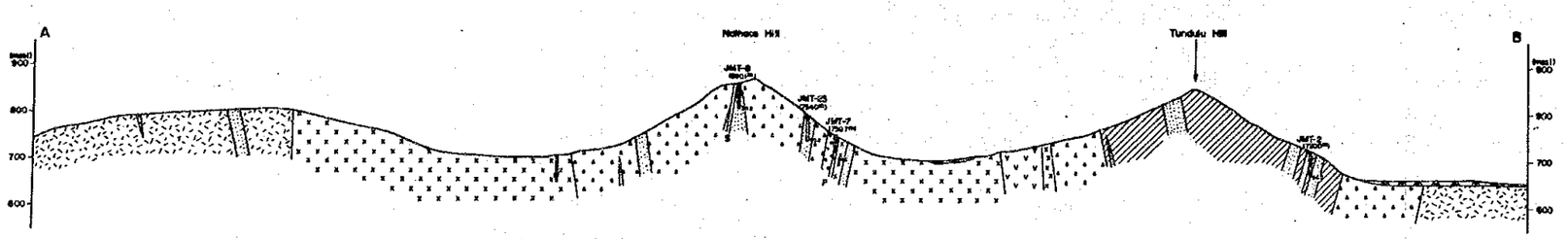


Fig. 10 Geological map and profile of Tundulu sector

drilling surveys were conducted in this sector to conclude that REE- and phosphorus-mineralized zones exist in the carbonatite body on the eastern half of Nathace Hill.

Drilling of the third phase survey was performed to define extent and grade of ore deposits.

2-3-1 Outline of drilling

Whole sets of drilling rigs are transported to the survey from Songwe sector. Operations were performed in the same way as in Songwe sector.

Contents of the drilling are as follows:

No. of drill holes	Hole length	Core length	Core Recovery except soils	No. of analyzed samples
3	150.7m	138.1m	96.7%	30

Drilling covers 6 days, from July 25 to 30.

2-3-2 Drilling procedure

Drilling rigs were transported from Songwe sector to the Tundulu sector, using trucks of 4 and 11 tons burden.

Setting up of rigs was firstly made at JMT-26. Drilling in Tundulu sector was performed in the following order of site number, JMT-26, 25 and 27. Location of drilling sites is shown in Fig. 11.

Transport routes of one meter wide were constructed from site to site, total length reached 700m. Construction of the routes and land readjustment around each site was performed by human power.

Water was transported from Lake Chilwa to the camp using midget truck of 3 tons burden with a $1.5m^3$ tank, a distance of 6km for Nathace Hill. Transported water was supplied to each drilling site by a set of pump and hoses with total length of 500m.

Drilling through surface soil was performed using Metal shoe (73mm in diamter), and after reaching hard rock, diamond shoe (73mm in diameter) 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 performance of the drilling.

After completion of the operation in Tundulu sector, drilling rigs were transported to Chilwa Island sector in 6 days time.

2-3-3 Geology and mineralization of drill holes

Drilling was performed, from outcrops of carbonatite and apatite rock at the surface to about 50m in depth.

Geology of each drill hole is shown in Fig. 12. Chemical compositions and REO of core samples are shown in Appendix 2.

REE-mineralized zones defined as having over 1.0% REE oxides content are listed in Tab. 8. In Tab. 9, 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.

In Tundulu sector, mineralized zones are recognized at every drill holes of JMT-25, 26 and 27. Main constituent minerals in the mineralized zone are bastnaesite, strontianite, pyrochlore and apatite.

A zone is recognized at JMT-25 in the apatite rock with fluorite and/or Fe-oxides in 25.4m long between 1.6m and 27.0. Its REO content is 1.19%. At JMT-26 sideritic carbonatite and apatite rock with siderite are mineralized in 16.0m long between 21.7m and 37.7m and its REO content is 1.50%. At JMT-27, sideritic carbonatite and altered rocks are mineralized in 10.5m long between 39.4m and 49.9m and its REO content is 1.28%.

Phosphorus-mineralized zone recognized at JMT-25 is 36.1m long between 1.6m and 37.7m. Its phosphorus content is 12.7% (approximately 29.1% in P_2O_5 equivalent). The zone at JMT-26 is 25.0m long between 21.7m and 46.7m. Its phosphorus content is 4.7% (approximately 10.8% in P_2O_5 equivalent). The zone at JMT-27 is 23.3m long between 12.4m and 35.7m. Its phosphorus content is 3.9% (approximately 8.9% in P_2O_5 equivalent). Phosphorus mineral in each zone is 0.1mm in grain size and associated by quartz and calcite (T2501 and T2607).

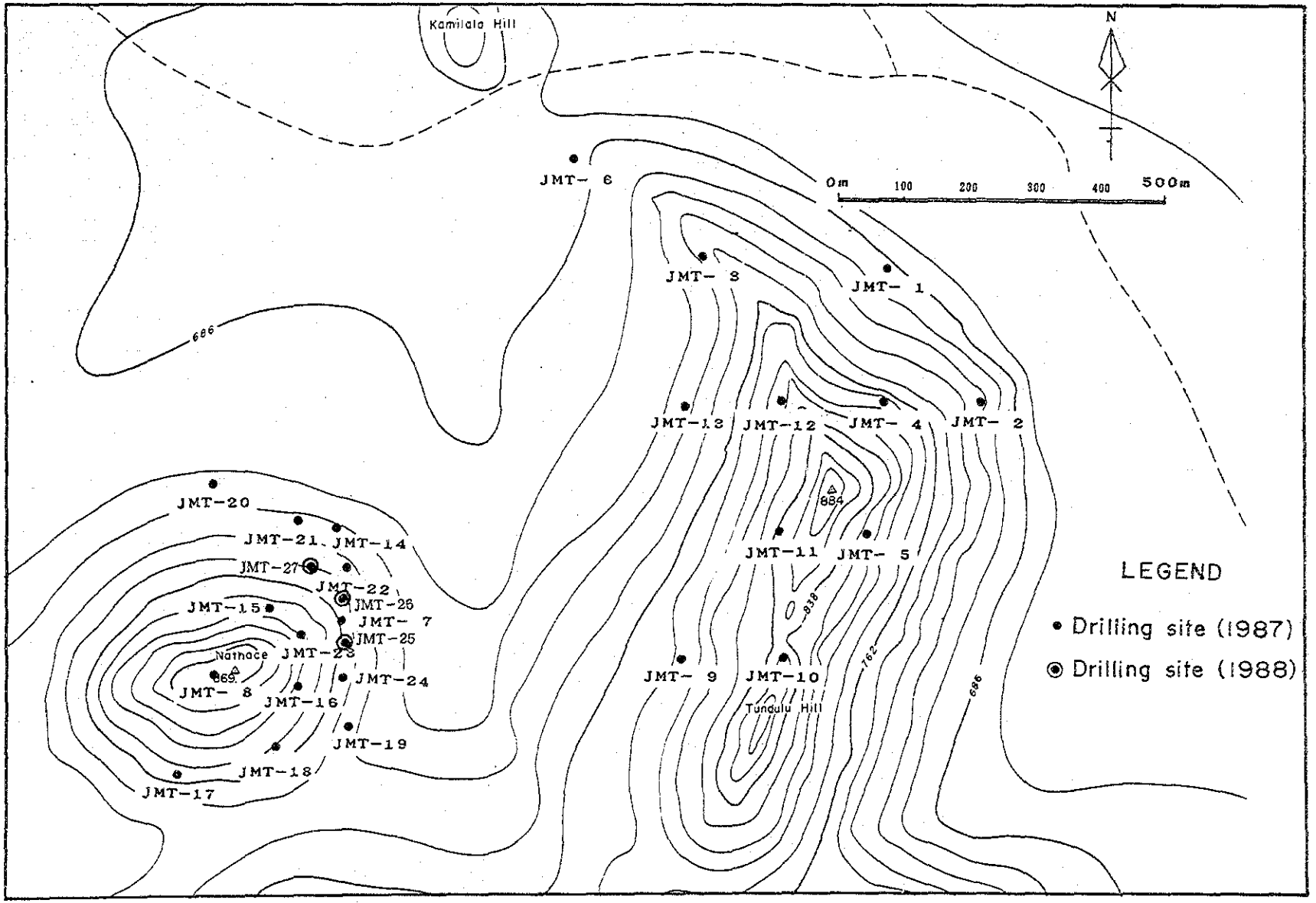


Fig.11 Location map of drilling sites, Tundulu

Performance of the drilling, Tundulu

Hole	Drilled length (m)	Core length (m)	Core recovery except soil(%)	Working period M.D.~M.D.	Bit size φ 73㎜		Bit size φ 56㎜	
					Depth(m)	Performance of the drilling	Depth(m)	Performance of the drilling
JMT-25	50.20	44.90	98.7	7. 27~7. 28	1.60	0~1.6m drilling with metal shoe, Using TK-60, Installation of BW casing pipe	45.30	Drilling with diamond bit, Using TK-60, 11.0m Escape of whole water
JMT-26	50.30	45.30	93.0	7. 25~7. 26	5.20	0~4.7m drilling with metal shoe, 4.7~5.2m drilling with diamond shoe, Using TK-60, Installation of BW casing pipe	44.90	Drilling with diamond bit, Using TK-60, 5.7m Escape of whole water
JMT-27	50.20	47.90	98.4	7. 29~7. 30	1.60	0~1.6m drilling metal shoe, Using TK-60, Installation of BW casing pipe	47.90	Drilling with diamond bit, Using TK-60, 11.0m Escape of whole water

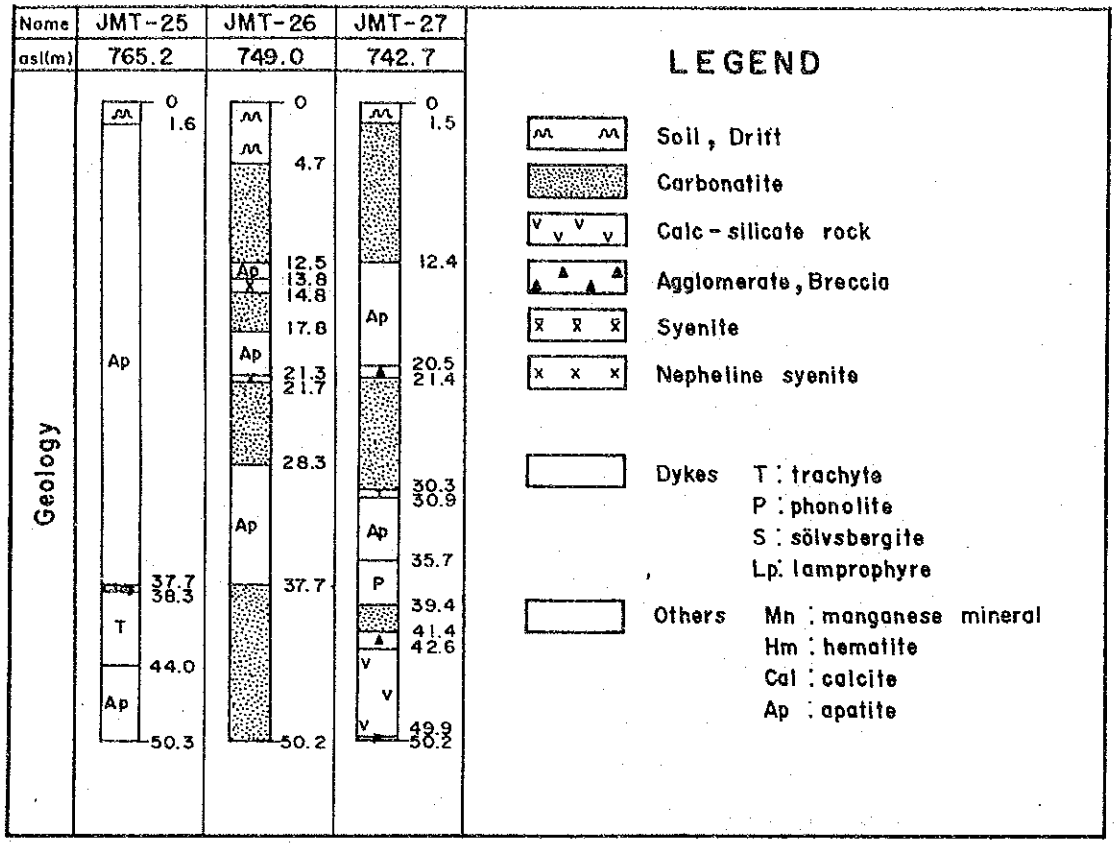


Fig.12 Compiled geologic log, Tundulu

Tab. 8 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-25	1.6 - 27.0	25.4	2427	4357	1386	256.37	88.35	29.91	1774.4	11062	1311	120110.5	11912.2
	44.0 - 50.3	6.3	2602	4978	1672	316.50	104.10	43.60	1797.0	4723	1401	113384.0	13431.8
JMT-26	4.7 - 7.8	3.1	1779	3947	1430	263.10	82.10	24.80	3232.0	4114	878	78724.0	10144.9
	12.5 - 13.8	1.3	2496	5151	1734	289.10	84.10	28.40	5198.0	4690	755	47295.0	12699.4
	14.8 - 21.3	6.5	3377	5234	1496	218.60	66.32	18.34	1191.1	18925	574	38664.7	13213.1
	21.7 - 37.7	16.0	3884	5847	1613	272.99	81.18	39.92	1117.2	23072	764	57632.4	15042.8
	29.4 - 49.9	10.5	3552	5240	1386	198.90	45.20	15.39	1126.8	27308	211	12771.2	12787.2
Bayan Obo (China)			2171	7166	5061	567	67	17	-	-	134		20000

Tab. 9 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-25	1.6 - 37.7	36.1	2152	3885	1255	248.46	89.57	28.67	1480.7	9371	1391	126596.8	10950.3
	44.0 - 50.3	6.3	2602	4978	1672	316.50	104.10	43.60	1797.0	4723	1401	113384.0	13431.8
JMT-26	4.7 - 13.8	9.1	1688	3575	1342	222.50	72.21	19.37	3353.8	3697	738	55511.6	9235.1
	14.8 - 21.3	6.5	3377	5234	1496	218.60	66.32	18.34	1191.1	18925	574	38664.7	13213.1
	21.7 - 46.7	25.0	3103	4820	1420	234.92	70.43	31.42	977.5	16571	646	46735.8	12425.0
JMT-27	12.4 - 35.7	23.3	1671	3062	1076	182.18	59.85	18.74	735.9	7608	536	39257.0	7958.0