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

(PHASE 1)

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(PHASE I)

MARCH 1987

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

PREFACE

In response to 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 Japan International Cooperation Agency (JICA) and 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 11 October to 8 December, 1986.

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, 1987

Keisuke Arita
President
Japan International Cooperation Agency

Junichiro Sato
President
Metal Mining Agency of Japan

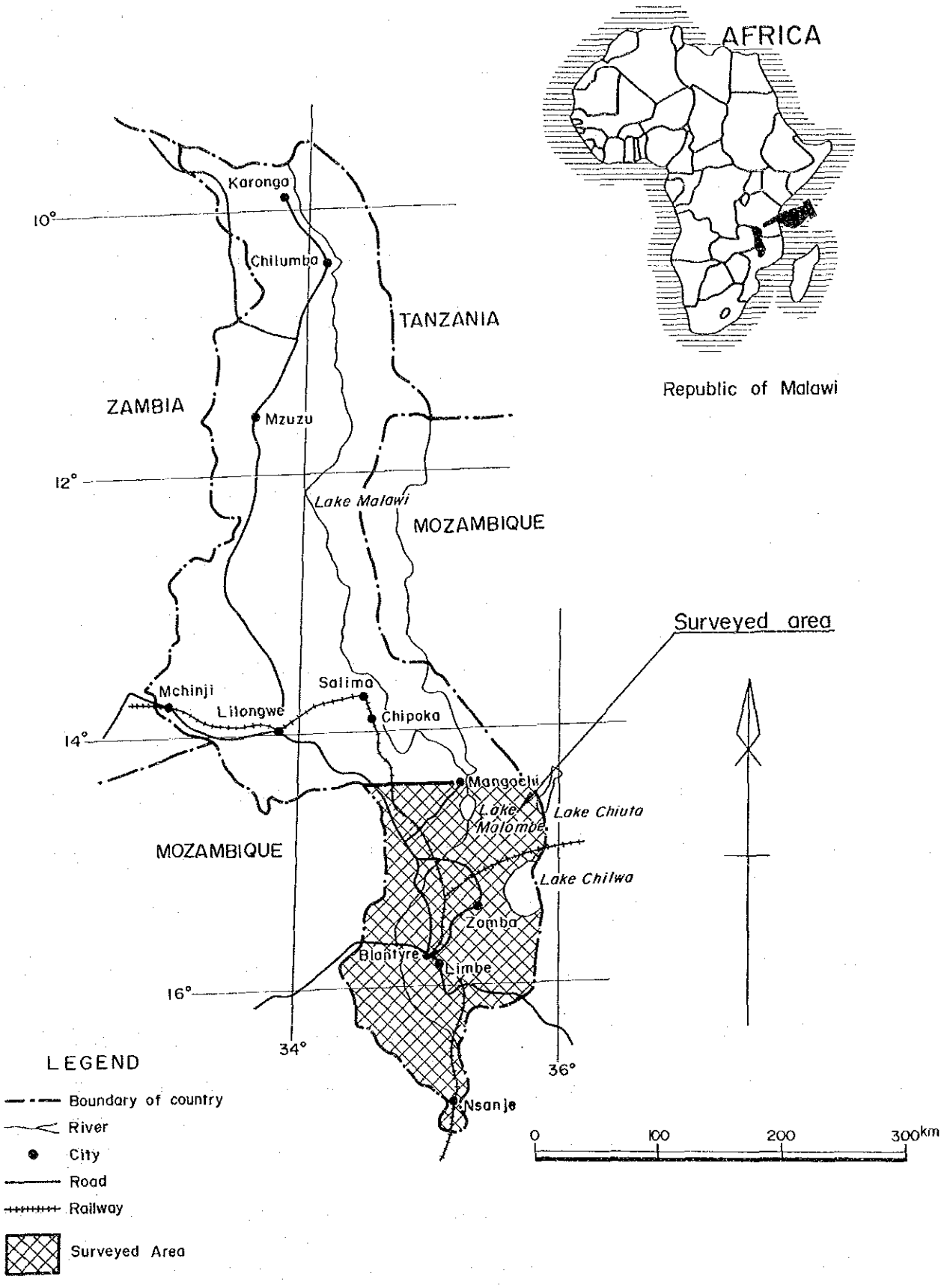

Fig. 1-1-1 Location Map of Surveyed Area

SUMMARY

This survey was carried out on the basis of the compilation of previous works and the LANDSAT image interpretation of the Chilwa alkaline area, 30,000 Km^2 wide, located in the southern part of the Republic of Malawi. The geological and geochemical surveys were carried out in the 25 sectors where were supposed to be mineralized by carbonatite from the results of the above mentioned work.

The purpose of this survey is to investigate the geological condition and the condition of the mineralization in the area. The field survey was performed from October to December, in 1986.

Contents of the survey are as follows.

Type of survey	Amount of survey	
Compilation of previous works	30,000 Km^2	
LANDSAT image interpretation	30,000 Km^2	
Geological survey, Geochemical survey	Surveyed sectors	25 sectors
	Length of surveyed route	300 Km
	Geochemical samples	1,000
	Chemical analysis (rocks)	75

Outline of the survey results is as follows.

(1) Compilation of previous works

Carbonatites and promising sites are recognized in 25 sectors. Among them, those in 16 sectors are volcanic cone type of the complex that associated carbonatite and those in 6 sectors are volcanic neck type. Moreover, those in 2 sectors show thorium anomalies in the airborne radiometric survey and one sector is the promising site of carbontite intrusion.

(2) LANDSAT image interpretation

206 circular structures are picked up by using the photogeological interpretation technique. They are classified into 4 types: projected ring structure, depressed ring structure, basin structure and cone structure. It becomes obvious that most of the known carbonitites and prospective sites belong to the projected ring structure.

(3) Geological survey

The geology of this area consists of the basement of gneisses, syenites and granites of late pre-Cambrian to early Paleozoic in age and the Jurassic to Cretaceous rocks of the alkaline complex that associate carbonatite of Chilwa alkaline complex. The alkaline complex forms ring structures by the combinations of cone sheets, valcanic necks, ring dykes and radial dykes. Most of them are associated with breccias and agglomerates. The lithology of the carbonatite in this area is mostly sövitic (calcitic), ankeritic and sideritic but quartzitic to also recognized in some places. Among the 25 sectors, the existence of massive carbonatite (large scale) in 4 sectors: Tundulu, Songwa, Chilwa Island and Kangankunde and dyke carbonatite (small scale) in 4 sectors: Nkalonje, Matoponi, Kapiri and Nsengwa is confirmed.

(4) Geochemical survey

Carbonatite samples were collected from the 25 sectors and chemically analyzed into 60 elements. The result of the analysis is statistically processed. 15 elements (Ce, Dy, Eu, La, Lu, Nd, Nb, P, Sm, Sr, Tb, Th, U, Yb and Y) are selected as the elements can be related to carbonatites. It was examined whether each sector has the geochemical anomalous values or not.

As a result of the examination, it is recognized that Tundulu, Songwe and Chilwa Island sectors indicate the anomalous values (including the strong anomalous values) in every 15 elements. Nkalonje, Salambidwa, Kadongosi, Kangankunde, Aligomba and Chiloli sectors are selected as the sectors not indicating the anomalous values in every elements but indicating some strong anomalous values. Moreover, Matoponi, Mikomwa, Chipalanji, Namangale, Naminga, Chaumbwi, Kapiri, Nsala, Kongwe and Achirundu sectors are selected as the sectors indicating some anomalous values and not indicating the strong anomalous values. Finally, Mongolwe, Chikala, Nsengwa, Mlindi, Liperembe and Kawanula sectors are selected as the sectors not indicating the anomalous values.

As the results of the geological and geochemical surveys, the sectors are evaluated as follows.

The sectors that can be considered as having high potentiality of the carbonatite deposit:

- Tundulu, Songwe, Chilwa Island and Kangankunde sectors

The sectors that can be considered as having potentiality of the carbonatite deposit:

- Nkalonje, Matoponi and Kapiri sectors

The sectors where the geochemical anomalies are recognized without the existance of carbonatite:

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

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INTRODUCTION

CHAPTER I INTRODUCTION

PART 1 OUTLINE OF THE SURVEY

1-1 Circumstances of the Survey

The Republic of Malawi occupies an area of about 119,000 Km^2 and the geology ranges from pre-Cambrian to Quarternary ages, comprising strata of various ages between them. As it lies in the southern part of the East African Graben, the potential of resources of rare metals such as gold, silver and rare earth is considered to be high. Up to date, however, the production of mineral commodities is very few. The Geological Survey of Malawi contributes the discovery of carbonatite deposits in Kangankunde, Chilwa Island, etc., by compilation of map survey and continuous efforts on mineral exploration.

This survey of mineral resources is performed 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 in August 14, 1986.

In the first step of this survey, an examination of previous works on the area of 30,000 Km^2 in the Chilwa alkaline area and the LANDSAT image interpretation were made. Depending on these results, 25 sectors considered to be related to the carbonatite mineralization were selected. Field work of geological and geochemical survey was carried out in these 25 sectors.

1-2 Purpose of the Survey

The purpose of the survey is to elucidate the geological conditions of carbonatites in the Chilwa alkaline area and to understand the mineralization related to carbonatites.

1-3 Area of the Survey

The Chilwa alkaline area is located in the south of Lake Malawi which is a portion of the East African Graven (Fig. 1-1-1). The area occupies one-fourth of the land of Malawi. The area is presented in the maps 1:250,000, published by the Government of Malawi, as the southern half of Mangochi (sheet 8), Blantyre (sheet 9) and Nsanje (sheet 10).

The following 25 sectors were selected from the results of the compilation of previous works and LANDSAT image interpretation (Fig. 1-1-2).

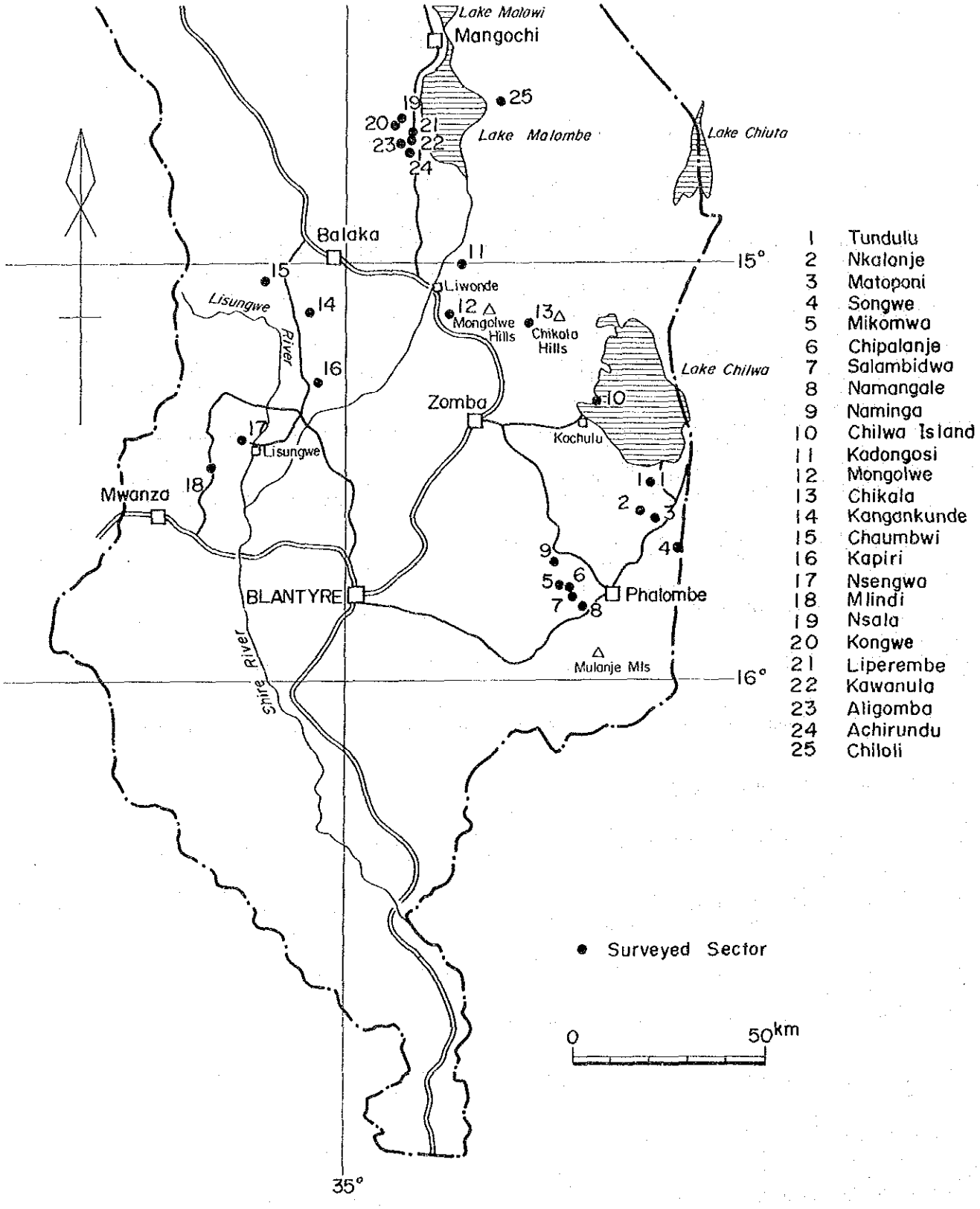


Fig. 1-1-2 Location Map of Surveyed Sectors

	Name of Sector		Name of Sector
1.	Tundulu	2.	Nkalonje
3.	Matoponi	4.	Songwe
5.	Mikomwa	6.	Chipalanje
7.	Salambidwa	8.	Namangale
9.	Naminga	10.	Chilwa Island
11.	Kadongosi	12.	Mongolwe
13.	Chikala	14.	Kangankunde
15.	Chaumbwi	16.	Kapiri
17.	Nsengwa	18.	Mlindi
19.	Nsala	20.	Kongwe
21.	Liperembe	22.	Kawanula
23.	Aligomba	24.	Achirundu
25.	Chiloli		

1-4 Location and Transportation

It takes about one hour by plane or four hours by car to reach Blantyre which is located in the center of the surveyed area, from the capital Lilongwe. Centering around Blantyre, an industrial city, and Zomba, the previous capital which is located about 70 Km to the north of Blantyre, cities and towns in the surveyed area are connected with paved and unpaved roads. Therefore, the surveyed area is in a good condition in transportation; and the cars can reach to every sector of the surveyed area. But, the condition of unpaved roads is in trouble in the rainy season (November-April).

1-5 Methods and Amount of the Survey

First, the compilation of previous works and LANDSAT image interpretation were made on the surveyed area, 30,000 Km^2; and the 25 promising sectors of carbonatite mineralization were selected. In these selected 25 sectors, geological and geochemical surveys were performed.

Geological survey was made on a 1:5,000 scale map, eularged from a 1:50,000 scale topographic map produced by the Department of Survey. A route map was produced on the 1:5,000 scale. Survey results were put on the 1:10,000 scale geological maps. Geological survey and geochemical survey were carried out contemporaneously; and the samples were collected, as a rule, from carbonatites. Analytical results were processed statistically with a computor.

Contents of the survey are described in Tab. 1-1-1.

1-6 Period of the Survey and Formation of the Survey Team

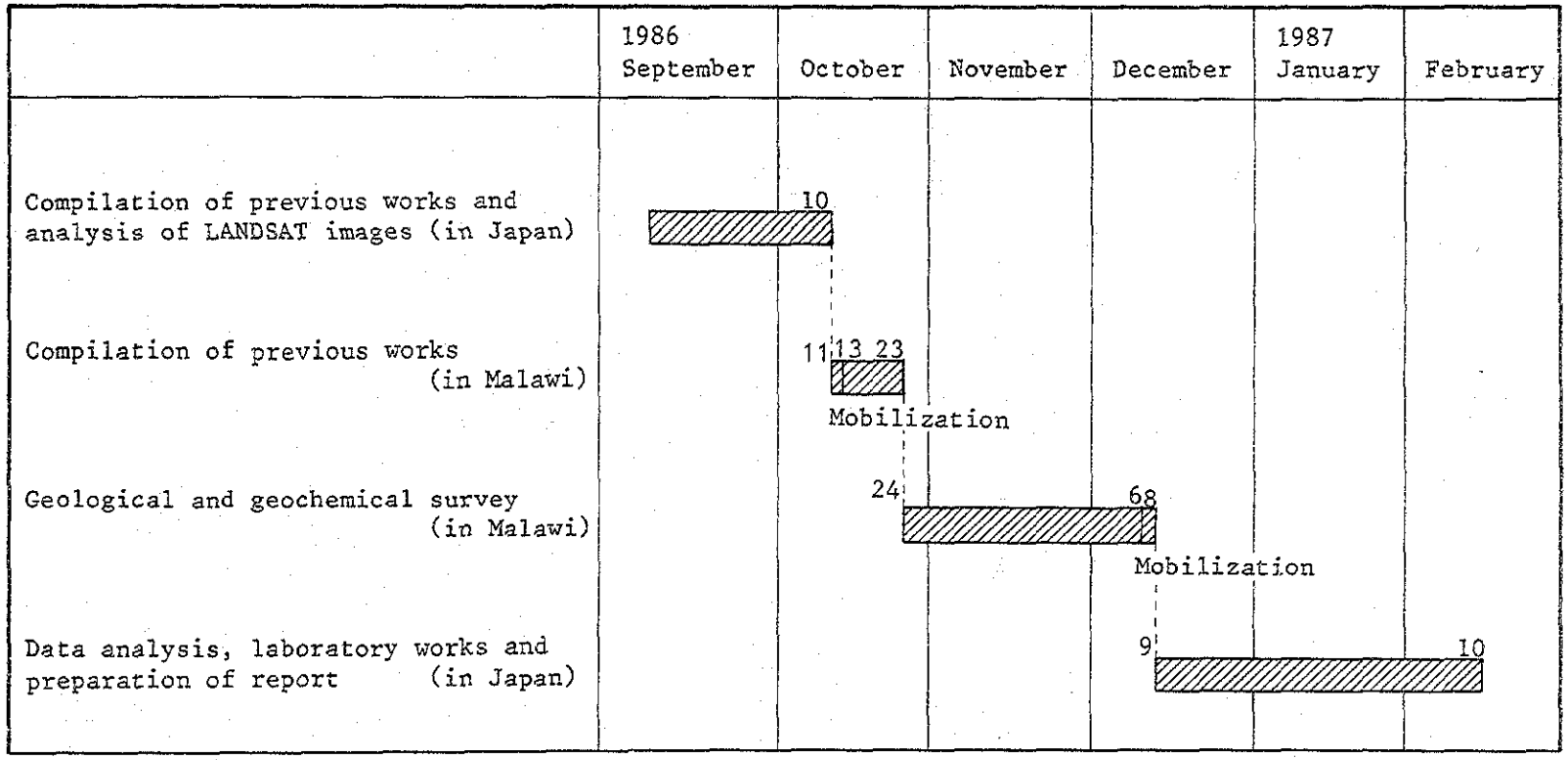
Examination of previous works and the interpretation of LANDSAT data were made from September to October, 1986. Field survey was made for 59 days, from October 11 to December 8, 1986. The laboratory works and the preparation of the report were made in Japan after the team had returned to the country. The process of the Survey is described in Tab. 1-1-2.

The list of members of the programming and negotiation for the execution of the project, the negotiation and the field survey of the first year phase are as follows.

Tab. 1-1-1 Contents of the Survey

Surveyed sector	Route survey kms	Geochemical samples	Whole rock analysis	Thin sections	Polished sections	Age determination	X-ray diffraction test	EPMA analysis	
								Qualitative	Quantitative
Tundulu	21	133	6	6	5	1	4	12	4
Nkalonje	11	48	2	1	-	-	-	-	-
Matoponi	8	13	2	2	-	-	-	-	-
Songwe	13	89	1	1	-	-	-	-	-
Mikomwa	7	10	-	-	-	-	-	-	-
Chipalanje	12	13	3	1	-	-	-	-	-
Salambidwa	8	21	1	1	-	-	-	-	-
Namangale	13	36	3	3	-	1	2	-	-
Naminga	7	22	3	1	-	-	-	-	-
Chilwa I.	27	196	1	2	2	-	1	5	2
Kadongosi	5	9	4	2	-	-	-	-	-
Mongolwe	12	31	8	3	-	1	2	-	-
Chikala	10	36	8	4	-	1	2	-	-
Kangankunde	20	185	6	4	3	-	4	8	1
Chaumbwi	8	7	2	2	-	-	-	-	-
Kapiri	10	21	1	3	-	1	2	-	-
Nsengwa	8	14	1	1	-	-	-	-	-
Mlindi	20	21	5	3	-	1	3	-	-
Nsala	17	16	6	3	-	1	2	-	-
Kongwe	18	30	-	-	-	-	-	-	-
Liperembe	13	7	1	1	-	-	-	-	-
Kawanula	10	6	2	1	-	-	-	-	-
Aligomba	10	13	3	2	-	-	1	-	-
Achirundu	10	25	3	1	-	-	1	-	-
Chiloli	5	10	4	2	-	-	-	-	-
Total	303	1,012	76	50	10	7	25	25	7

Tab. 1-1-2 Process of the Survey



Survey Programming and Negotiation

Japan Side		
	KOHEI ARAKAWA	Metal Mining Agency of Japan
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	TAKASHI KAMIKI	Japan International Cooperation Agency
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	C.E. Kaphwiyo	Department of Geological Survey

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PART 2 OUTLINE OF THE SURVEYED AREA

2-1 Geography

The Chilwa alkaline area occupies nearly all of the Southern Region and some of the adjoining Central Region of Malawi; located between latitude N14°30' - 17°16' and longitude E34°15' - 35°55'.

In the surveyed area, the eastern part is occupied by the precipitous Mulange mountains having 3,000 m elevation. In the north and the northeastern parts, there are Lake Malombe and Lake Chilwa. In the western part, savanna plane having 300 - 500 m elevation is developing along the Shire River which runs from north to south.

As this area belongs to the tropical savanna climate, it has three seasons, i.e., the dry season (May - August), the cool season (September - October) and the rainy season (November - April). In Blantyre, the average annual rainfall is 870 mm and the average temperature is 15 - 21°C.

2-2 Previous Works

Field surveys carried out in this area in recent years are by Ganson, M.S. (1965) and Bloomfield, K. (1966), etc. Garson energetically made geological survey in the southern part of Malawi, reported about the discovered carbonatite and the prospective areas, and described petrographic observations, structural geology, sequence of carbonatites and petrogenesis of carbonatite complexes. Bloomfield followed Garson's work and at the same time made geological map of the whole Malawi.

Moreover, UNDP made airborne magnetic survey and airborne radiometric survey in the southern part of Malawi by 1985.

The rock classification used in this report is largely based on the previous researches.

2-3 Outline of the Geology and Ore Deposits

The greater part of Malawi is underlain by late pre-Cabmrian - early Paleozoic (400 ~ 650 Ma) metamorphie rocks such as crystalline sehists and gneisses of granulite or amphibolite facies which are parts of the Mozambique metamorphic belt (Fig. 1-2-1). Rocks of the granulite facies comprise hypersthene granitic rocks and garnet-sillimanite-graphite siliceous schists, and rocks of amphibolite facies consist of biotite gneiss, arenite, argillite, marble, garnet-sillimanite-graphite siliceous schists, and amphibolites. The general trend of these basement is north-south.

Many small intrusive bodies of ultrabasic rocks (500 Ma) such as metapyroxenite and metagabbro, are recognized in the basement of the southern Malawi.

Syenites and granites intruded into the basement in early Paleozoic period (450 Ma) forming lenses or deep-seated ring structures. It is considered that these igneous rocks were the products of the last activity of complex regional metamorphism occurred in the Mozambique belt.

In Jurassic period, the intrusion of dolerite dykes and the eruption of basaltic lavas occurred in the southern part of Malawi.

During Jurassic to Cretaceous period, the activity of alkaline rocks and carbonatites had occurred forming volcanic necks and small intrusives that can be called "Chilwa Alkaline Province".

Although there is no metal mines now in operation, carbonatite and bauxite deposits are known to be occurred. Bauxite deposit is situated on the top of Mulanje mountains of 2,000 to 3,000 m elevation. Ore reserve of 70 million tons Al_2O_3 about 43% is known to present. Mulange mountains consist of the old syenite and syenite of the Chilwa alkaline province which intrudes into the former. Bauxite is the weathering product of these rocks. Carbonatites are described in detail in Chapter II.

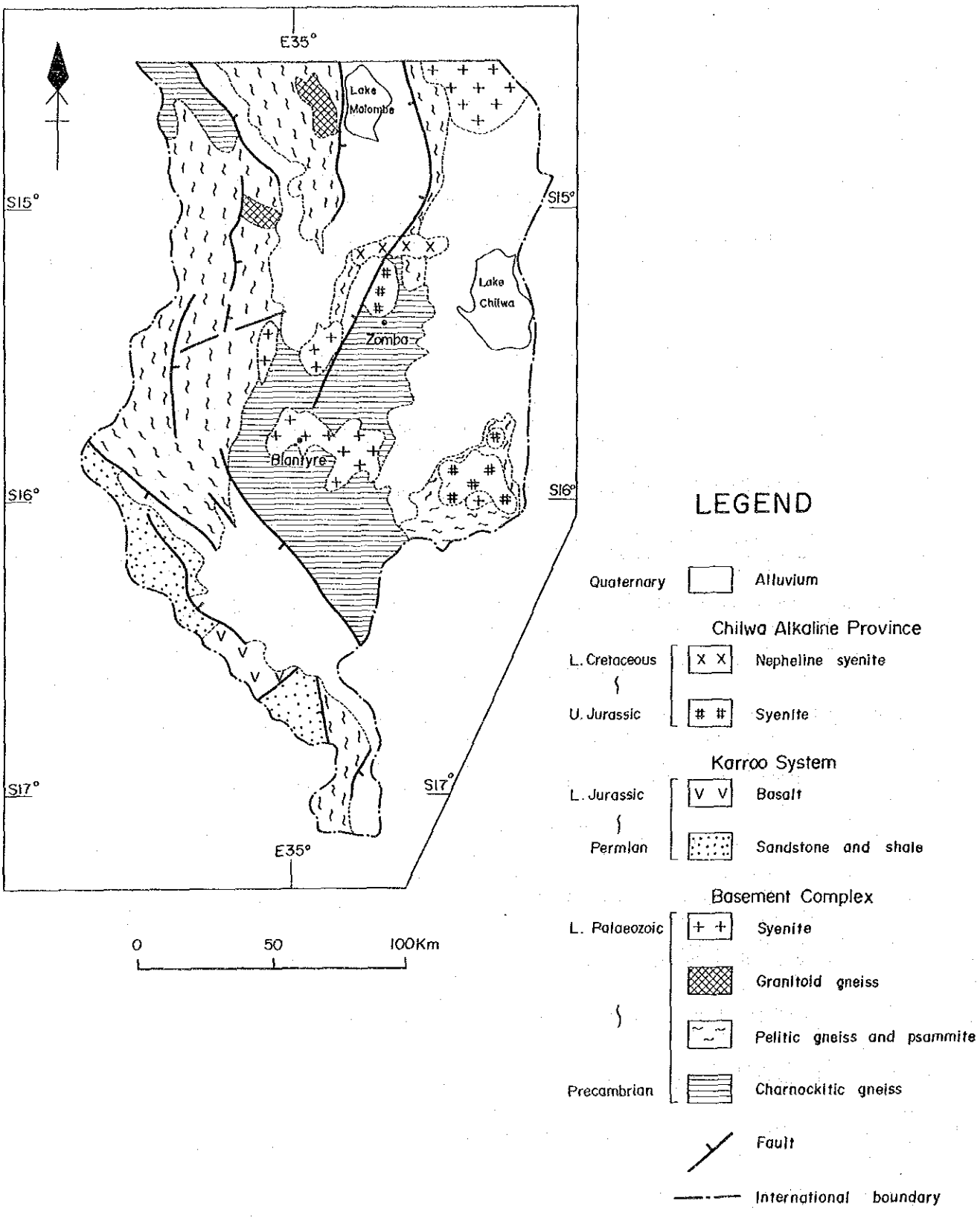


Fig. 1-2-1 Geological Map of Chilwa Alkaline Area

COMPILATION OF PREVIOUS WORKS

CHAPTER II COMPILATION OF PREVIOUS WORKS

PART 1 OUTLINE OF COMPILATION

The purpose of the compilation is to select promising sectors of carbonatite mineralization distributed in the Chilwa alkaline area.

Materials of the compilation are presented in the references. Among them, the data from the reports of Bloomfield, K. (1956), Garson, M.S. (1965) and those from the map of Cannon, R.T. (1970) were used. The countour map of airborne radiometric survey issued from the Geological Survey Department of Malawi (1985) was also used as the data of airborne geophysical survey.

PART 2 COMPILATION OF PREVIOUS WORKS ON GEOLOGY AND ORE DEPOSITS

In Malawi carbonatites intrude in some places and the prospective areas where fenitization takes place due to carbonatite intrusion are also known. Though most of these carbonatites are distributed in this surveyed Chilwa alkaline province, some of them are in the Ilomba Hill alkaline province which lies near the border of northern Malawi with Tanzania.

In this surveyed area, carbonatites and prospective sites of carbonatite are recognized in 25 sectors (Fig. 1-1-2, Tab. 2-2-1).

Carbonatites and prospective sites of carbonatite are closely associated to the alkaline complexes of the Chilwa alkaline rock province. These alkaline complexes represent ring structures by the combination of cone sheets, volcanic necks, ring dykes and/or radial dykes, and most of them accompany breccias and agglomerates. Syenite, nepheline syenite, trachyte, phonolite, nephelinite, lamprophyre, etc., are known to be of alkaline rocks in this area.

In general, fenitization, carbonitization, feldspathization are occurred as alteration, but in some cases, nephelinization, phlogopitization and silicification are also recognized.

Fenitization is the metasomatic process which takes place by leaching of a large amount of SiO_2 from the original rocks and addition of Na (sometimes K) and Fe^{3+}. In many cases, this process took place just before or in early stages of the intrusion of alkaline complexes; and for this, the gneisses and granites of the basement were metasomatized and altered to syenitic rocks. This effect reached on an extent of 1,000 - 2,000 m encompassing the intruding rock body.

In many cases, carbonitization and feldspathization occurred just after the brecciation, replacing breccias and agglomerates. In some sectors, carbonitization (and feldspathization) occurred prior to fenitization.

The petrology of the carbonatites in this area is, in general trend, sövitic (calcitic) in the early stage and sideritic in the late stage through ankeritic. Quartzitic (leucocratic) carbonatite and beforsite are also seen in some sectors.

These carbonatites were emplaced as follows in the igneous activity of the alkaline complexes. Dome structures and cone sheets were formed in the basement due to the intrusion of alkaline magma, and after the succeeding fenitization and brecciation, carbonatite was formed due to the intrusion of carbonatite magma.

Tab. 2-2-1(1) Compilation of Previous Works

Surveyed sector	Alkaline complex	Breccia/ agglomerate	Occurrence	Fenitization	Carbonatization	Feldspathization	Carbonatite	Type	Ore minerals	Remarks
1. Tundulu	nepheline syenite	breccia, agglomerate	circular structure arcuate ring dyke	basement	-	breccia	sövite (earlier) apatite bastneasite beforsite (later)	II	pyrochlore, bastneasite, synchysite, monazite, apatite	nephelinization
2. Nkalonje	nephelinite, nepheline syenite	breccia, agglomerate	volcanic neck	basement	-	breccia	sövite sideritic leucocratic	II	pyrochlore, bastneasite, synchysite, florencite	quartz-fluorite vein
3. Matoponi	phonolite, trachyte	-	dyke	-	-	-	sövite	I	pyrochlore, apatite	
4. Songwe	nephelinite, foyaite	breccia, agglomerate	volcanic neck	basement	-	breccia	sideritic	II	apatite, pyrochlore, bastneasite, synchysite	apatite-fluorite vein
5. Mikomwa	phonolite, sölvsbergite	agglomerate	dyke	-	-	-	-	I	-	
6. Chipalanje	microfoyaite, phonolite	agglomerate	dyke	-	-	-	-	I	-	
7. Salambidwa	phonolite	agglomerate	dyke	-	-	-	-	I	-	
8. Namangale	phonolite, microfoyaite	breccia	volcanic neck	basement	-	breccia	sövite	II	apatite	
9. Naminga	(gneiss, granite)	-	(dome structure)	-	-	-	-	-	-	The anomaly by airborne survey
10. Chilwa I.	nepheline syenite, phonolite, nephelinite	breccia, agglomerate	ring dyke cone sheet radial dyke	basement	-	agglomerate	sövite (earlier) ankeritic sideritic (later)	II	pyrochlore, basteeasite, synchysite, apatite	quartz fluorite vein
11. Kadongosi	foyaite, phonolite	agglomerate	volcanic neck	basement, agglomerate	-	-	-	I	-	
12. Mongolwe	pulaskite, nepheline syenite	agglomerate	volcanic neck	basement	-	-	-	I	-	
13. Chikala	pulaskite, foyaite	agglomerate	volcanic neck	basement, pulaskite	-	agglomerate	-	I	-	silicification

Tab. 2-2-1(2) Compilation of Previous Works

Surveyed sector	Alkaline complex	Breccia/ agglomerate	Occurrence	Fenitization	Carbonatization	Feldspathization	Carbonatite	Type	Ore minerals	Remarks
14. Kangankunde	nephelinite, sölvsbergite	breccia, agglomerate	circular structure	basement	nephelinite, breccia, agglomerate	fenite, breccia, agglomerate	sideritic (earlier) ankritic manganiferous (later)	II	monazite, bastneasite, strontianite, florencite	siliceous rock (late hydrothermal) phlogopitization
15. Chaumbwi	-	agglomerate	volcanic vent	agglomerate	agglomerate	-	-	I	-	
16. Kapiri	nephelinite, phonolite	-	dyke	nephelinite	nephelinite	-	ankeritic	I	monazite, florencite, bastneasite	
17. Nsengwa	microsyenite	breccia, agglomerate	ring dyke	-	-	breccia	ankeritic	I	pyrochlore, monazite	
18. Mlindi	(Ultrabasic rocks)	-	(ring structure)	-	-	-	-	-	-	infracrustal ring-complex
19. Nsala	microfoyaite, phonolite	agglomerate	ring neck radial dyke	feldspathic agglomerate	-	agglomerate	sövite	I	-	
20. Kongwe	nephelinite, phonolite	agglomerate	circular structure	basement	agglomerate	agglomerate	-	I	-	
21. Liperembe	nephelinite, phonolite	agglomerate	elongated neck	-	agglomerate	-	-	I	apatite	
22. Kawanula	lamprophyre, nephelinite	agglomerate	elongated neck	-	-	-	-	I	apatite	
23. Aligomba	phonolite	agglomerate	elongated neck	-	agglomerate	-	-	I	apatite	
24. Achirundu	phonolite	agglomerate	elongated neck	-	agglomerate	-	-	I	apatite	
25. Chiloli	(granulite, gneiss)	-	(dome structure)	-	-	-	-	-	-	Th anomaly by airborne survey

Forms of the complexes that accompany carbonatites are classified into 4 types according to the depth of erosion as shown in Fig. 2-2-1 (Garson, 1966).

I) Volcanic cone: characterized by cones consisting of lavas and pyroclastics of nephelinite, agglomerates and carbonatites.

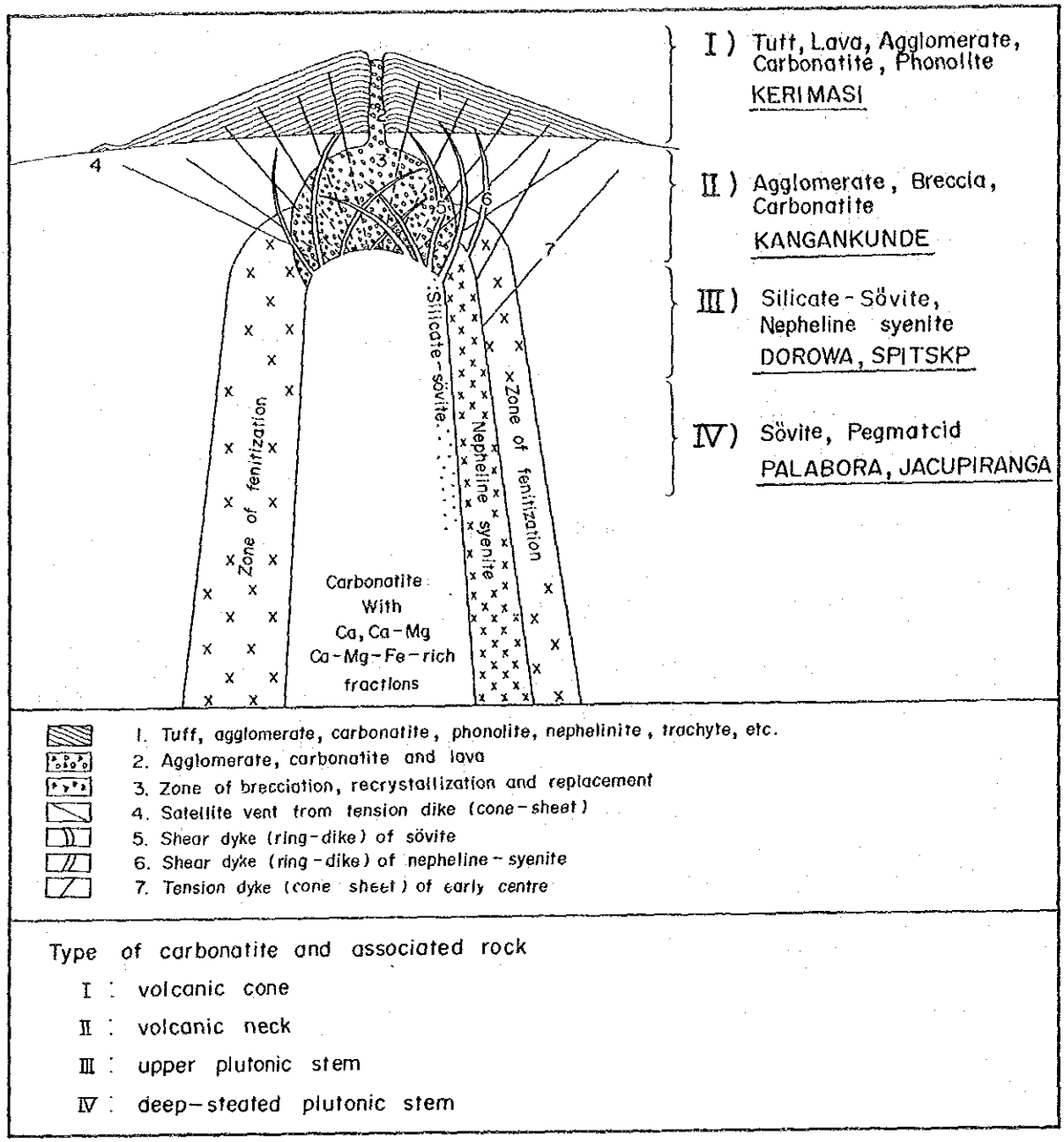
II) Volcanic neck: characterized by carbonatized or feldspathized breccias and agglomerates. Addition of a large quantity of K is recognized during fenitization.

III) Upper plutonic stem: usually rich in calcitic and dolomitic carbonatites; in fenitization, much Na was added.

IV) Deep-seated plutonic stem: accompanied with syenite, pyroxenite, dunite or olivine-vermiculite pegmatite; dyke is rare.

Carbonatites in this area can be classified as - 16 sectors in type I and 6 sectors in type II. Carbonatites of type II are relatively larger than type I. Carbonatities of type III and IV are not recognized in this area. Pyrochlore, monazite, bastnaesite, synchysite, strontianite, florencite, apatite, fluorite, etc. occur as minerals accompanied with carbonatite. Pyrochlore predominates in sövite (calcitic carbonatite) associated with apatite. RE minerals (monazite, bastnaesite, synchysite, etc.) predominate in ankeritic or quartzitic carbonatite with baryte.

The airborne magnetic survey and airborne radiometric survey (K, Th, U, K+Th+U) were carried out by UNDP in the southern Malawi. Among them, the airborne radiometric data on thorium agree well with the known distribution of carbonatites. Strong anomaly of 500 cps and over and anomaly of 500 to 250 cps correspond to the alkaline complexes with carbonatites and a part of the old syenitic and granitic bodies. Naminga and Chiloli sectors are selected as promising sites for the carbonatite exploration because the thorium anomaly and the circular structures picked up from the LANDSAT image interpretation overlap in these two sectors. Mlindi sector is also selected as a promising site for carbonatite intrusion, as the intrusion of an alkaline complex is anticipated in a deeper place.



(after Garson, 1966)

Fig. 2-2-1 Schematic Diagram of the Structural Pattern in a Carbonatite Complex

LANDSAT IMAGE INTERPRETATION

CHAPTER III LANDSAT IMAGE INTERPRETATION

PART 1 OUTLINE OF INTERPRETATION

The purpose is to pick up the structures that suggest the indication of carbonatite intrusions in the Chilwa alkaline area by using the photogeological interpretation technique.

Five scenes of LANDSAT images were used. They are shown in Fig. 3-1-1 and Tab. 3-1-1 as (path/row = 179/70, 179/71, 179/72, 180/70, 180/71) - their false color images (scale 1:250,000, 4.5.7 band composite) and black and white images (scale 1:250,000, 7 band). GEOPIC images (combined images with edge enhancement processing and contrast stretch processing) are used in both false color images and black and white images.

PART 2 RESULT OF LANDSAT IMAGE INTERPRETATION

As a photogeological interpretation technique, the same scenes of false color image and black and white image were put together under the stereoscope and studied; the circular structures and liniaments (linear structures) were picked up and classified. Results are shown in Fig. 3-2-1 and PL. 1-1, 1-2, 1-3, 1-4, 1-5.

(1) Circular Structures

206 circular structures picked up from images are classified into 4 types according to their morphology as shown in Tab. 3-2-1.

A) Projected ring structure: can be assumed as ring dykes, cone sheets, and craters.
B) Depressed ring structure: can be assumed to exist ring dykes and intrusive pipes.
C) Basin structure: can be assumed as explosive craters, meteoritic craters.
D) Cone structure: can be assumed as intrusive bodies, cinder cones.

These 4 types are the structures suggesting circular rock bodies, ring dykes and cone sheets of the alkaline igneous rocks, and the carbonatites related to them. Moreover, by comparing the previous works, it is clearly recognized that the majority of the circular structures of the known carbonatites belong to the A type projected ring structure.

The distribution of the A type circular structures concentrate in 7 districts (Fig. 3-2-2). i.e.,

1) East district of Lake Malombe
2) West district of Lake Malombe
3) Kangankunde district
4) South district of Lake Chilwa
5) North district of Chiromo
6) Chiromo district
7) South district of Chiromo

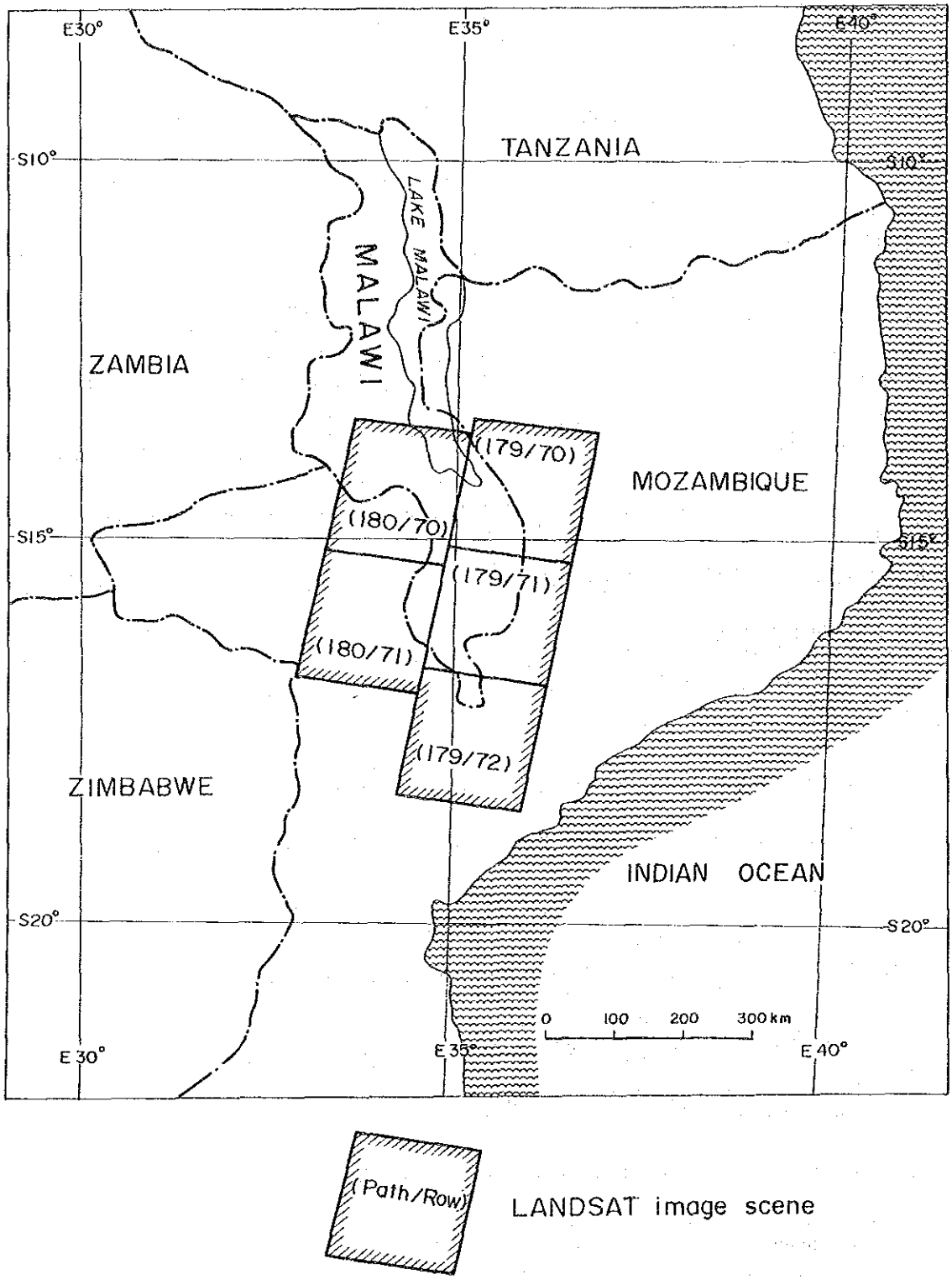
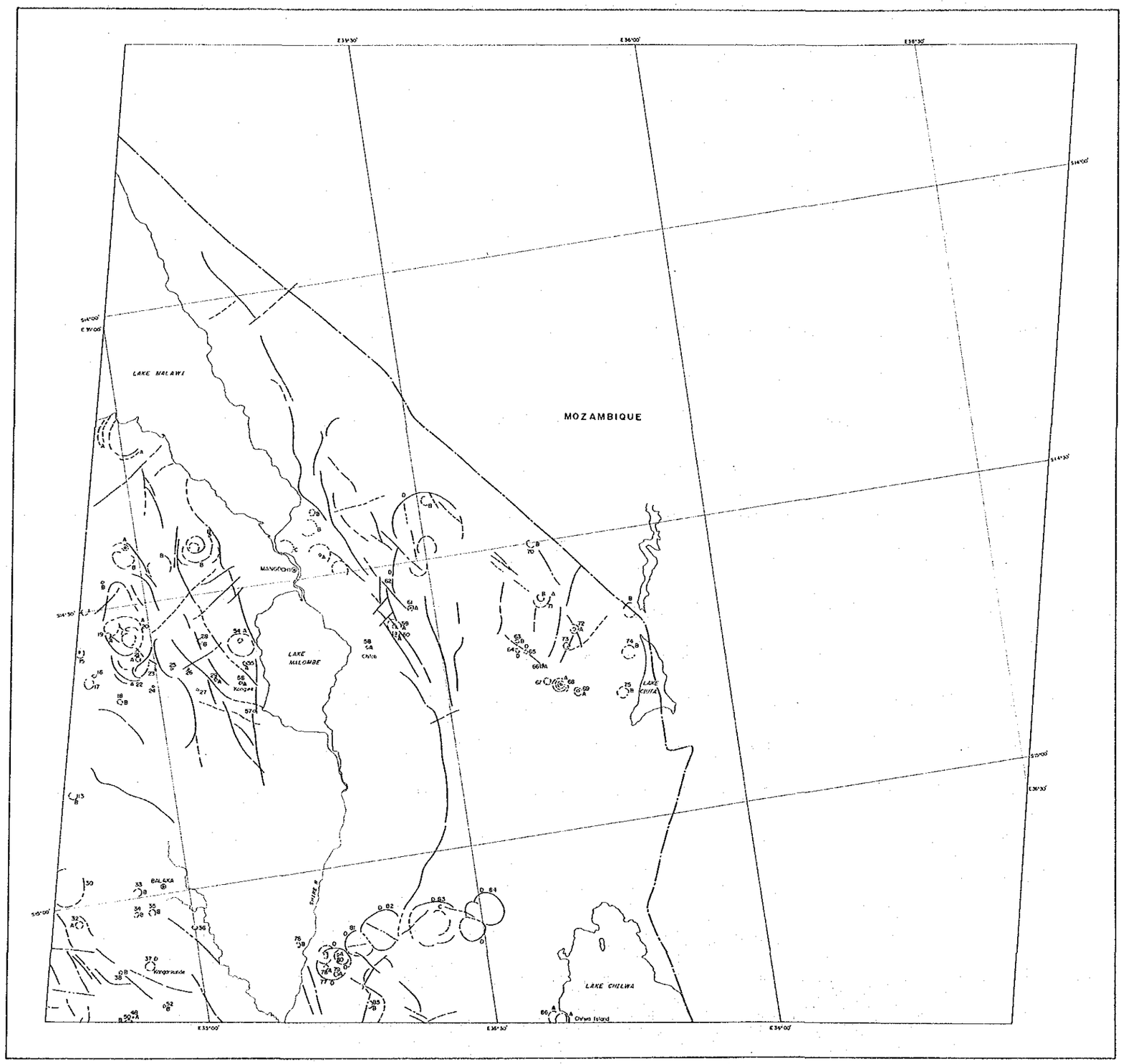


Fig. 3-1-1 Location Map of LANDSAT Image Scenes

Tab. 3-1-1 List of LANDSAT Data

Location	Path/Row	ID No.	Scene Date	Longitude	Latitude
Shire Valley	179/70	10442-07082	08/Oct/1973	E35°45'	S14°30'
Blantyre	179/71	10442-07084	08/Oct/1973	E35°24'	S15°58'
Blantyre-2	179/72	10388-07102	15/Aug/1973	E34°58'	S17°14'
Monkey Bay	180/70	10425-07143	21/Sep/1973	E34°18'	S14°23'
Zobue	180/71	10425-07145	21/Sep/1973	E33°57'	S15°50'



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

RESULT OF LANDSAT IMAGE
PHOTOGEOLOGICAL INTERPRETATION
(SHIRE VALLEY)

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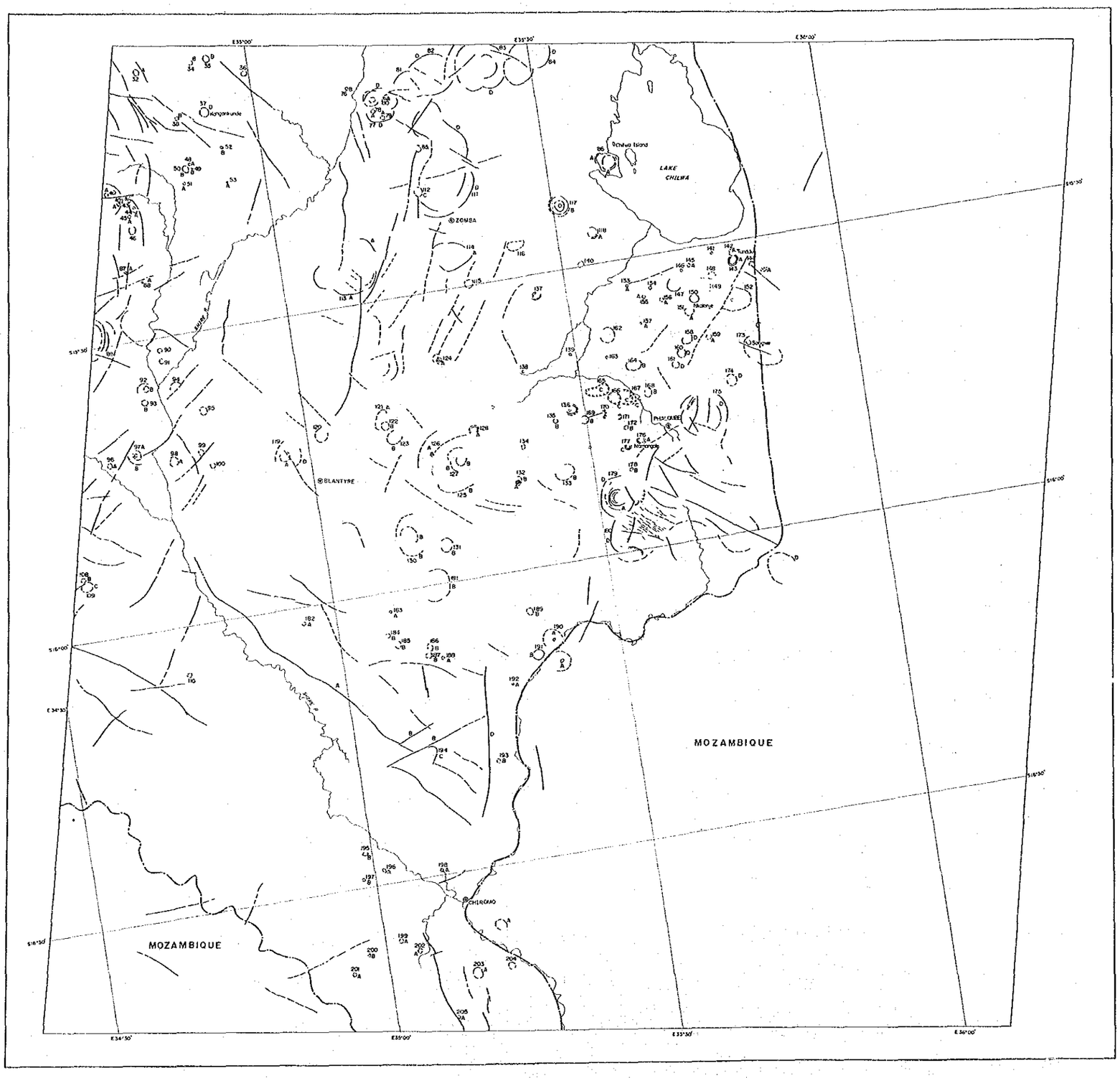
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

LEGEND

- Circular Structure (Clear)
- Circular Structure (Dim)
- Lineament (Clear)
- Lineament (Dim)
- Basin Structure
- International Boundary

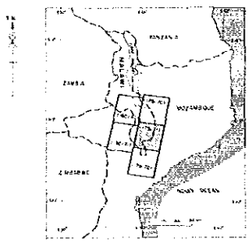
A : Projected Ring Structure
B : Depressed Ring Structur
C : Basin Structure
D : Cone Structure

Fig. 3-2-1(1) Result of Photogeological Interpretation



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

RESULT OF LANDSAT IMAGE PHOTOGEOLOGICAL INTERPRETATION (BLANTYRE)



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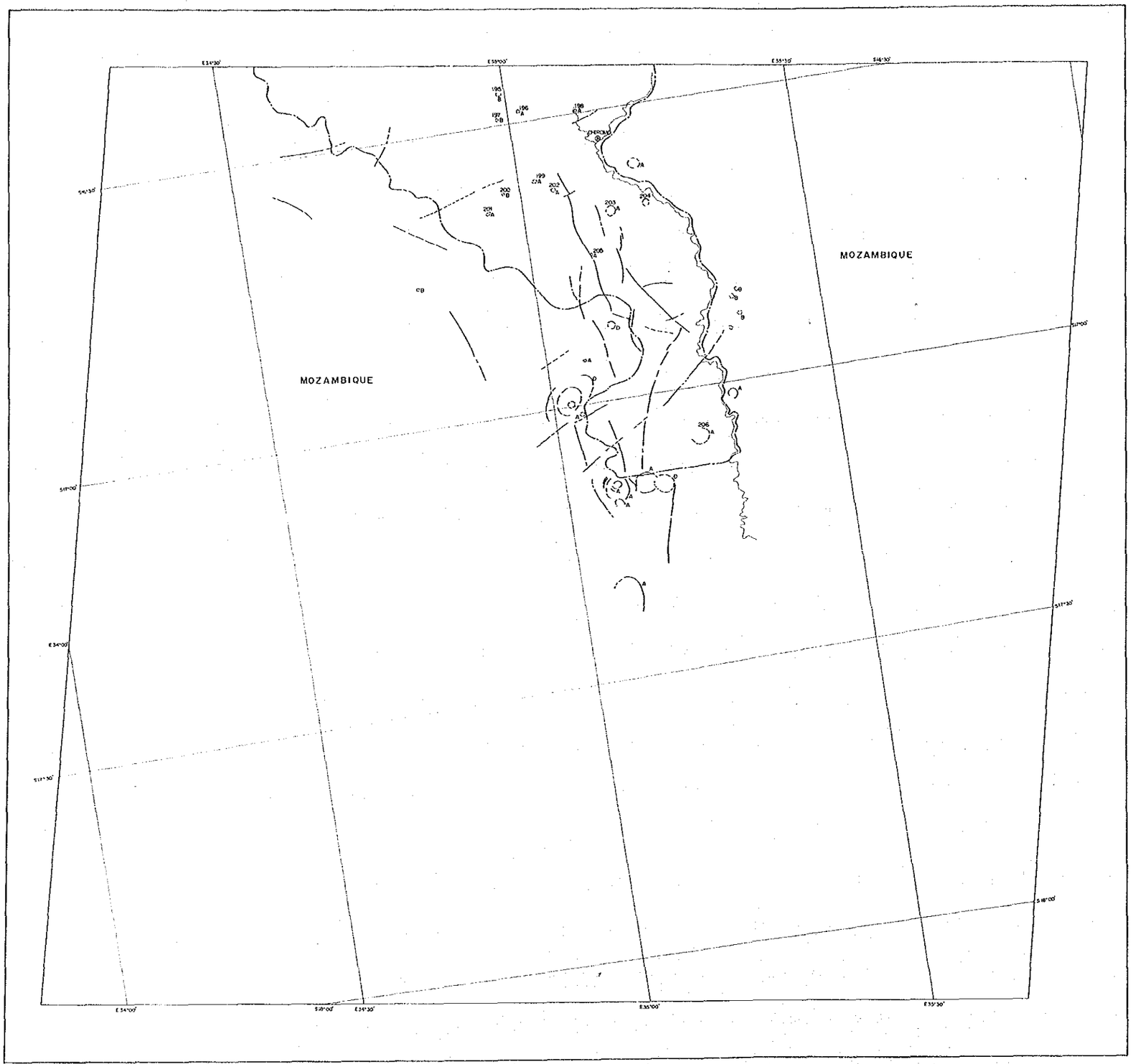
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

LEGEND

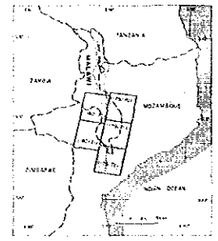
- Circular Structure (Clear)
- Circular Structure (Dim)
- Lineament (Clear)
- Lineament (Dim)
- Basin Structure
- International Boundary
- A Projected Ring Structure
- B Depressed Ring Structure
- C Basin Structure
- D Cone Structure

Fig. 3-2-1(2) Result of Photogeological Interpretation



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

RESULT OF LANDSAT IMAGE
PHOTOGEOLOGICAL INTERPRETATION
(BLANTYRE – 2)



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

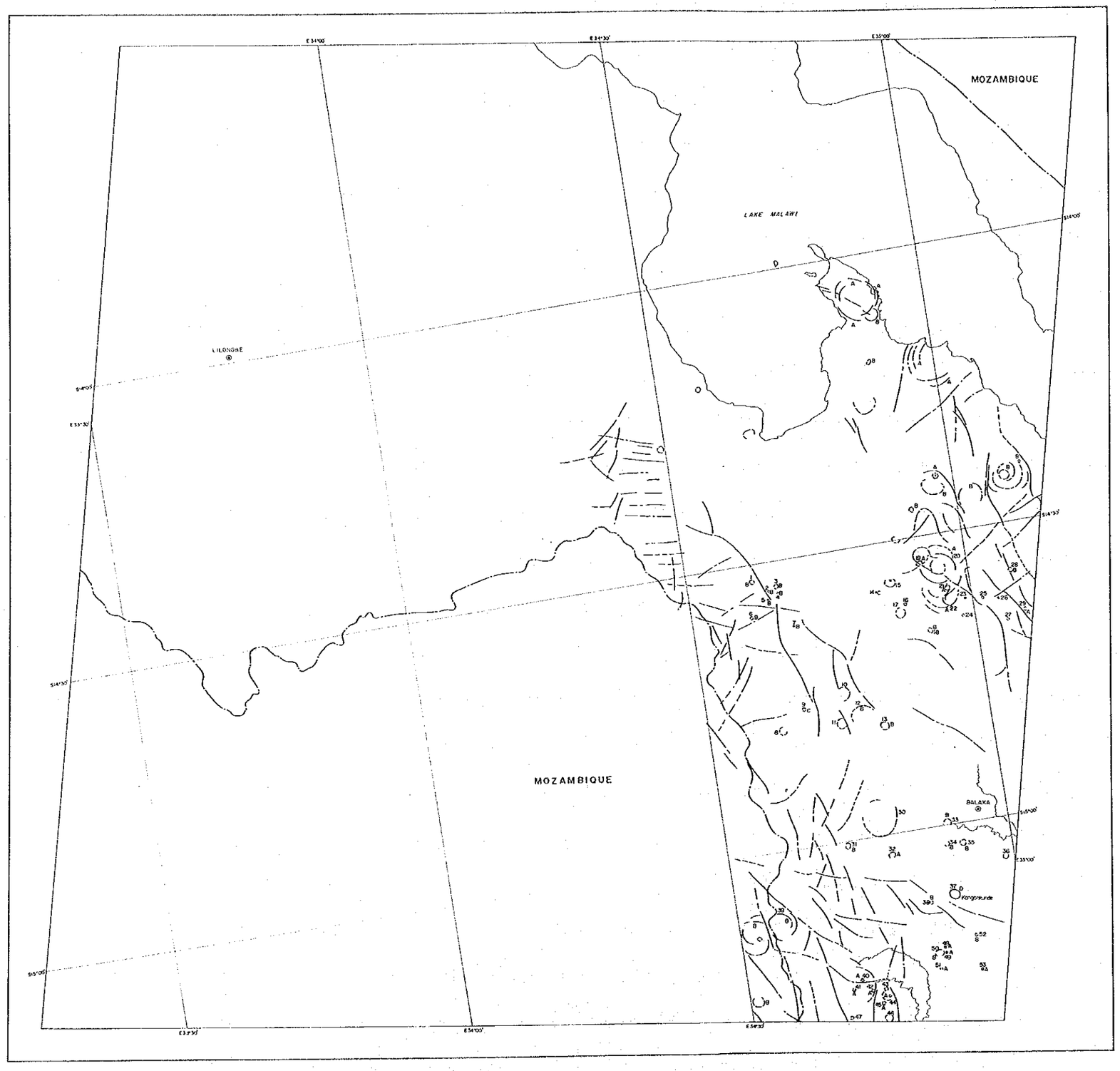
0 10 20km

LEGEND

- Circular Structure (Clear)
- Circular Structure (Dim)
- Lineament (Clear)
- Lineament (Dim)
- Basin Structure
- International Boundary

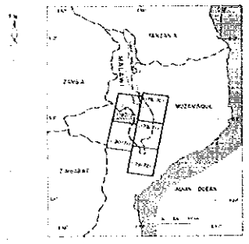
A Projected Ring Structure
B Depressed Ring Structure
C Basin Structure
D Cone Structure

Fig. 3-2-1(3) Result of Photogeological Interpretation



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

RESULT OF LANDSAT IMAGE
PHOTOGEOLOGICAL INTERPRETATION
(MONKEY BAY)



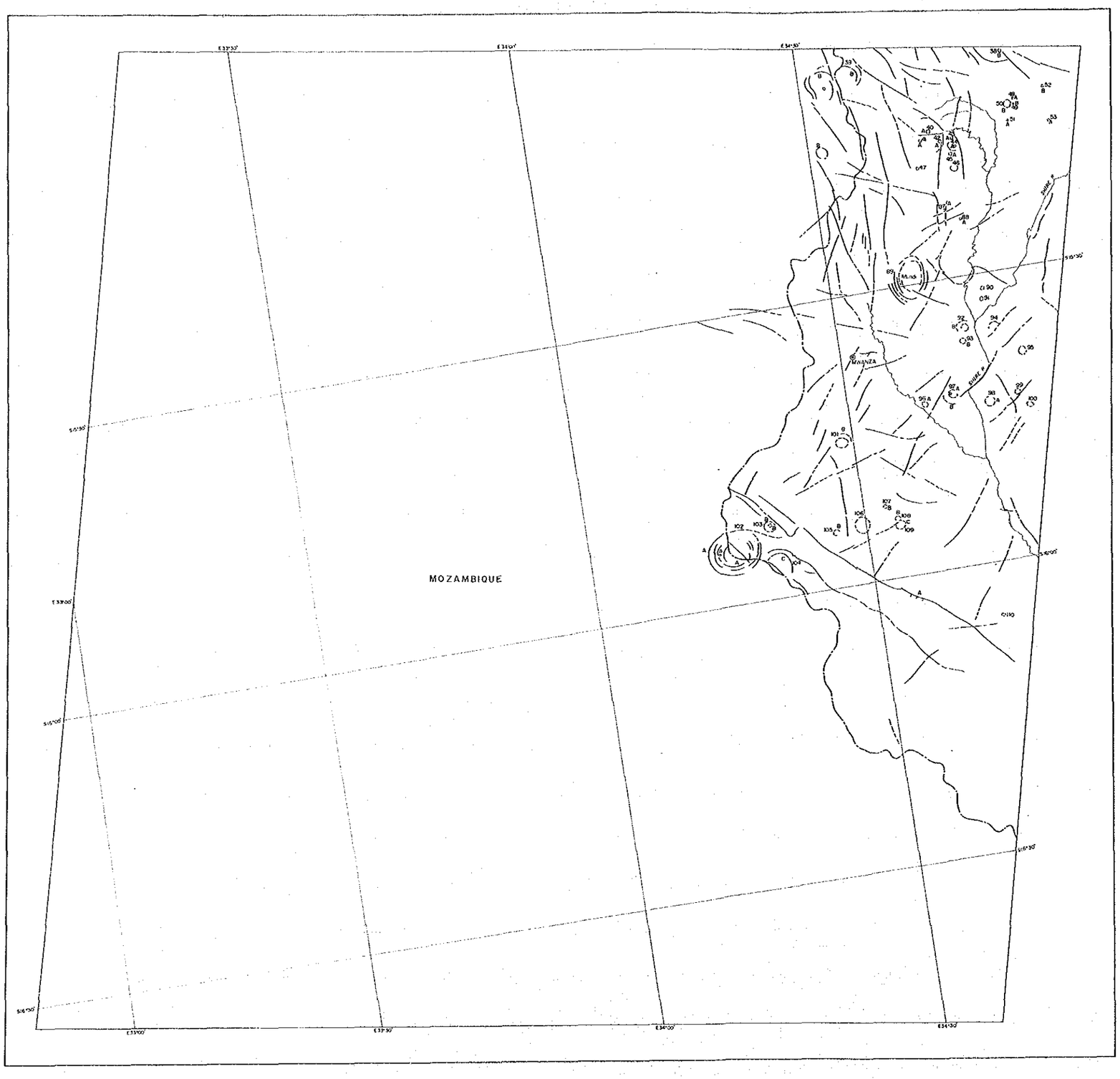
JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0 10 20km

LEGEND

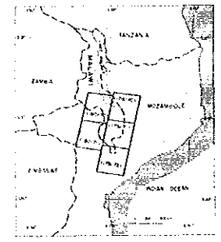
- Circular Structure (Clear)
- Circular Structure (Dim)
- Lineament (Clear)
- Lineament (Dim)
- Basin Structure
- International Boundary
- A Projected Ring Structure
- B Depressed Ring Structure
- C Basin Structure
- D Cone Structure

Fig. 3-2-1(4) Result of Photogeological Interpretation



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

RESULT OF LANDSAT IMAGE
PHOTOGEOLOGICAL INTERPRETATION
(ZOBUE)



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

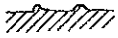
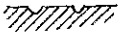
Scale 1 : 250,000

LEGEND

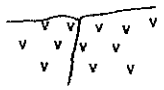
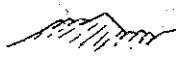
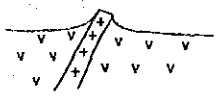
- Circular Structure (Clear)
- Circular Structure (Dim)
- Lineament (Clear)
- Lineament (Dim)
- Basin Structure
- International Boundary
- A Projected Ring Structure
- B Decressed Ring Structure
- C Basin Structure
- D Cone Structure

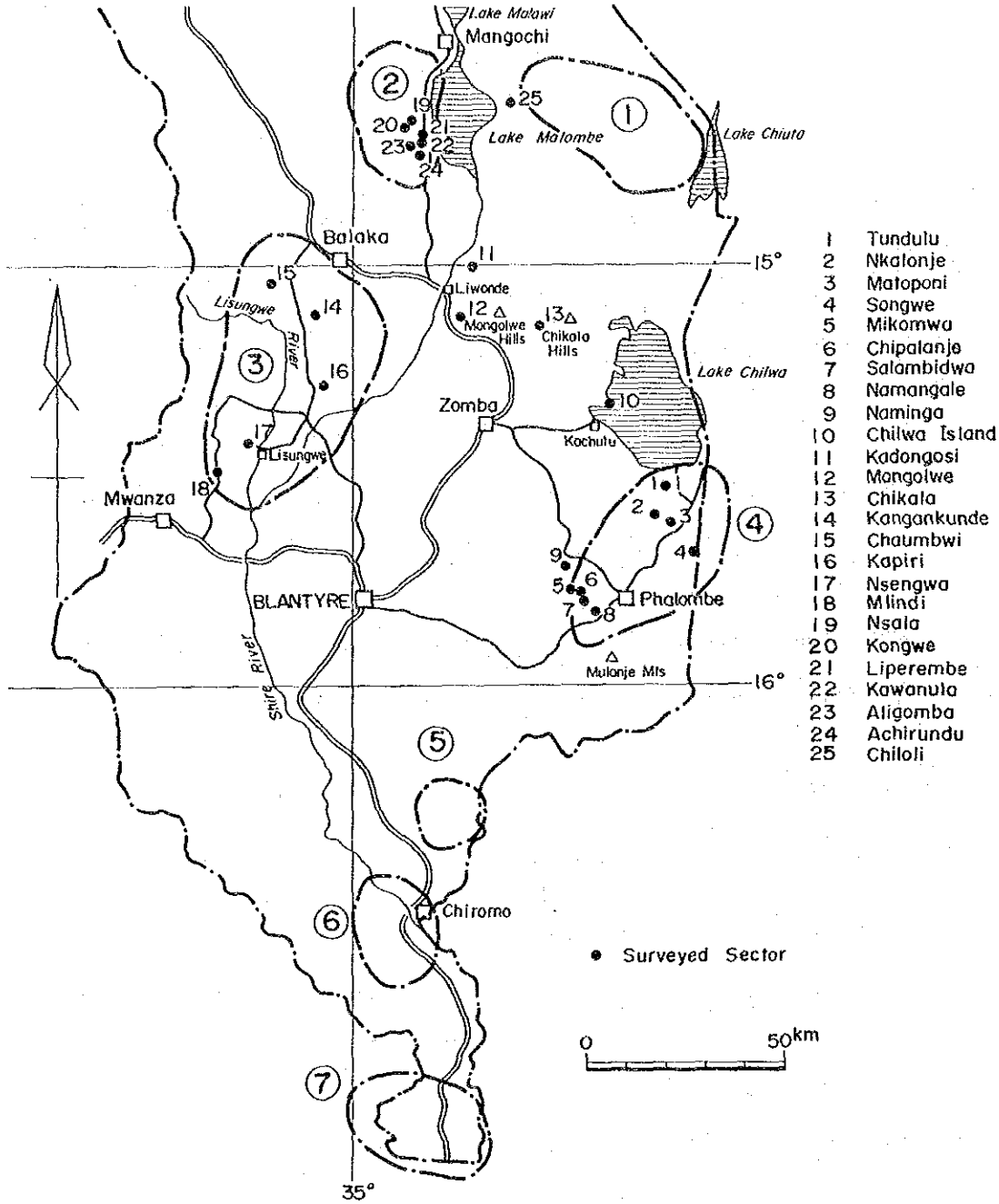
Fig. 3-2-1(5) Result of Photogeological Interpretation

Tab. 3-2-1 Classification of Circular Structure

Type	Illustration	Profile	Inferred geological structure
A. Projected ring structure			ring dyke, cone sheet, crater
B. Depressed ring structure			ring dyke, intrusive pipe
C. Basin structure			explosion crater, meteoric crater
D. Cone structure			intrusive cone, effusive cone

Tab. 3-2-2 Classification of Liniament

Type	Profile
A. Abut, Fault	
B. Fissure	
C. Bedding Schistosity	
D. Dyke	



① East district of Lake Malombe

② West district of Lake Malombe

③ Kangankunde district

④ South district of Lake Chilwa

⑤ North district of Chiromo

⑥ Chiromo district

⑦ South district of Chiromo

Fig. 3-2-2 Distribution of Projected Ring Structures

Among them some of the carbonatites are distributed in 3 districts: 2), 3) and 4). Though the occurrence of carbonatites has not been known yet in the remaining 4 districts: 1), 5), 6) and 7), it can be said that the districts are promising in the discovery of new carbonatite complexes.

The characteristics of the circular structures occurred in each district is described below.

1) East district of Lake Malombe

A type circular structures are recognized at 10 places in the district between Lake Malombe and Lake Chiuta. In this district 2 alkaline igneous bodies are widely distributed and 10 circular structures distribute in the margine of the igneous bodies. These circular structures are generally less than 1 Km in diameter and are almost perfect circles. Moreover, though radiated structures are not obvious, concentric structures are well seen. It is possible that these are ring dykes and cone sheets related to carbonatite.

2) West district of Lake Malombe

A type circular structures are recognized at 8 places in this district. These circular structures are almost less than 1 Km in diameter and concentric structures are partly seen. In this district 6 carbonatities or prospective sites represented by Nsala are distributed.

3) Kangankunde district

A type circular structures are recognized at 14 places in this district. These circular structures are 1-2 Km in diameter and perfect circles. Though radiated structures are not obvious, concentric structures are partly seen. 5 carbonatities or prospective sites represented by Kangankunde are distributed in this district.

4) South district of Lake Chilwa

A type circular structures are recognized at 10 places. In this district 8 carbonatities or prospective sites represented by Tundulu and Songwe are distributed. These circular structures are less than 2 Km in diameter and concentric structures are partly seen.

5) North district of Chiromo

A type circular structures are recognized at 4 places. Though all are perfect circles of less than 1 Km in diameter, radial and concentric structures are not obvious.

6) Chiromo district

Though A type circular structures are recognized at 4 places, it is not very distinct.

7) South district of Chiromo

Though A type circular structures are recognized at one place in Malawi and 6 places in Mozambique, the one in Malawi is not clear.

(2) Lineaments

As shown in Tab. 3-2-2, the liniaments occurred in this area can be conceived as 4 types considering from the genesis. Abut type (A) is seen clearly along the rift valley. (eg: liniament that runs continuously about 70 Km in the NW direction from Chiromo). Fracture type (B) are comparatively short liniament that run irregularly in a homogeneous texture. (eg: NE trending liniament that can be seen in the north of Chiromo). Schistosity type (c) can be taken as closely spaced parallel liniaments. Dyke type (D) can be clearly differentiable from type A and B its 15 projected lines (eg: 30 Km long NS trending liniament in the north of Chiromo).

However, such a kind of classification of liniaments is not necessarily applied to all of the picked up structures and there is no characteristics in their distribution. No special relation is observed between the liniament and carbonatite.

COMPREHENSIVE RESULT OF COMPILATION OF PREVIOUS WORKS AND LANDSAT IMAGE INTERPRETATION

CHAPTER IV COMPREHENSIVE RESULT OF COMPILATION OF PREVIOUS WORKS AND LANDSAT IMAGE INTERPRETATION

As it is shown in Tab. 4-1-1, 25 sectors are selected as the surveyed sectors from the compilation of previous works and the result of LANDSAT image interpretation.

According to the LANDSAT image interpretation, all of the carbonatites and the prospective sites in this surveyed area do not necessarily come out as circular structures. It is considered that alkaline complexes which accompany carbonatites are generally small, i.e., less than 1 Km in diameter, and alkaline complexes having the forms of dykes or volcanic necks are not reflected topographically as circular structures.

It became clear that majority of the circular structures associated with carbonatites belong to the projected ring structure (A type). The projected ring structures are considered as the concentric geologic structures consisting of ring dykes, cone sheets and volcanic craters of alkaline complexes. From that fact, it is assumed that carbonatites were produced by a series of igneous activity during the emplacement of alkaline complexes.

The characteristics of carbonatites of this area is that most of them are associated with breccias and agglomerates. Syenite, nepheline syenite, trachyte, phonolite, nephelinite, etc. are seen as alkaline rocks.

Many of the thorium anomaly of the airborn radiometric survey reflect the alkaline complexes associated with carbonatites. From that fact, it is shown that the radiometric survey (especially thorium) is effective in the exploration of carbonatites.

Tab. 4-1-1 Comprehensive Result of Compilation of Previous Works and LANDSAT Image Interpretation

Surveyed sector	LANDSAT Circular Structure		Chilwa alkaline complex			Airborne survey Thorium anomaly
	Number	Type	Lithology	Occurrence	Type	
1 Tundulu	143	A	nepheline syenite	circular structure	II	anomaly
2 Nkalonje	150	-	nephelinite, nepheline syenite	volcanic neck	II	strong anomaly
3 Matoponi	-	-	phonolite, trachyte	dyke	I	-
4 Songwe	-	-	nephelinite, foyaite	volcanic neck	II	strong anomaly
5 Mikomwa	-	-	phonolite, sölvsbergite	dyke	I	-
6 Chipalanje	-	-	microfoyaite, phonolite	dyke	I	-
7 Salambidwa	172	B	phonolite	dyke	I	-
8 Namangale	176	A	phonolite, microfoyaite	volcanic neck	II	anomaly
9 Naminga	165	C	(gneiss, granite)	(dome structure)	-	strong anomaly
10 Chilwa Island	86	A	nepheline syenite, phonolite	ring dyke, cone sheet	II	strong anomaly
11 Kadongosi	-	-	foyaite, phonolite	volcanic neck	I	-
12 Mongolwe	-	-	pulaskite, nephelinite syenite	ring neck	I	-
13 Chikala	-	-	pulaskite, foyaite	volcanic neck	I	-
14 Kangankunde	37	D	nephelinite, sölvsbergite	circular structure	II	strong anomaly
15 Chaumbwi	32	A	-	volcanic neck	I	-
16 Kapiri	-	-	nephelinite, phonolite	dyke	I	-
17 Nsengwa	-	-	microsyenite	ring dyke	I	-
18 Mlindi	89	-	(ultrabasic rocks)	(ring structure)	-	-
19 Nsala	-	-	microfoyaite, phonolite	ring neck	I	anomaly
20 Kongwe	56	A	nephelinite, phonolite	circular structure	I	anomaly
21 Liperembe	-	-	nephelinite, phonolite	volcanic neck	I	-
22 Kawanula	-	-	nephelinite, lamprophyre	volcanic neck	I	-
23 Aligomba	-	-	phonolite	volcanic neck	I	-
24 Achirundu	57	-	phonolite	volcanic neck	I	-
25 Chiloli	58	A	(granulite, gneiss)	(dome structure)	-	strong anomaly

Note 1: Type of circular structure from LANDSAT image
A: projected ring structure
B: depressed ring structure
C: basin structure
D: cone structure

Note 2: Type of carbonatite and associated alkaline complex
I: volcanic cone
II: volcanic neck
III: upper plutonic stem
IV: deep-steated plutonic stem

Note 3: Thorium anomaly by airborne radiometric survey
strong anomaly: 500 c.p.s. and over
anomaly: 500 ∿ 250 c.p.s.

FIELD SURVEY

CHAPTER V FIELD SURVEY

PART 1 METHOD OF THE SURVEY

In the first year phase, geological and geochemical surveys were done in 25 sectors. Topographic maps of 1/5,000 scale were made from the published topographic maps of 1/50,000 scale. The route map was produced from the enlarged maps. Survey routes were established on the basis of the previous works, paying attention to grasp whole aspects of the carbonatite mineralization. The outcrops of mineralized zone were determined by a simplified survey using a tape and a pocket-compass. The results were put on the 1:10,000 scale geological map. The 1:100 - 200 scale sketches and color photographs were taken at important outcrops.

Geochemical survey was performed at the same time with geological survey. As a principle, samples were collected from carbonatites. In collecting samples, a consideration is taken to elucidate the distribution of elements in carbonatites, characteristics of mineralization, etc. Collected samples were analyzed by the ICP (Inductively Coupled Plasma) method. Analyzed elements were of 60 components as indicated in Tab. 5-1-1. The results of analyses were processed and analyzed statistically with the large, general-use computor HITAC M260D.

Tab. 5-1-1 Elements and Detectable Limits in Geochemical Survey

Aluminum	0.01 %	Germanium	0.01 ppm	Selenium	1 ppm
Antimony	0.1 ppm	Gold	1 ppb	Silicon	0.01 %
Arsenic	0.1 ppm	Hafnium	0.5 ppm	Silver	0.01 ppm
Barium	1 ppm	Iron	0.01 %	Sodium	0.01 %
Beryllium	0.1 ppm	Lanthanum	1 ppm	Strontium	1 ppm
Bismuth	0.1 ppm	Lead	1 ppm	Sulfur	10 ppm
Boron	10 ppm	Lithium	1 ppm	Tantalum	1 ppm
Bromine	50 ppm	Lutetium	1 ppm	Tellurium	0.05 ppm
Cadmium	0.1 ppm	Magnesium	0.01 %	Terbium	1 ppm
Calcium	0.01 %	Manganese	5 ppm	Thallium	0.1 ppm
Carbon	0.01 %	Mercury	5 ppb	Thorium	0.2 ppm
Cerium	2 ppm	Molybdenum	1 ppm	Tin	0.1 ppm
Cesium	1 ppm	Neodymium	5 ppm	Titanium	10 ppm
Chromium	0.5 ppm	Nickel	0.1 ppm	Tungsten	2 ppm
Cobalt	0.1 ppm	Niobium	1 ppm	Uranium	0.1 ppm
Copper	1 ppm	Phosphorous	5 ppm	Vanadium	1 ppm
Dysprosium	1 ppm	Potassium	0.01 %	Ytterbium	0.1 ppm
Europium	0.1 ppm	Rubidium	1 ppm	Yttrium	1 ppm
Fluorine	1 ppm	Samarium	0.1 ppm	Zinc	1 ppm
Gallium	0.1 ppm	Scandium	1 ppm	Zirconium	1 ppm

PART 2 DESCRIPTION OF EACH SECTOR

2-1 Tundulu Sector

2-1-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-1)

Tundulu sector is located in the northern part of Mulanje district. It lies on the southern coast of Lake Chilwa near to the border between Mozambique and Malawi, having 4 Km east-west by 4 Km north-south in width. To reach this sector, it takes about 1 hour (about 43 Km) from Phalombe, the seat of the sub-district headquarters, by a 4-wheel vehicle.

In addition, it takes about 1 hour (about 80 Km) to reach Phalombe from Blantyre or about 1 hour 40 minutes (about 85 Km) from Zomba by car.

This sector displays a double ring topography which rises about 300 m from the plain of 650 m elevation, forming partly steep slopes. The land at the foothill is used for agriculture.

2-1-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by syenite and granite of the basement of late pre-Cambrian to early Paleozoic era which are intruded by the nepheline syenite, feldspathic breccia and and carbonatites of the Chilwa alkaline province (Fig. 5-21, PL. 2-1).

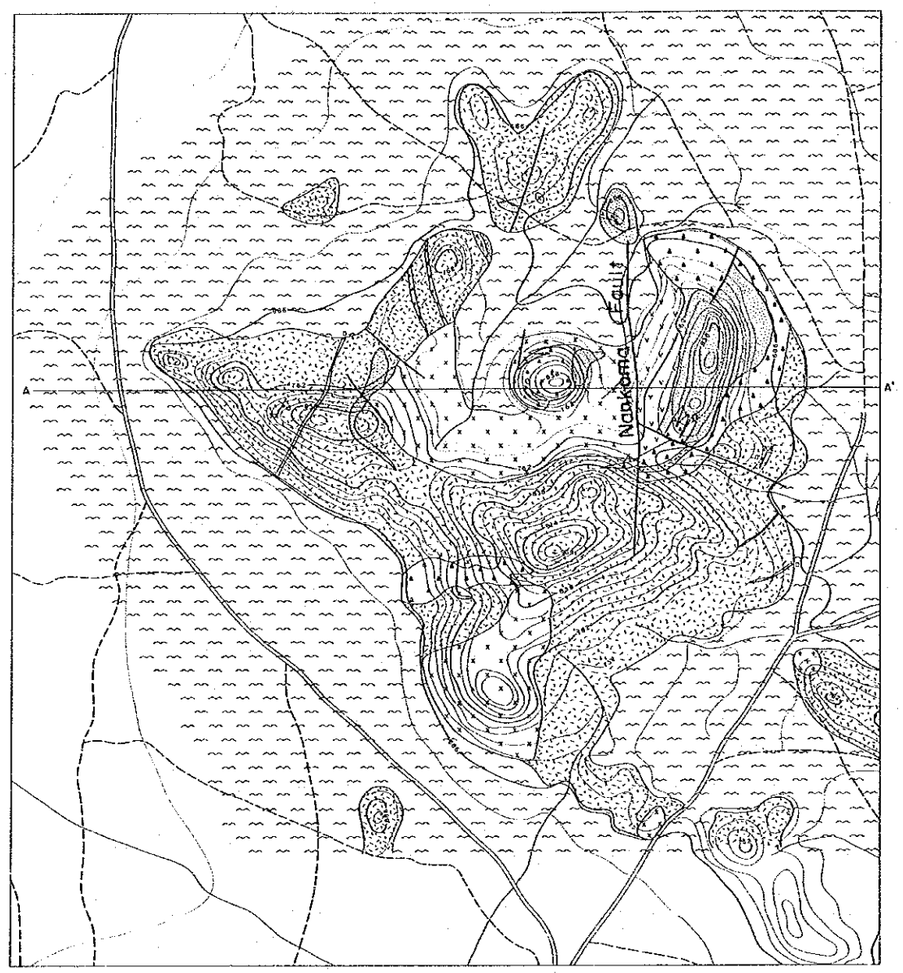
Granite in the basement is pinkish in color, hard and compact and associates amphibole. Syenite is grayish-white in color, hard, compact and associates a few quartz.

Nepheline syenite is greenish in color, hard, compact and shows medium-grained equigranular texture. Under the microscope, it is composed of orthoclase, nepheline, biotite and aegirine, with cancrinite, calcite, sphene and apatite (Appendix 5, Appendix 9). From the results of the whole rock analysis and norm calculation, it is correspond to urtite (Appendix 4, Appendix 12). The result of age determination is 132.4 - 136.2 Ma and it shows that the time of intrusion is in the early Cretaceous (Appendix 10).

Feldspathic breccia is a vesicular and britle rock showing a characteristic color of pale vermillion to reddish-brown and often contains rock fragments of carbonatite. Under the microscope, it contains rock fragments of monzonite or tuff, and is often observed a intersertal texture with carbonates.

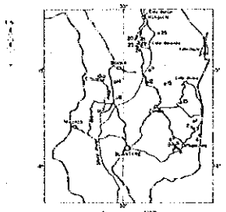
The geological structure of this sector consists of 2 ring structures overlapping each other. The first ring structure is a circle of 1,600m diameter having the center at the west foothill of the Tundulu hill. The second ring structure is an elliptical circle of 600m x 800m, centering the Nathace hill. The first ring structure is made up of feldspathic breccia and carbonatized feldspathic breccia. The second ring structure consists of nepheline syenite ring dyke having breccia in its cone, and apatitic and bastnaesitic carbonatite ring dyke.

Garson (1962) made the analysis of strain patterns and assumed that the center of the volcanic activity that formed the first ring structure was situated 1,200m - 1,300m depth and the centers of the second ring structure were located in 2 places 2,400m - 3,000m and 500m - 700m depths under the present ground surface.



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

GEOLOGICAL MAP AND PROFILE
OF THE Tundulu (1)



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LEGEND

- Drift
- Sodaine carbonatite
- Alkaline lavite
- Lavite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolite breccia
- Foyaite gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Eqvite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granulite
- Pyroxenite
- Biotite-metagyrowinite, metagabbro & benfite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte
  P – Phonolite
  N – Nephelinite
  MF – Microfoyaite
  S – Sölvsbergite
  I – Ijolite
  D – Dolerite
  M – Monchiquite
  A – Aplite
- Fault
- Dip of foliation of gneiss

A–A' Section
(W–E)

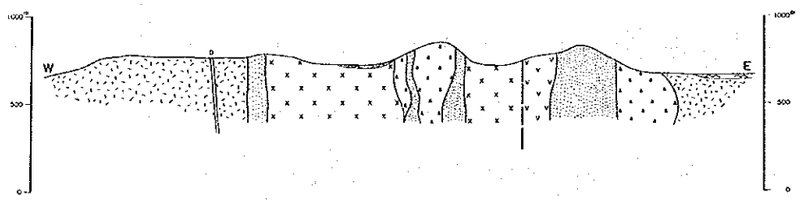


Fig. 5-2-1 Geological Map and Profile of Tundulu Sector

The major fault direction in this sector is N-S to NNE-SSW. A system of ESE-WNW trending faults perpendicular to the former is small faults. Nankoma fault can be represent as one of the major fault system which trends along the Nankoma stream that runs in the west of the Tundulu hill. It displaces the west block about 250m relatively to the north.

(2) Carbonatite

Carbonatites in the sector are as large ones as those of Chilwa Island, Kangankunde sectors. These carbonatites can be classified as sövitic, apatitic and bastnaesitic. The sövite are located in an area of 400m east-west by 1,000m north-south centering Tundulu hill which lies in the eastern part of this sector; and in an area of 100m east-west and 400m north-south at the west foothill of Makhanga which lies in the western part. Apatitic and bastnaesitic carbonatites are small ones that are located at the Nathace hill which is in the center of this sector.

Feldspathic breccias that associate with carbonatites are widely distributed at the Nathace hill, eastern foothill of the Tundulu, Milala and Chigwakwalu hill.

Sövite is milky white in color, compact and show medium to fine-grained equigranular texture. It is rich in magnetite and concentrated parts of magnetite about 10cm in size are formed in some places. Under the microscope, it is composed mainly of carbonates, with biotite, aegirine, apatite and minute crystals of magnetite, pyrite and iron oxides (Appendix 7). EPMA analysis shows that aegirine contains a few amount of Sr (Appendix 11).

Apatitic carbonatite is greenish-white in color, equigranular and often carries dark brown siderite. Under the microscope, it is composed mainly of apatite and quartz, with alkali feldspar and limonite and minute crystals of rutile and zircon (Appendix 7). EPMA analysis shows that rutile contains a few amount of Nb and apatite contains Sr (Appendix 11).

Bastnaesitic carbonatite is mostly recognized as dull yellow, fine-grained brittle, powdery rock.

2-2 Nkalonje Sector

2-2-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-2)

Nkalonje sector is located in the northern part of Mulanje district, about 10 Km from the south coast of Lake Chilwa, having 2 Km east-west by 1.5 Km north-south in width. To reach this sector, it takes about 1 hour (about 35 Km) from Phalombe by car.

The topography is a hill of about 180 m high rising from the plain of 640 m elevation. The land at the foothill is used for agriculture.

2-2-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by granulite of the basement and feldspathic breccia, nepheline syenite and carbonatite of the Chilwa alkaline province which intrude into the basement (Fig. 5-2-2, PL. 2-2). Feldspathic breccia is distributed in a cricle of 800m in diameter centering Nkalonje hill.

Nepheline syenite can be seen on the southern and the northeastern slopes of the Nkalonje hill. The former is medium to coarse-grained sheets while the latter is fine-grained dykes. Under the microscope, it shows medium-grained granular texture and consists of plagioclase, orthoclase, aegirine and sodalite. Biotite, sphene and cancrinite are also observed as accessory minerals (Appendix 5). From the results of the whole rock analysis and norm calculation, it is correspond to foyaite (Appendix 4, Appendix 12).

(2) Carbonatite

A dyke of carbonatite occurs in granulites on the northeastern slope of the Nkalonje hill. The dyke has the strike N10° - 20°W, dipping vertical, having 0.6m - 4m in width and about 150m in length along the strike.

Lithology is grayish-white in color, fine-grained, sövitic and often contains vermillion-colored feldspathic rock fragments. Through rare minerals are not observed in this survey, pyrochlore, bastnaesite, strontianite and sphalerite are reported as minerals (Garson, 1965).

2-3 Matoponi Sector

2-3-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-3)

Matoponi sector is located in the northern part of Mulanje district, about 5 Km to the southeast of Nkalonje sector, having 1 Km east-west by 2 Km north-south in width. To reach this sector, it takes about 40 minutes (about 29 Km) from Phalombe by car.

The topography is a small hill of about 100 m rising from the plain of 650 m elevation. The plain at the foothill is used for agriculture.

2-3-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by granulite and hornblende gneiss of the basement and nephelinite, phonolite and carbonatite of the Chilwa alkaline province which intrude into the basement (Fig. 5-2-3, PL. 2-3).

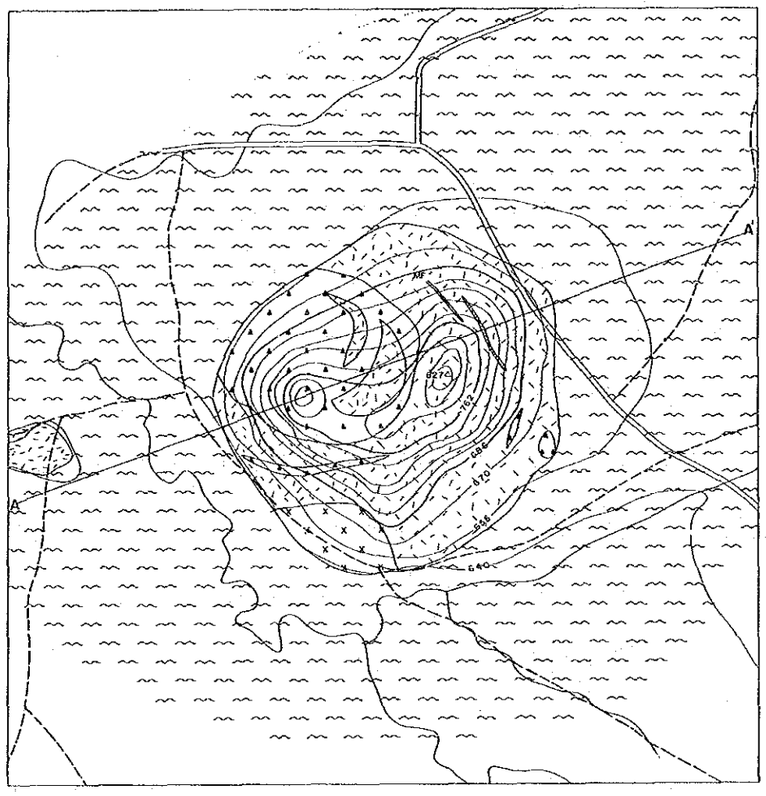
Nephelinite occurs as dykes having a few meters in width on the ridge of the Matoponi hill.

Phonolite occurs as dykes having a maximum width of 1.5m on the western slope of the Matoponi hill. Under the microscope, it shows spherulitic texture and comprises K-feldspar, biotite, aegirine, cancrinite, calcite, natrolite, sodalite and magnetite (Appendix 5, Appendix 9). From the results of the whole rock analysis and norm calculation, it is correspond to phonolite (Appendix 4, Appendix 13).

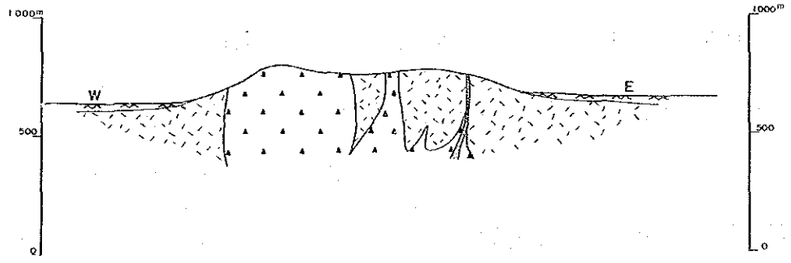
(2) Carbonatite

A dyke of carbonatite crops out near the contact between granulite and gneiss on the northeastern slope of the Matoponi hill. The lithology is sövitic to ankeritic and thin lense-like layers of feldspathic breccias (maximum 10cm in width) are often sandwitched in it.

Pyrochlore and apatite are reported as minerals (Garson, 1965).



A–A' Section
(N70E)



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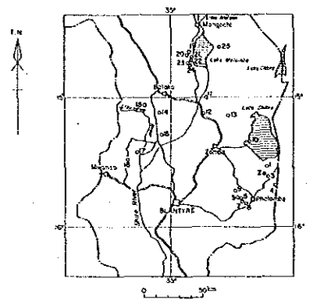
GEOLOGICAL MAP AND PROFILE OF THE Nkalonje (2)



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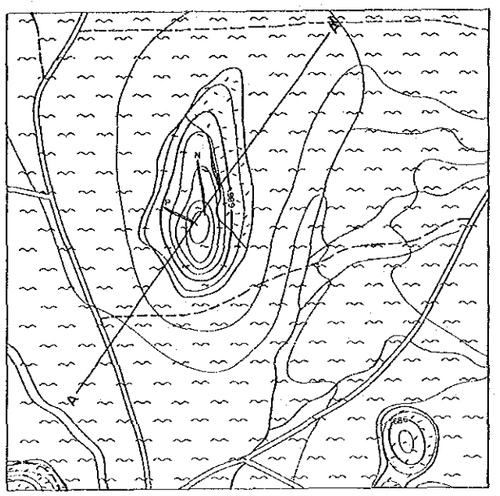
0m 500m 1000m

LEGEND

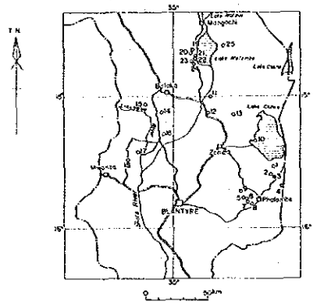
- Drift
- Siderilic carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, melagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T—Trachyte
  P—Phonolite
  N—Nephelinite
  MF—Microfoyaite
  S—Sölvsbergite
  I—Ijolite
  D—Dolerite
  M—Monchiquite
  A—Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-2 Geological Map and Profile of Nkalonje Sector



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

GEOLOGICAL MAP AND PROFILE
OF THE Matoponi (3)



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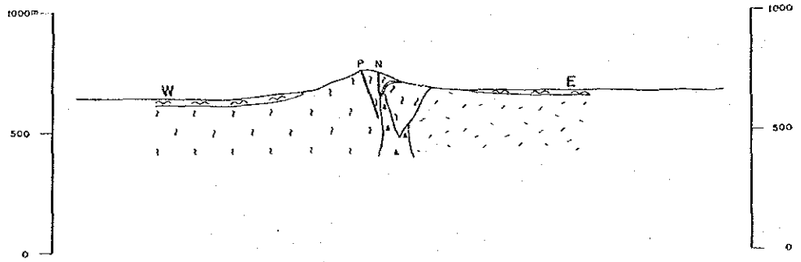
0m 500m 1,000m

A-A' Section
(N35E)



LEGEND

- Drift
- Siderite carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Fujaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte
  P – Phonolite
  N – Nephelinite
  MF – Microfoyaite
  S – Sölvsbergite
  I – Ijolite
  D – Dolerite
  M – Monchequite
  A – Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-3 Geological Map and Profile of Matoponi Sector

2-4 Songwe Sector

2-4-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-4)

Songwe sector is located in the northern part of Malanje district. It lies in the middle part of the northwest flank of the Mauze mountain which is in the northeast of Mulanje mountains, having 2 Km east-west by 2 Km north-south in width. To reach this sector, it takes about 1 hour (about 28 Km) from Phalombe by car.

The topography is characterized by a small peak (990 m), having very steep slopes on the flank of the Mauze mountain (1363 m). The hillside is covered by a thick miscellaneous forest.

This surveyed sector is located about 2 Km from the Mozambique border.

2-4-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by gneiss of the basement and nepheline syenite, feldspathic breccia and carbonatite of the Chilwa alkaline province which intrude into the basement (Fig. 5-2-14, PL. 2-4).

Nepheline syenite that forms the Mauze mountain is gray-colored, medium-grained rock containing pink nepheline and dark green pyroxene. Under the microscope, it comprises microperthite, nephelinite, cancrinite and aegirine with sphene, magnetite, sodalite and apatite (Appendix 5). From the results of the whole rock analysis and norm calculation, it is correspond to foyaite (Appendix 4, Appendix 12).

Feldspathic breccia is distributed in an ellipstical area of 600m x 500m centering the Songe hill. Breccia often contains lens-like carbonatites.

(2) Carbonatite

Carbonatites in this sector form 2 ring dykes in feldspathic breccia on the northern slope of the Songwe hill. The west carbonatite ring dyke is larger than the east, having the maximum width of 50m and 500m in length.

Lithology is mostly grayish-white and sövitic, dark brown ankeritic and bastnaesite rich ones can also be observed.

Pyrochlore, bastnaesite, siderite, apatite and fluorite as minerals are reported (Garson, 1965).

2-5 Mikomwa Secttor

2-5-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-5)

Mikomwa sector is located in the center of Mulanje district, having a width of 1 Km east-west by 1.5 Km north-south, in the Phalombe plain which spreads out in the northwest of Mulanje mountains. To reach this sector, it takes about 30 minutes (about 13 Km) from Phalombe by car.

The topography is a small hill of about 130 m high rising from the plain of 730 m elevation. Agriculture prospers at the foothill.

2-5-2 Geology and Ore Deposits

(1) Geology

This sector is widely distributed with gneiss of the basement, and some dolerite and phonolite dykes and small bodies of feldspathic breccia of the Chilwa alkaline province (Fig. 5-2-5, PL. 2-5).

Dolerite is dark green, hard and compact rock. Sometimes fine-grained pyroxenes are observed in it.

A phonolite dyke having a width of 5m, striking N10°E along the ridge of the Mikomwa hill is recognized. It is dark green to dark grey in color and often comprises phenocrysts of biotite.

Feldspathic breccia forms an ellipstical body of 40m x 100 m on the northern flank of the Mikomwa hill. The matrix in the rock is filled with carbonate materials and some parts contain rock fragments of fine-grained, porphyritic trachyte.

The gneissose structure of the basement is clear; striking N10° - 15°W and dipping 70° - 80°W.

(2) Carbonatite

Carbonatite is not recognized in this sector.

2-6 Chipalanje Sector

2-6-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-6)

Chipalanje sector is located in the center of Mulanje district, 1 Km to the southeast of Mikomwa sector; having 1 Km east-west by 1 Km north-south in width. To reach this sector, it takes about 30 minutes (about 12 Km) from Phalombe by car.

The topography is a small hill of about 60 m high rising from the plain of 730 m elevation.

2-6-2 Geology and Ore Deposits

(1) Geology

This sector is widely underlain by gneiss of the basement and some dolerite dykes, fine-grained foyaite dykes and breccias of the Chilwa alkaline province (Fig. 5-2-6, PL. 2-6).

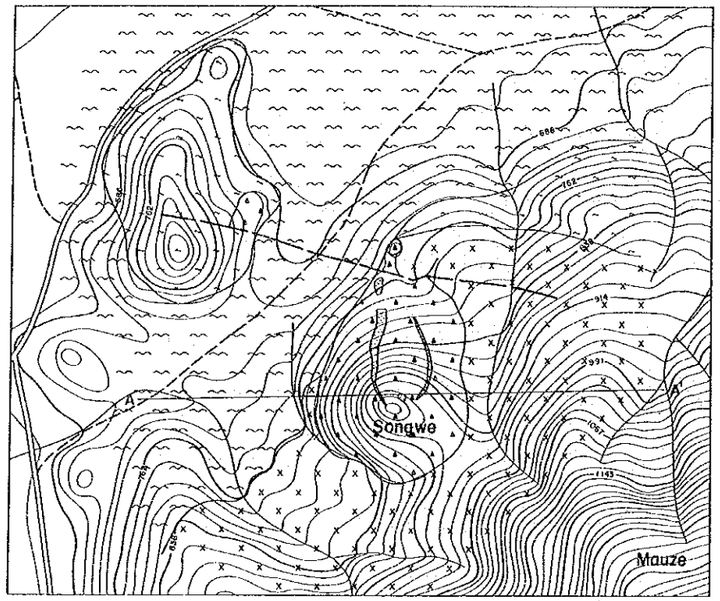
The fine-grained foyaite occurs as nearly perpendicular dykes of 4m in width striking N10°E on the northern slope of the Chipalanje hill. Under the microscope, it consists of plagioclase, orthoclase, quartz and biotite with hornblende, magnetite, apatite and zircon (Appendix 5). From the results of the whole rock analysis and norm calculation, it is correspond to pulaskite (Appendix 4, Appendix 12).

Feldspathic and trachytic breccia outcrop having 1 - 2m in width, trending WNW is exposed on the northern hillock of the Chipalanje hill. Some matrices of feldspathic breccia are metasomatically changed into carbonate minerals.

The gneissose structure in the basement shows strike N10°E - N20°W and dip 75° - 80°W.

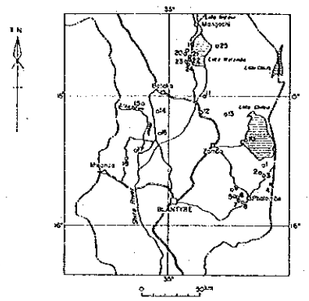
(2) Carbonatite

Carbonatite is not recognized in this sector.



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

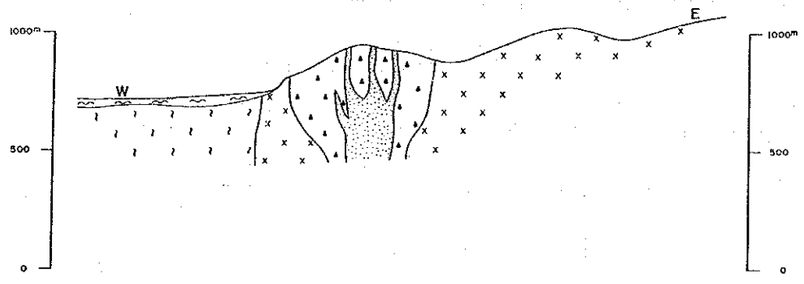
GEOLOGICAL MAP AND PROFILE
OF THE Songwe (4)



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1000m

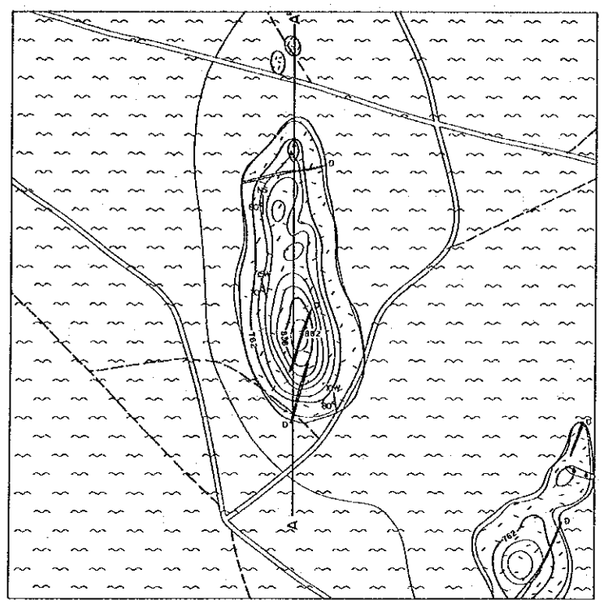
A-A' Section
(W-E)



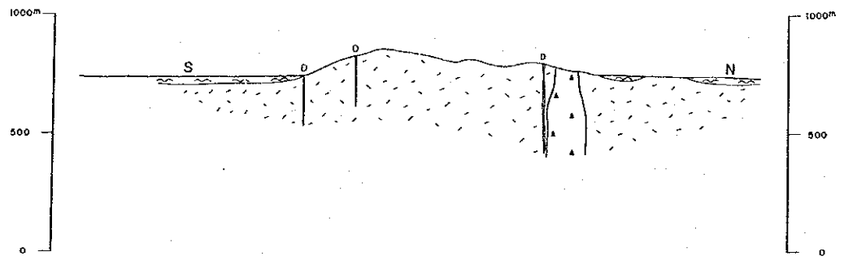
LEGEND

- Drift
- Sidenitic carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T-Trachyte, P-Phonolite, N-Nephelinite, MF-Microfoyaite, S-Sölvsbergite, I-Ijolite, D-Dolerite, M-Monchiquite, A-Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-4 Geological Map and Profile of Songwe Sector

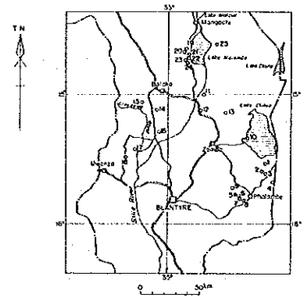


A-A' Section
(S - N)



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

GEOLOGICAL MAP AND PROFILE OF THE Mikomwa (5)



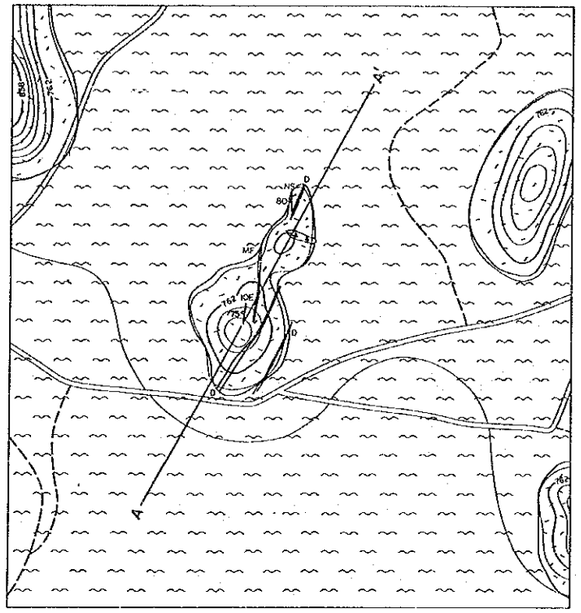
JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1,000m

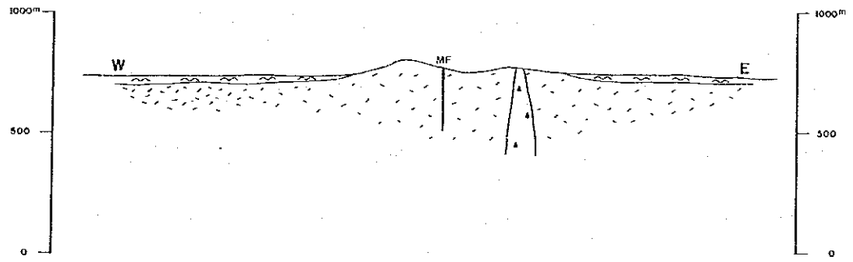
LEGEND

- Drift
- Sideritic carbonatite
- Ankeritic sövite
- Sovite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte
  P – Phonolite
  N – Nephelinite
  MF – Microfoyaite
  S – Sölvsbergite
  I – Ijolite
  D – Dolerite
  M – Monchiquite
  A – Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-5 Geological Map and Profile of Mikomwa Sector

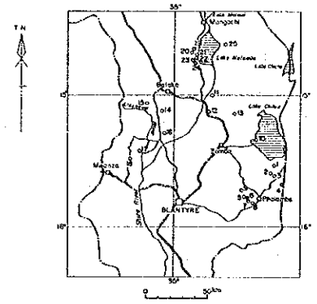


A–A' Section
(N30E)



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

GEOLOGICAL MAP AND PROFILE OF THE Chipalanje (6)



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1000m

LEGEND

- Drift
- Sideritic carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T–Trachyte, P–Phonolite, N–Nephelinite, MF–Microfoyaite, S–Sölvsbergite, I–Ijolite, D–Dolerite, M–Monchiquite, A–Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-6 Geological Map and Profile of Chipalanje Sector

2-7 Salambidwa Sector

2-7-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-7)

Salambidwa sector is located in the center of Mulanje district, 1.5 Km to the southeast of Chipalange sector, having 1 Km east-west by 1 Km north-south in width. To each this sector, it takes about 25 minutes (about 11 Km) from Phalombe by car.

The topography is a gentle hill of about 60 m high rising from the plain of 730 m elevation.

2-7-2 Geology and Ore Deposits

(1) Geology

This sector is widely underlain by gneiss of the basement and some dolerite dykes, phonolite dykes, fine-grained foyaite and breccias of the Chilwa alkaline province (Fig. 5-2-7, PL. 2-7).

Phonolite occurs as a set of dykes trending N20E on the western slope of the Salambidwa hill. Under the microscope, phenocryst is of anorthoclase with haüyne, plagioclase, cancrinite, apatite, magnetite and calcite (Appendix 5). From the results of the whole rock analysis and norm calculation, it is correspond to phonolite (Appendix 4, Appendix 13).

Fine-grained foyaite occurs as a dyke of 1m in width on the northwestern slope of the Salambidwa hill.

Breccia forms 3 small lens-shape bodies having 20m in width and 100 - 200m in length. The lithology is feldspathic and trachytic.

The gneissose structure of the basement shows strike N10°E and dip 60° - 85°W.

(2) Carbonatite

Carbonatite is not recognized in this sector.

2-8 Namangale Sector

2-8-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-8)

Namangale sector is located in the center of Mulanje district, 3 Km southeast of Salambidwa sector, having 1.5 Km east-west by 2 Km north-south in width. To reach this sector, it takes about 15 minutes (about 8 Km) from Phalombe by car.

The topography is a hill of about 220 m high rising from the Phalombe plain of 760 m elevation, partly developing steep slopes.

Farms are cultivated up to the slope near the mountain top.

2-8-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by granitic gneiss of the basement and feldspathic breccia and brecciated phonolite of the Chilwa alkaline province. Small bodies of phonolite, trachyte and fine-grained foyaite are also recognized (Fig. 5-2-8, PL. 2-8).

Feldspathic breccia is recognized in an area of 700m x 1,000m on the northeastern to north slope of the Namangale hill. It is rich in pink to vermillion-colored anthoclase. Fenitized fragments of the basement are also observed in it.

Brecciated phonolite crops out in two places on the east and north ridges of the Namangale hill having 100m x 100m and 200m x 300m in width respectively. It contains dark grey, subangular to subrounded phonolite fragements of a few centimeters to tens of centimeter in size. Its matrix is hard.

Phonolite is compact and hard rock exposing on the eastnortheastern slope of the hill. Under the microscope, it shows porphyritic texture and consists of phenocrysts of sanidine, aegirine, magnetite and sphene, groundmass of sanidine, plagioclase, aegirine, nepheline, cancrinite, apatite and biotite (Appendix 5, Appendix 9). From the results of the whole rock analysis and norm calculation, it is correspond to phonolite (Appendix 4, Appendix 13). The result of age determination is 128.2 - 134.2 Ma, showing the time of intrusion in the early Cretaceous (Appendix 10).

Trachyte is exposed as small dykes in the east and north of the hill. Pinkish to greenish trachytic feldspars are the characteristic of this rock. Under the microscope, it shows trachytoid texture, comprises phenocrysts of anorthoclase and biotite, groundmass of nepheline, analcime, calcite, cancrinite, sphene, magnetite and apatite (Appendix 5). From the results of the whole rock analysis and norm calculation, it is correspond to phonolite (Appendix 4, Appendix 13).

(2) Carbonatite

Carbonatite is not recognized in this sector.

2-9 Naminga Sector

2-9-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-9)

Naminga sector is located in the northwest of Mulanje district, 7 Km northwest of Mikomwa sector, having a width of 4 Km east-west by 1.5 Km north-south in the Phalombe plain. To reach this sector, it takes about 50 minutes (about 20 Km) from Phalombe by car.

Topographically, this sector is occupied by the hill of Naminga about 60 m high and the hill of Mingambo about 140 m high which lies to the east of the former, rising from the plain of 720 m elevation.

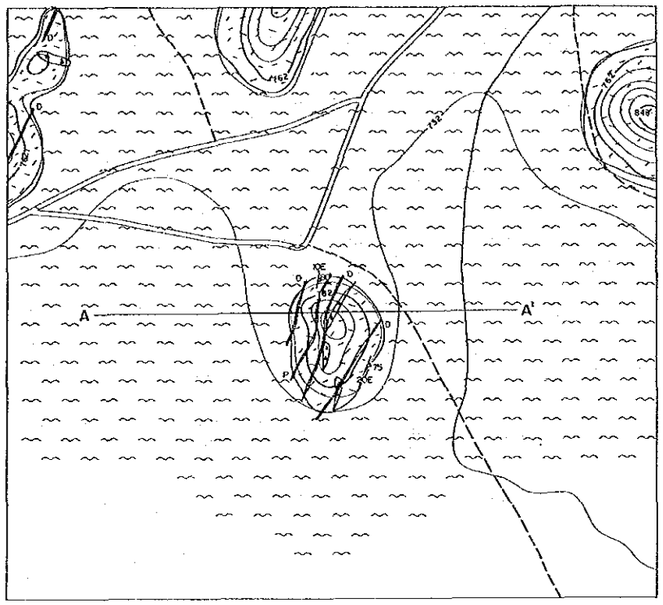
2-9-2 Geology and Ore Deposits

(1) Geology

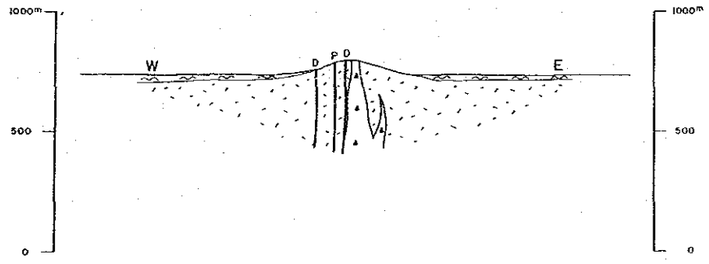
This sector is underlain by granite of the basement. Granite is fine to coarse-grained and equigranular, biotite and hornblend are recognized in it (Fig. 5-2-9, PL. 2-9).

(2) Carbonatite

In this sector, neither carbonatite nor breccia is recognized. However, a pegmetitic quartz vein of 25cm - 30 m in width, striking N75°W and dipping 50°N, is recognized on the southeastern slope of the Mingambo hill in the eastern part of this sector.

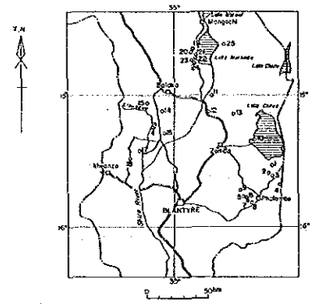


A–A' Section
(W–E)



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

GEOLOGICAL MAP AND PROFILE OF THE Salambidwa (7)



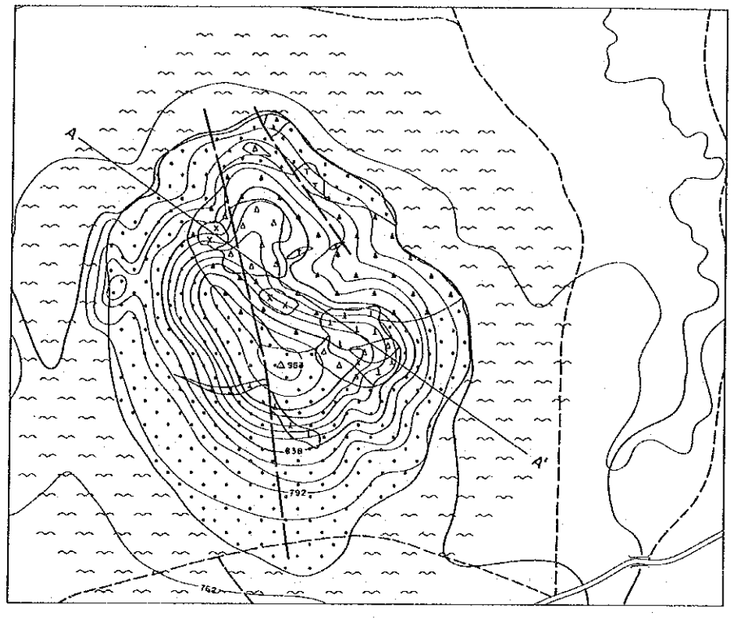
JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1000m

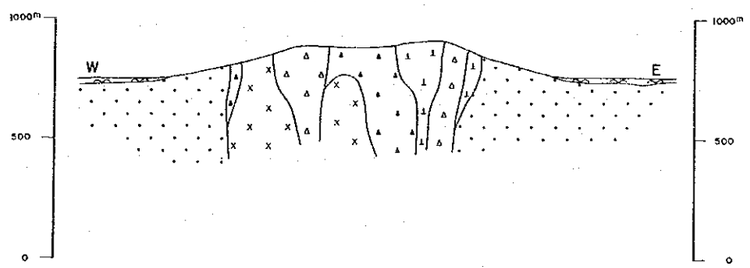
LEGEND

- Drift
- Sideritic carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, melagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte; P – Phonolite; N – Nephelinite; MF – Microfoyaite; S – Sölvsbergite; I – Ijolite; D – Dolerite; M – Monchiquite; A – Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-7 Geological Map and Profile of Salambidwa Sector

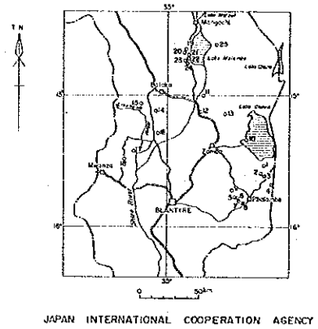


A–A' Section
(N55W)



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

GEOLOGICAL MAP AND PROFILE
OF THE Namangale (8)



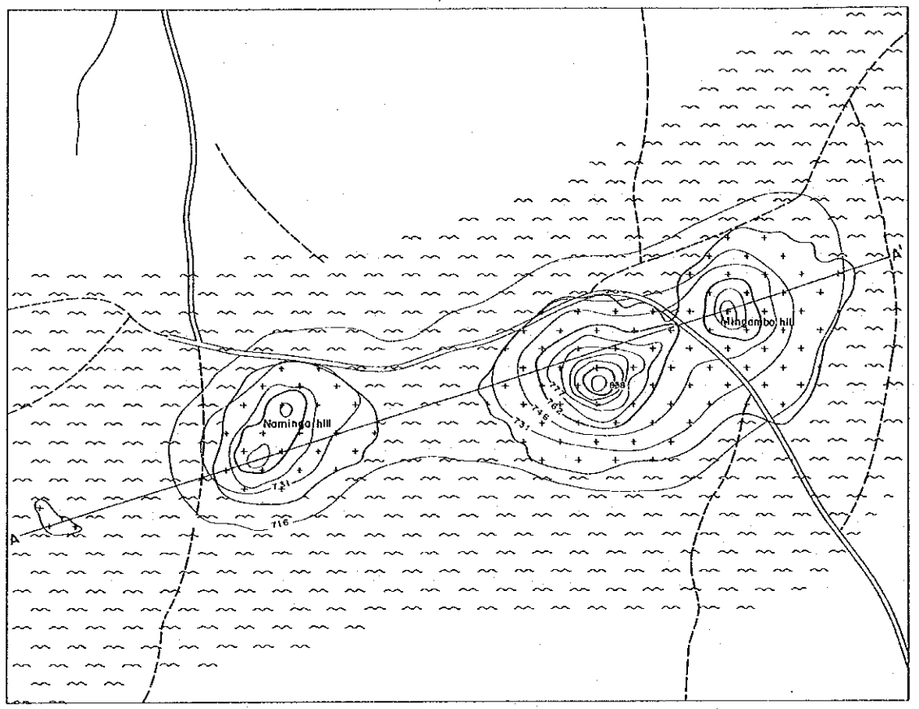
JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1000m

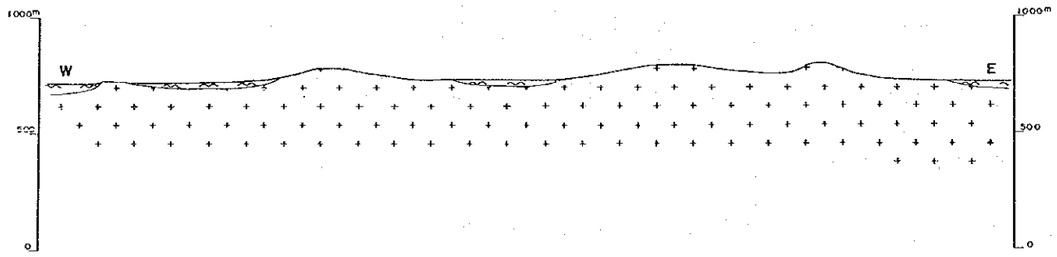
LEGEND

- Drift
- Sidentic carbonatite
- Ankeritic sövite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotitite
- Meta conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte
  P – Phonolite
  N – Nephelinite
  MF – Microfoyaite
  S – Sölvsbergite
  I – Ijolite
  D – Dolerite
  M – Monchiquite
  A – Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-8 Geological Map and Profile of Namangale Sector

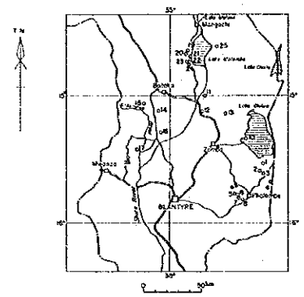


A – A' Section
(N73° E)



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

GEOLOGICAL MAP AND PROFILE
OF THE Naminga (9)



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1987

0m 500m 1000m

LEGEND

- Drift
- Sidentic carbonatite
- Ankeritic sovite
- Sövite
- Carbonate-Silicate rock
- Feldspathic breccia, agglomerate
- Phonolitic breccia
- Fenitized gneiss
- Trachyte
- Phonolite
- Nephelinite
- Syenite (Pulaskite)
- Nepheline syenite (Foyaite)
- Hornblende biotite-gneiss
- Granulite and gneissose granite
- Dolomitic marble
- Dolerite
- Granite
- Perthosite
- Biotite-metapyroxenite, metagabbro & biotite
- Melo conglomerate
- Green pyroxene skarn
- Dykes and plugs T – Trachyte
  P – Phonolite
  N – Nephelinite
  MF – Microfoyaite
  S – Sölvsbergite
  I – Ijolite
  D – Dolerite
  M – Monchiquite
  A – Aplite
- Fault
- Dip of foliation of gneiss

Fig. 5-2-9 Geological Map and Profile of Naminga Sector

2-10 Chilwa Island Sector

2-10-1 Location, Transportation and Topography (Fig. 1-1-2 & Fig. 5-2-10)

Chilwa Island sector is located in the eastern part of Zomba district. It is an island near to the west shore of Lake Chilwa, having 4 Km east-west by 4 Km north-south in width. To reach this sector, it takes about 1 hour (about 31 Km) from Zomba to Kachulu port which is situated on the west shore of Lake Chilwa, by car; and it takes about 40 minutes (about 2.5 Km) from Kachulu port to Tchuka village which is situated on the southwest coast of the Chilwa Island.

The island possesses a precipitous mountainous topography having a large height difference of about 440 m from the lake surface to the mountain top. As the slopes of the island are densely covered with plants of strong vines called buffalo beans, cultivation is only limited to the low land along the lake shore.

2-10-2 Geology and Ore Deposits

(1) Geology

This sector is underlain by gneiss of the basement and feldspathic breccia and carbonatite of the Chilwa alkaline province (Fig. 5-2-10, PL. 2-10).

Gneiss is exposed in the outer rim of the Chilwa Island and is strongly fenitized.

Feldspathic breccia is distributed along the inner side of gneiss. It is vessicular hard rock of pink to reddish-brown in color. The matrix is filled with pink feldspars and ankeritic carbonatite.

Carbonatite is exposed inside feldspathic breccia forming a circle of about 1,600m in diameter. Lithology changes from sövitic, ankeritic to sideritic towards the inner part. It is considered that the inner carbonatites are newly formed (Garson, 1965).

(2) Carbonatite

Carbonatites in this sector are as large as those of Kangankunde and Tundulu sectors. Carbonatites can be classified as sövite, ankeritic and sideritic.

Sövite is grayish-white in color, fine to medium-grained and rich in pyroxene and biotite. Under the microscope, it is composed mainly of carbonates with iron-oxides, sphalerite and minute crystals of pyrite and brucite (Appendix 7). EPMA analysis shows that there are no rare elements in sphalerite and brucite (Appendix 11).

Ankeritic carbonatite is yellowish-brown, fine-grained rock. Under the microscope, it consists of alkali feldspar, carbonates, quartz and rutile (Appendix 7). EPMA analysis shows that rutile contains a few amount of Nb and alkali feldspar contains Sr (Appendix 11).

Sideritic carbonatite is brown to reddish-brown in color, coarse-grained, britlle rock. Siderite crystals of 1cm in length are sometimes recognized in it. Calcite and dull-yellow fine-grained bastnaesite are recognized; though not in large quantity.