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

(CONSOLIDATED REPORT)

MARCH 1989

JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN

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 1986 to 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 this consolidated 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
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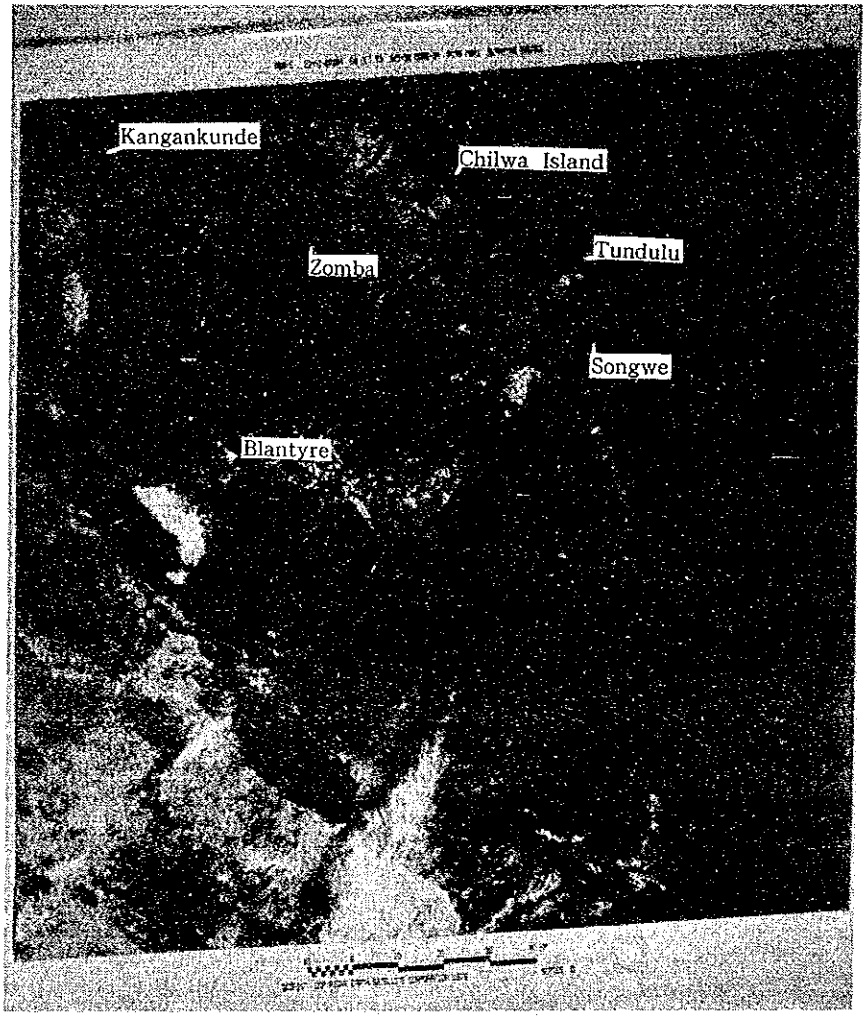

Landsat image of Chilwa Alkaline area

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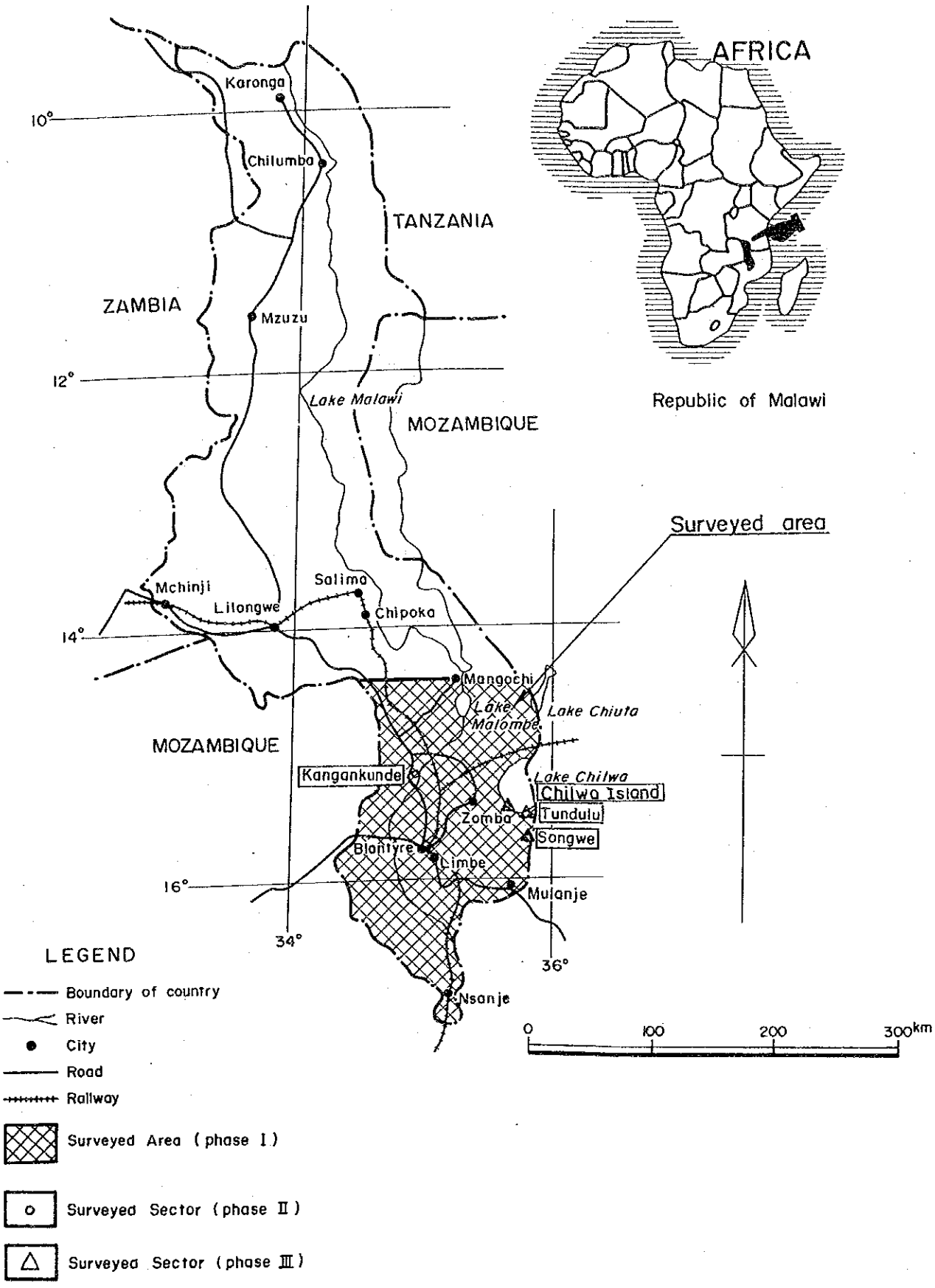


Fig. 1 Location map of survey area

SUMMARY

This report summarizes the results of the three phases cooperative mineral exploration from 1986 to 1988 in the Chilwa Alkaline area in the Republic of Malawi.

The aim of the survey is to investigate the geological setting of carbonatites, their characteristics of mineralization and potential for economic resources.

The Chilwa Alkaline area lies in the southern part of the Republic of Malawi, covering about one-fourth of the country. The total survey area is 30,000 km^2.

From the results of previous works, the Landsat image interpretation and preliminary geological survey and geochemical survey, the following four sectors have been considered as having higher potential for economic deposits of carbonatites:

Songwe, Tundulu, Kangankunde and Chilwa Island sectors.

In the above four sectors, detailed geological, geochemical and drilling (except in Kangankunde sector) surveys have been conducted.

Depending on the results of geological survey, mineralized area have been confirmed in 25 sectors and geochemical survey revaled that most of them have anomaly for REE and phosphorous.

Among the sectors, rather massive and large-scaled carbonatites bodies exist in the four sectors of Songwe, Tundulu, Kangankunde and Chilwa Island.

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.

(4) Kangankunde sector

Carbonatites are composed mainly of sideritic and ankeritic, which are widely distributed on the northern and western slope of Kangankunde Hill. Manganese carbonatite occurs on the top and eastern slope of the hill. It is inferred that carbonatite body on the northern slope of Kangankunde Hill has the highest potential for REE and phosphorus resources.

No recommendation is given here for Kangankunde sector, because BRGM of France has been given a license for exclusive prospecting right in the sector.

Part I General remarks

Chapter 1 Outline of the survey

1-1 Area and purpose 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 purpose of the survey is to elucidate the geological conditions of carbonatites in the Chilwa-Alkaline area and to understand the REE-, rare metals and phosphorus-mineralization related to carbonatites.

1-2 Method and contents of the survey

During the three phases, geological, geochemical and drilling surveys are conducted.

Method and contents of the survey are shown in Tab. 1.

During the first phase survey in 1986, at first an examination of previous work on the Chilwa-Alkaline area (30,000 km^2) and Landsat image interpretation were made to select 25 sectors expected to have carbonatite mineralization. Then geological and geochemical field surveys were carried out in the selected 25 sectors. From the results obtained, the following four sectors out of them were selected as having high potential of carbonatite deposits; Songwe, Tundulu, Chilwa Island and Kangankunde sectors.

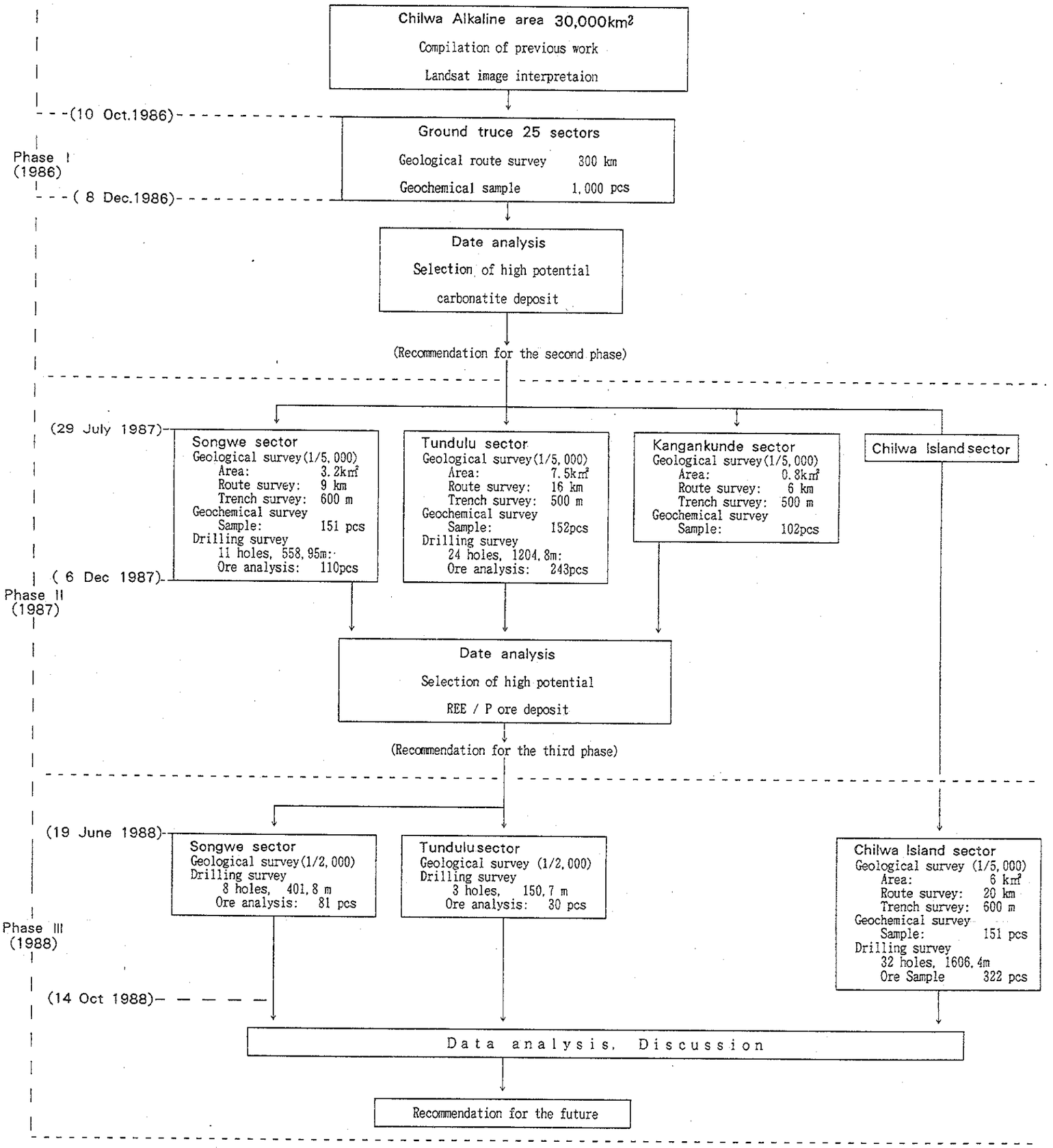
In 1987, geological, geochemical and drilling surveys were conducted in Songwe, Tundulu and Kangankunde (no drilling was carried out) sectors, to elucidate the geological conditions of carbonatites and to understand the mineralization. Chilwa Island sectors was left for the survey in 1988.

In 1988, detailed geological and drilling surveys were conducted in Songwe and Tundulu sectors, which were selected as the areas having the highest potential for carbonatite deposits, to define extent and grade of ore deposits. In Chilwa Island sector, geological, geochemical and drilling surveys were carried out to elucidate the potential for economic deposits.

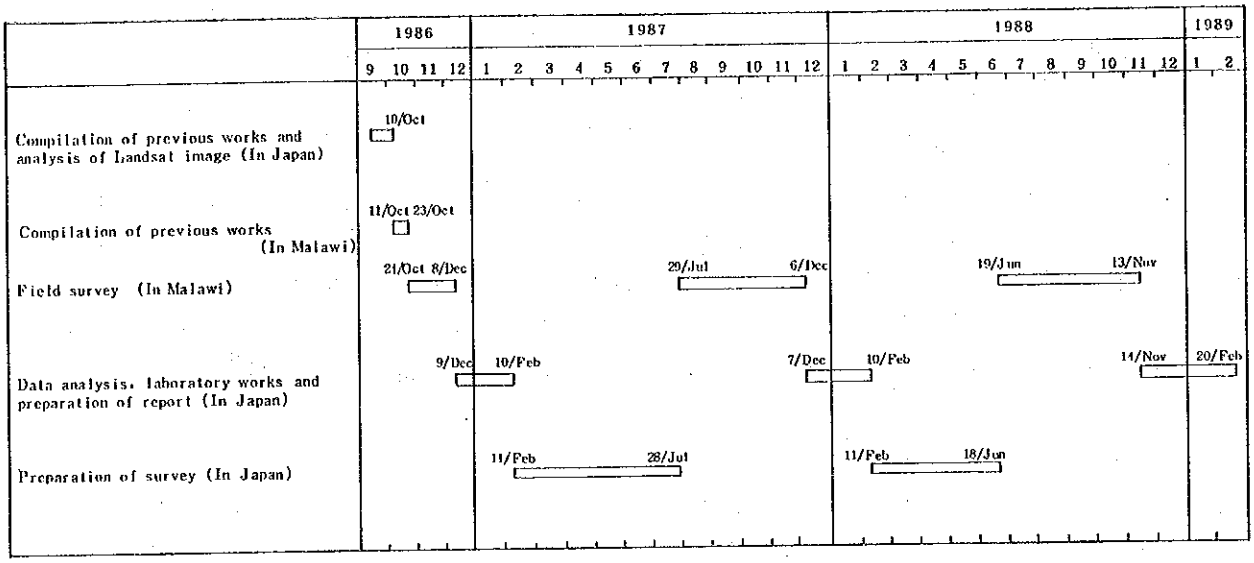
1-3 Period of the survey and organization of the survey team

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

Tab. 1 Flow chart of the Chilwa Alkaline project



Tab. 2 Process of the survey



Tab. 3 is a list of coordinators, administrators and field survey team.

Tab. 3–1 Coordinator and administrator

	Japan side		Malawi side	
	Name		Name	
(Phase I)	Kohei Arakawa	(MMAJ)	H.A. Juwa	(Ministry of Forestry and Natural Resources)
	Ken-ichi Orita	(MITI)	J.C. Chatupa	(Geological Survey Department)
	Takashi Kamiki	(JICA)	A.T. Mndala	(Geological Survey Department)
	Yoshiyuki Kita	(MMAJ)	C.E. Kaphwiyo	(Geological Survey Department)
	Kenji Sawada	(MMAJ)		
(Phase II)	Yoshiyuki Kita	(JICA)	J.C. Chatupa	(Geological Survey Department)
	Kenji Sawada	(MMAJ)	A.T. Mndala	(Geological Survey Department)
(Phase III)	Toshihiko Hayashi	(MMAJ)	J.C. Chatupa	(Geological Survey Department)
	Kenji Sawada	(MMAJ)	A.T. Mndala	(Geological Survey Department)
			F.R. Phiri	(Geological Survey Department)
			R.S. Mshali	(Geological Survey Department)

Tab. 3--2 Field survey team

	Japan side	Malawi side
	Name	Name
(Phase I)	Tsuyoshi Yamada (MINDECO) Leader, Geology & Geochemi. Masaharu Marutani (MINDECO) Geology & Geochemi. Fukuji Hibi (MINDECO) Geology & Geochemi.	A.S.O. Mwafulirwa (Geological Survey Department) G.W.P. Malunga (Geological Survey Department)
(Phase II)	Tsuyoshi Yamada (MINDECO) Leader, Geology & Geochemi. Tsutomu Aoyama (MINDECO) Drilling Hiromi Horishita (MINDECO) Drilling Yukio Chiba (MINDECO) Drilling	G.W.P. Malunga (Geological Survey Department)
(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.

Chapter 2 Compilation of previous works

In Malawi, carbonatites and associated alkaline rocks are developed in some places. Though most of them are distributed in this surveyed Chilwa Alkaline area, some of them are in Ilomba Hill which lies near the border of northern Malawi with Tanzania.

Carbonatites and their associated rocks in the survey area are grouped as "Chilwa Alkaline province", whose petrological characteristics have been clarified by Garson (1965) and Bloomfield (1966).

Based upon the detailed geological survey in the southern Malawi, Garson discriminated many bodies of carbonatites and elucidated the petrographical characteristics, geological structure and petrogenesis of the carbonatites.

Bloomfield re-examined the results of Garson and made detailed geologic mapping in the whole area of Malawi.

Based upon the results of previous works, it is inferred that in this surveyed area carbonatites and their prospective sites are recognized in 25 sectors (Tab. 4).

Carbonatites and prospective sites of carbonatite are closely associated to the alkaline complexes of the Chilwa Alkaline province. This 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 alkaline rocks in this area.

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

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

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, sovitic (calcitic) in the early stage through ankeritic to sideritic in the late stage.

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.

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

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

II) Volcanic neck: characterized by carbonitized 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, pyroxinite, peridotite, olivine- and vermiculite-bearing pegmatite; dyke is rare.

Pyrochlore, monazite, bastnaesite, synchysite, strontianite, fluorencite, apatite, fluorite, etc, occur as minerals accompanied with carbonatite.

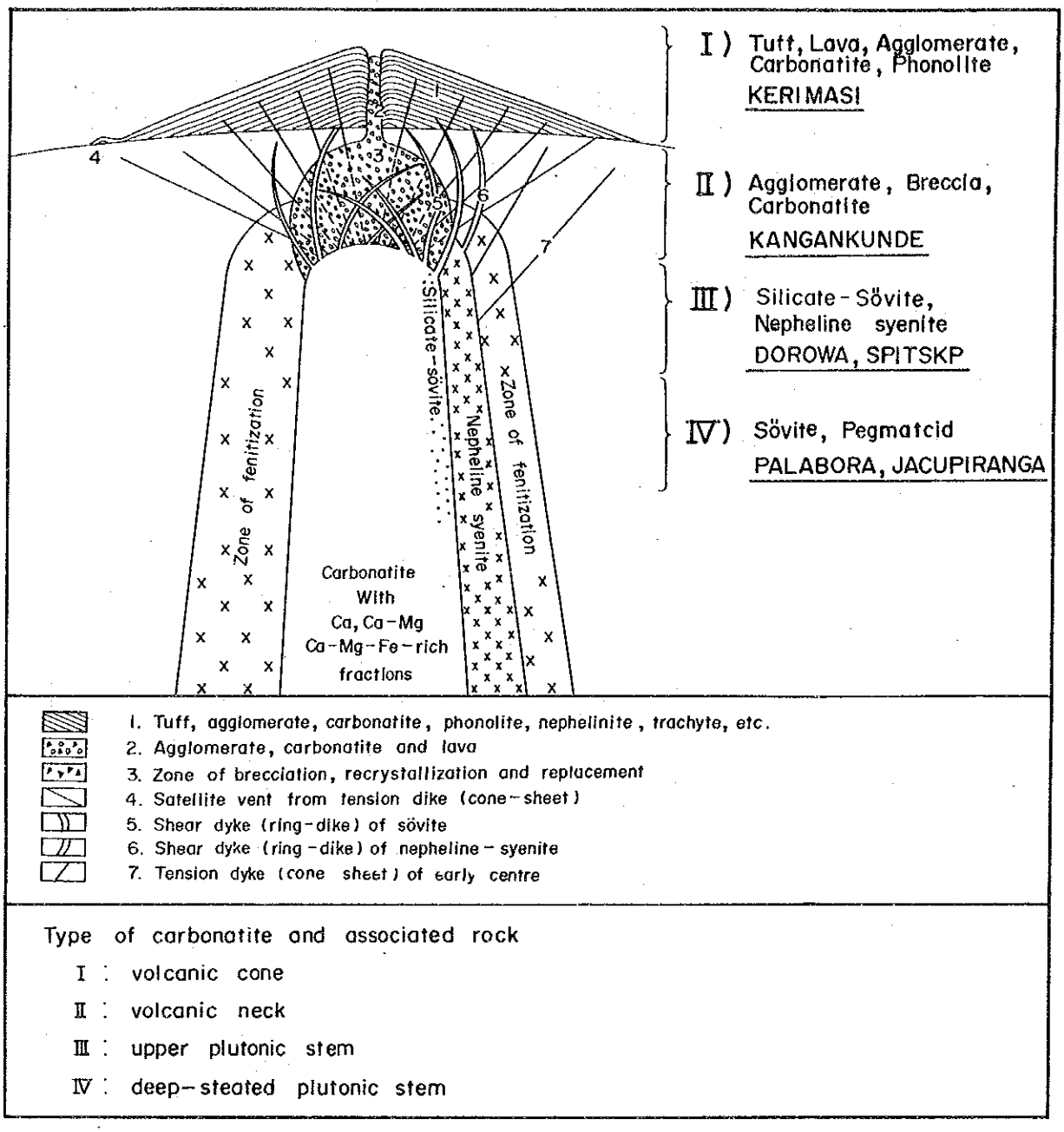
The airborne magnetic survey and airborne radiometric survey (K, Th, U, K+Th+U) were carried out by UNDP in the southern Malawi. Among them,

Tab. 4-1 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. 4-2 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



(after Garson, 1966)

Fig. 2 Schematic diagram of the structural pattern in a carbonatite complex

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 older syenitic and granitic bodies.

Chapter 3 Geology of the Chilwa Alkaline area (Fig. 3)

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

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, alkaline rocks and carbonatites were active. These intrusive rocks constitute "Chilwa-Alkaline Province" and form volcanic necks and small intrusive bodies.

Carbonatite bodies in Tundulu, Songwe Kangankunde and Chilwa Island sectors which are in the survey area belong to "Chilwa-Alkaline Province".

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 to occur in the area. Bauxite deposit is situated on the top of Mulanje mountain with a 2,000 to 3,000 m elevation. Ore reserve of 60 million tons with the grade of Al_2O_3 about 43% is known to present (Garson et al. 1969).

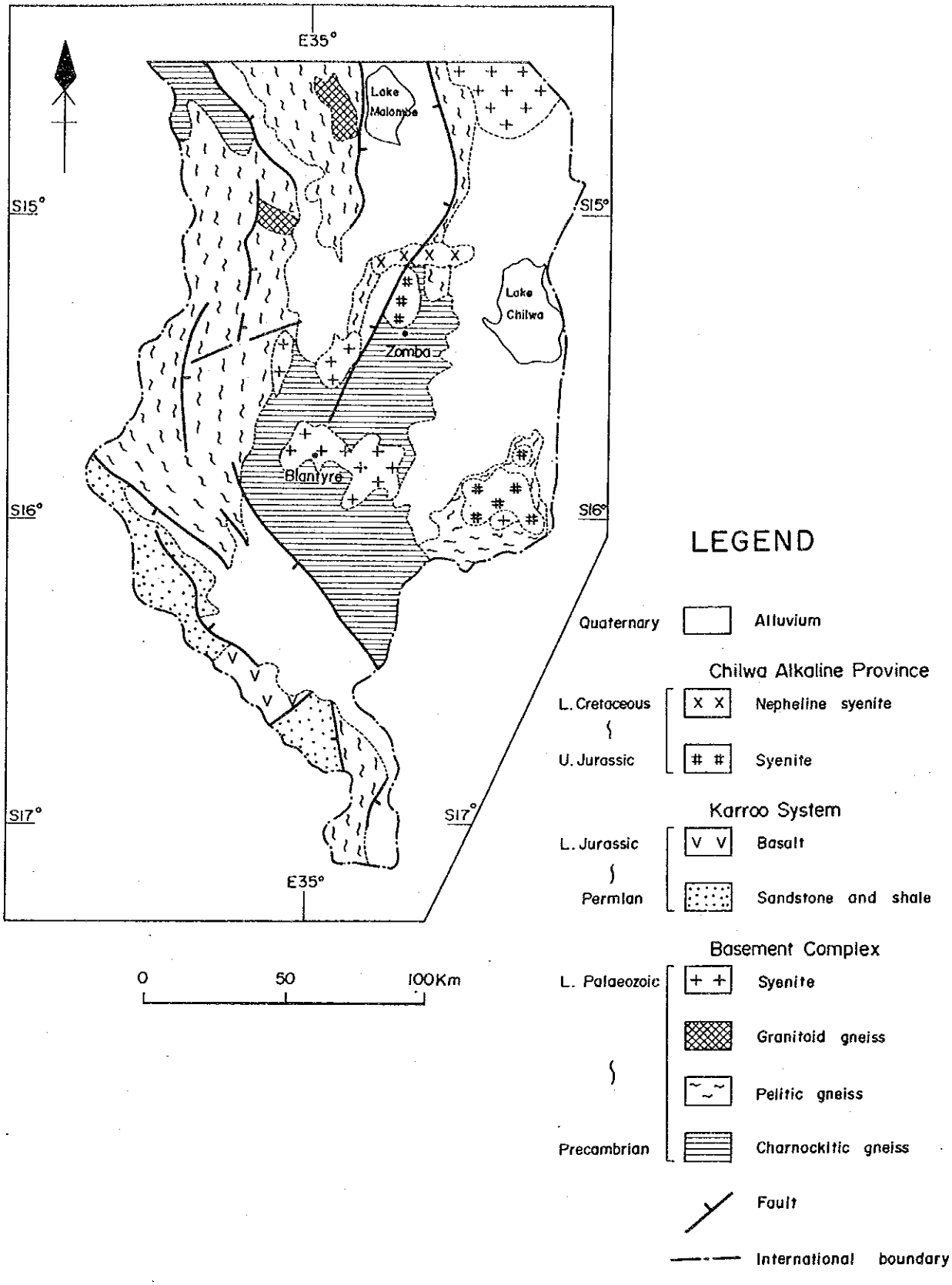


Fig. 3 Geological map of Chilwa Alkaline area

Chapter 4 Location and physical features of the survey area

4-1 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 survey area, kfrom 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 survey area are connected with paved and unpaved roads. Therefore, the survey area is in a good condition in transportation; and the cars can reach to every sector of the survey area. The condition of unpaved roads, however, is rather bad in the rainy season (November-April).

4-2 Physical features of the survey area

4-2-1 Landforms and drainage

In the survey area, the eastern part is occupied by steep Mulanje Mountains having 3,000m 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. Tundulu and Songwe sectors are situated in Phalombe Plain and are mountainous area having 200m-700m elevation. Chilwa Island sector is located in Lake Chilwa. It is rather steep having 400-500m elevation above the surface of the lake. The central and western parts of the survey area are valley running along Shire River which starts from Lake Malawi and Kirk Range lying to the west of the valley. Kangankunde sector is located between Shire River valley and Kirk Range. It is rather mountainous having 200m elevation.

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

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

4-2-2 Climate and Vegetation

The survey area belongs to tropical savanna climate and it has two seasons, i.e., a dry season (April-October) and a rainy season (November-March). In Blantyre situated near the center of the survey area, the average annual rainfall is 1000mm and the average temperature is 17°C (Fig. 4).

During the dry season, diurnal variation of temperature is very large, i.e., the temperature rises up to 40°C in daytime of October to November and goes down to 10°C in nighttime 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 Mulanje and Zomba are covered by such afforested needle as pine and cedar etc..

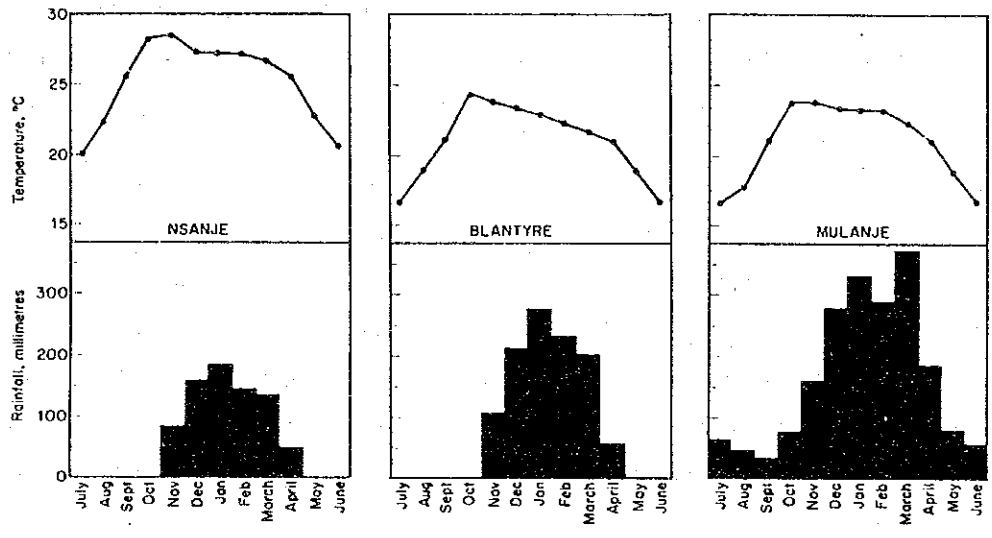


Fig. 4 Temperature and rain fall

Chapter 5 Conclusion and recommendation for the future

5-1 Conclusion.

The common characteristics of geology of carbonatites bodies in "Chilwa Alkaline Province" are as follows:

1) constituent rocks have concentric arrangement
2) the shape of the bodies on a plane figure is elliptical, showing ring structure
3) adjoining basement rocks have undergone intense fenitization
4) the bodies tend to consist of sovitic, ankeritic and sideritic carbonatite from rim inward
5) breccias are often associated
6) constituent rocks tend to dip stteply outward or inward

Judged from the characteristics shown above, it is inferred that the depth of formation of the bodies are effusive and shallow level or intermediate plutonic level, which are the first and the second shallowest among the 3-fold division by GSJ and DNPM (1987).

It is inferred that REE are used to concentrate in ankeritic and sideritic carbonatites in Chilwa Alkaline area. It is clarified that samples from Chilwa Alkaline area are more enriched in medium REE than those from Mountain Pass Mine and Bayan Obo Mine.

Conclusion of each sector is shown below.

(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) Kangankunde sector

Carbonatites are mainly of sideritic, ankeritic and dolomitic, which are widely distributed on the northern and western slope of Kangankunde Hill. Manganese carbonatite occurs on the top and eastern slope of the hill. It is inferred that carbonatite body on the northern slope of Kangankunde Hill has the highest potential for REE resources.

(4) 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 three phases 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, Kangankunde 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.

(4) Kangankunde sector

No recommendation is given here for Kangankunde sector, because BRGM of France has been given a license for exclusive prospecting right in the sector.

Part Ⅱ Landsat image interpretation and compilation of previous works

Chapter 1 Outline of the survey

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

Five Landsat images were used. They are of path/row=179/70, 179/71, 179/72, 180/70 and 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 color images (Fig. 5).

Chapter 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 structure and lineaments (linear structure) were picked up and classified.

(1) Circular structure

206 circular structures picked up from images (Fig. 6) are classified into 4 types according to their morphology as shown in Tab. 5.

A) Projected ring structure: can be assumed as ring dykes, cone sheetes 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 and meteoric craters

D) Cone structure: can be assumed as intrusive bodies and cinder cones.

These for types are the structure 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 structure concentrate in the following 7 districts (Fig. 7):

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

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

The characteristics of the circular structures in each district will be shown below.

1) East district of Lake Malombe

A-type circular structures are recognized at ten places in the district between Lake Malombe and Lake Chiuta. In this district two alkaline igneous bodies are widely distributed and ten circular structures are distributed along the margin 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 seen clearly, 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 eight places in this district. These circular structures are almost less than 1 km in diameter and concentric structures are partly seen. Six carbonatites or prospective sites such as Nsala are developed.

3) Kangankunde district

A-type circular structures are recognized at 14 places in this

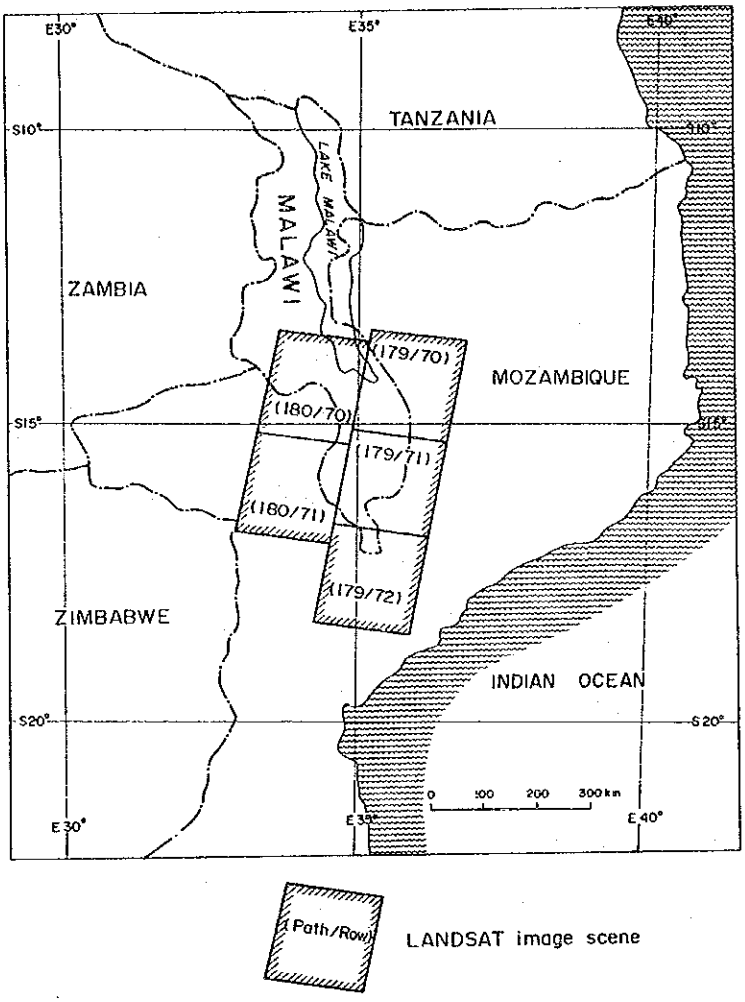
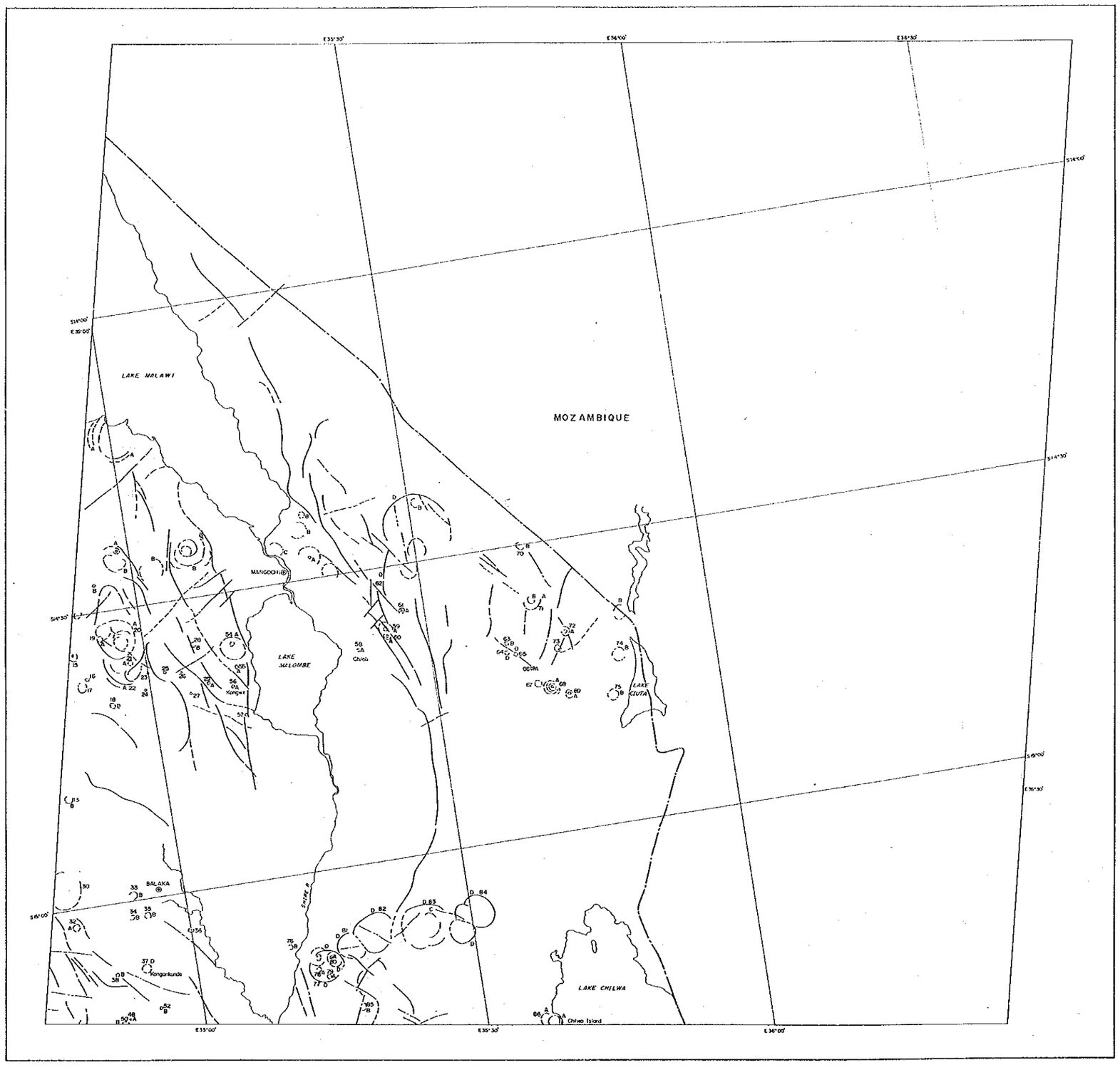


Fig. 5 Location map of LANDSAT image scenes

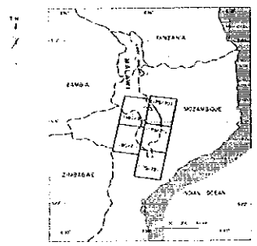
Tab. 5 Classification of circular structure

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



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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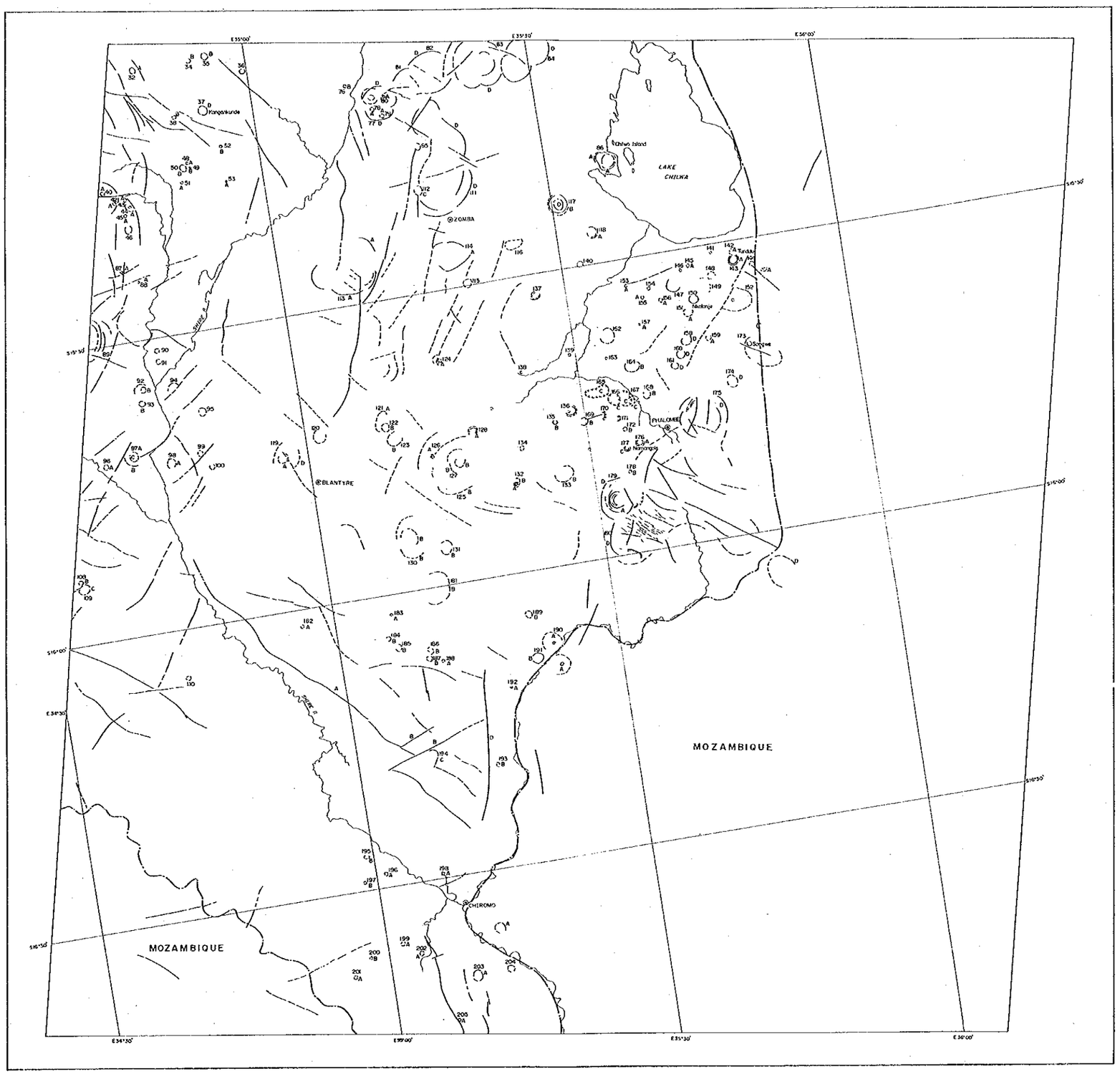
0 10 20km

LEGEND

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

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

Fig. 6—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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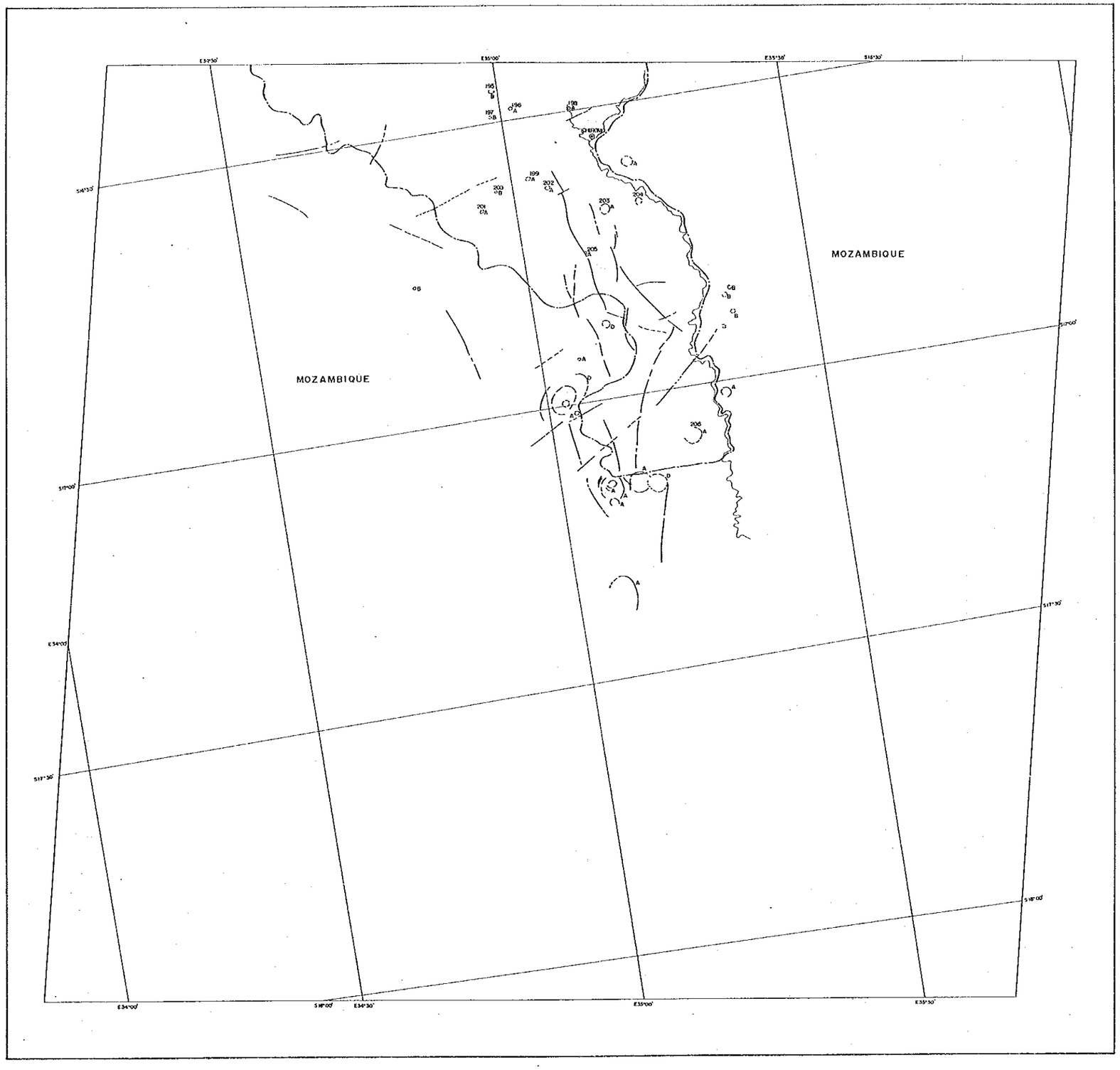
0 10 20km

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. 6—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)

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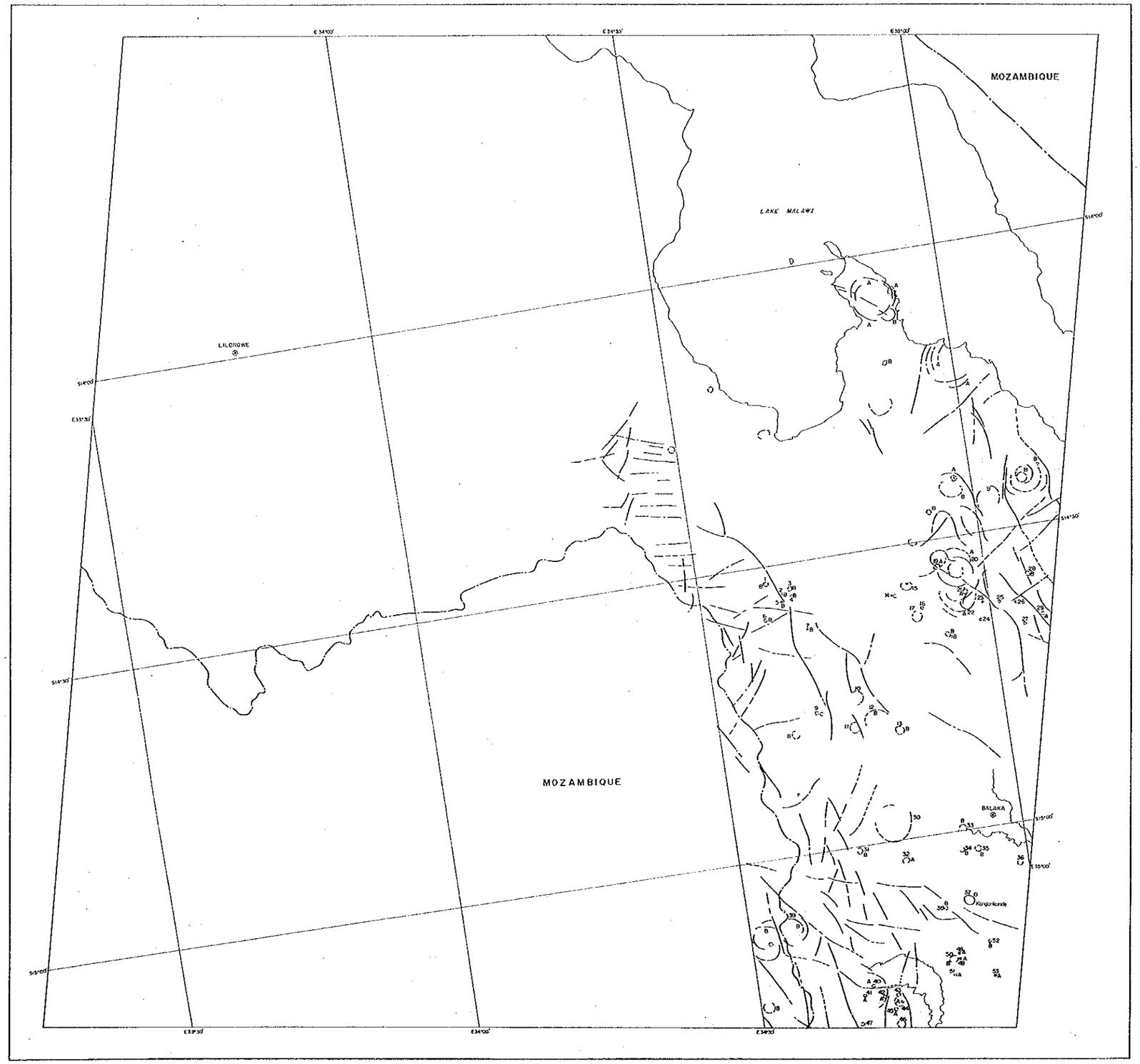
0 10 20km

LEGEND

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

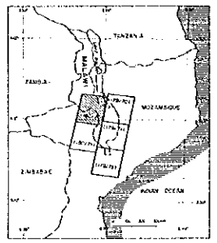
A : Projected Ring Structure
B : Depressed Ring Structure
C : Basin Structure
D : Cone Structure

Fig. 6—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)



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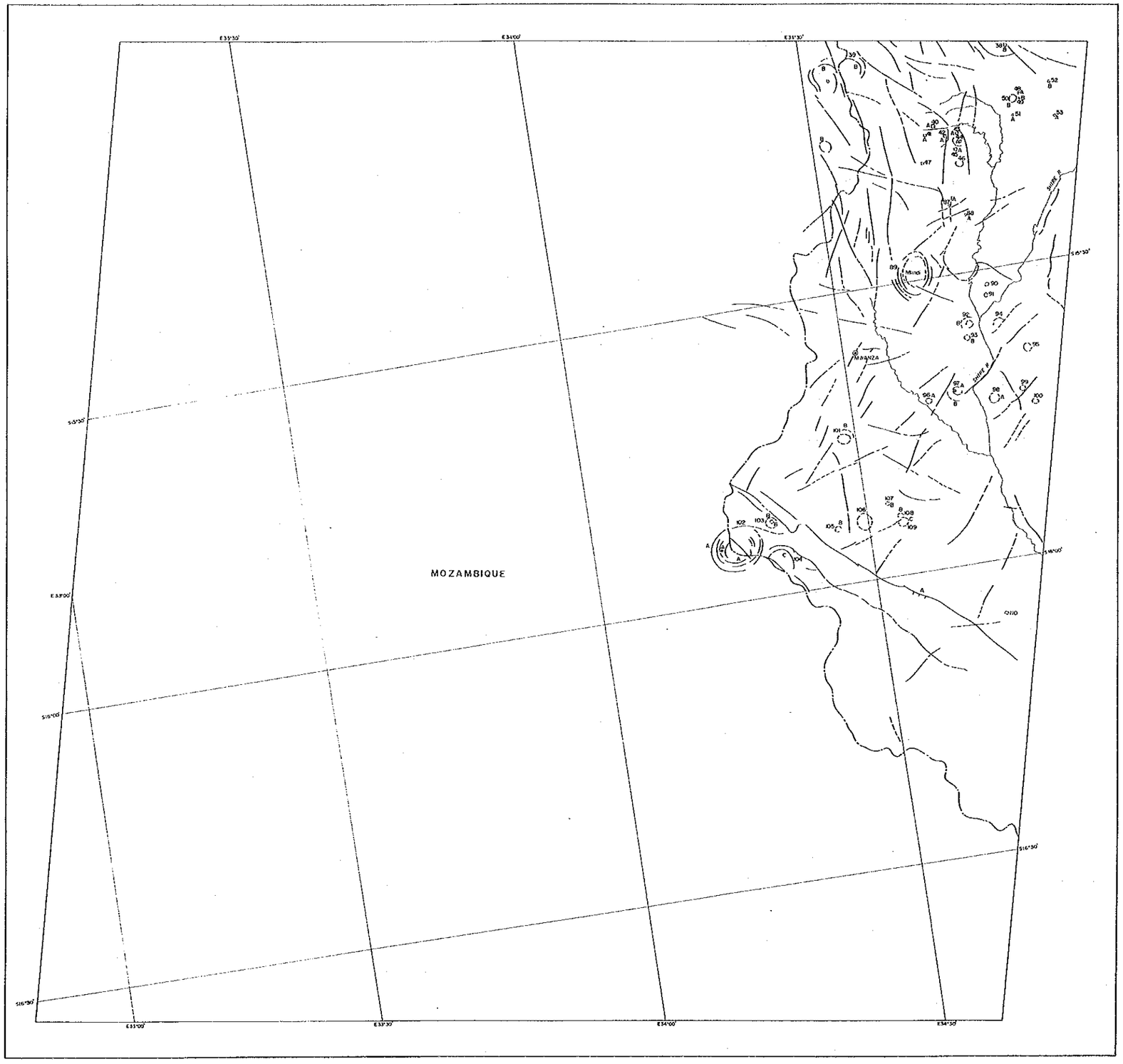
0 10 20km

LEGEND

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

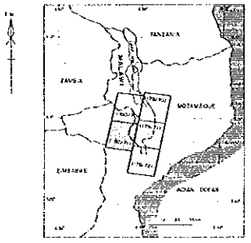
A : Projected Ring Structure
B : Depressed Ring Structure
C : Basin Structure
D : Cone Structure

Fig. 6—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)



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Scale 1 : 250,000

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. 6 — 5 Result of Photogeological Interpretation

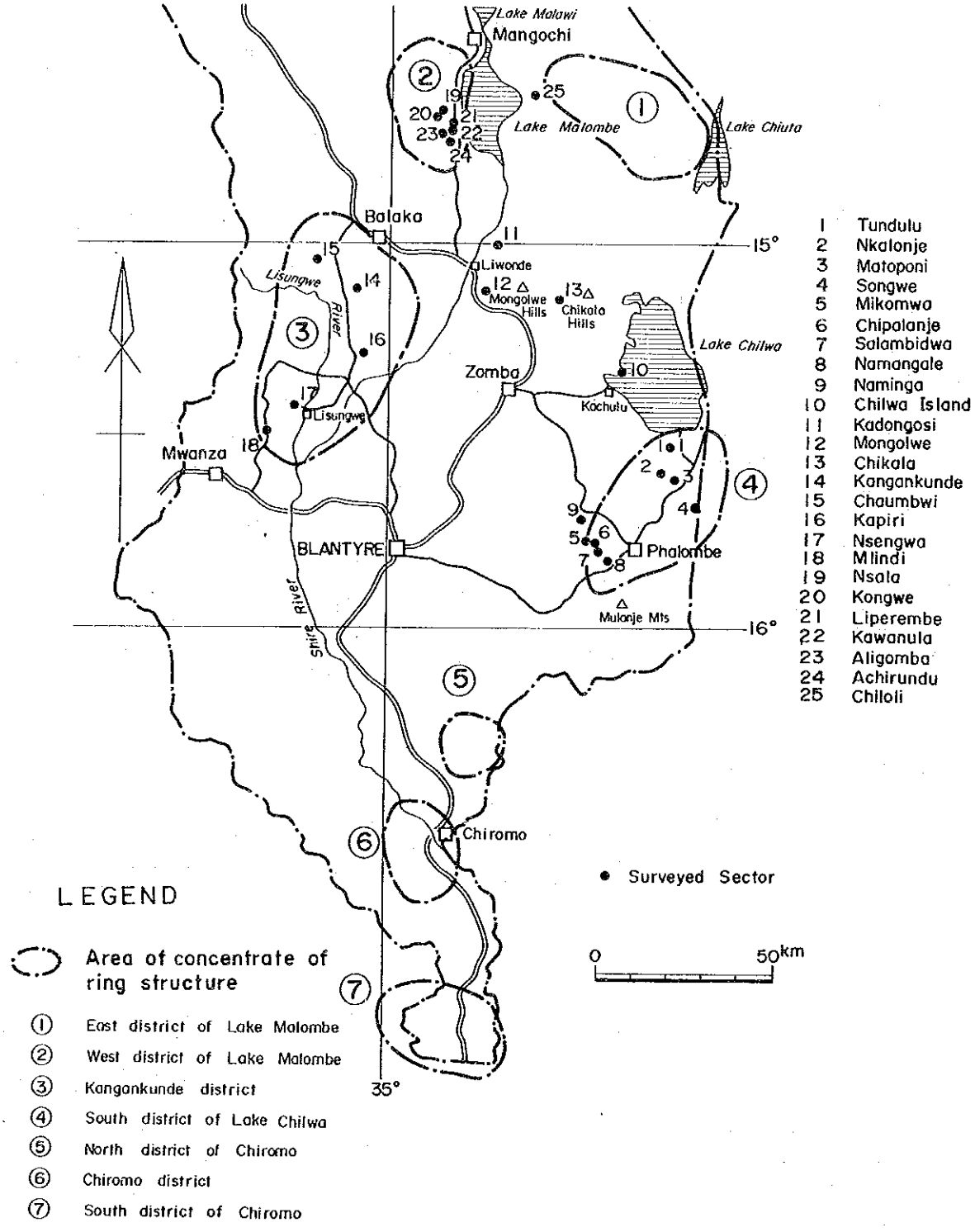


Fig. 7 Distribution of Ring Structures

district. These circular structures are generally 1-2 km in diameter and are almost perfect circles. Moreover, though radiated structures are not seen clearly. Concentric structures are partly seen. Five carbonatites or prospective sites such as Kangankunde are developed.

4) South district of Lake Chilwa

A-type circular structures are recognized at ten places in this district. Eight carbonatites or prospective sites such as Tundulu and Songwe are developed. These circular structures are almost less than 2 km in diameter and concentric structures are partly seen.

5) North district of Chiromo

A-type circular structures are recognized at four places. Though all are perfect circles of less than 1 km in diameter, radial and concentric structures are not distinct.

6) Chiromo district

Though A-type circular structures are recognized at four places, they develop unclearly.

7) South district of Chiromo

A-type circular structures are recognized at one place in Malawi and six in Mozambique. That in Malawi is not clearly developed.

Chapter 3 Comprehensive result of compilation of previous works and Landsat image interpretation

The result of compilation of previous works and Landsat image interpretation is shown in Tab. 6.

According to the Landsat image interpretation, all of the carbonatites and prospective sites in this survey area do not necessarily come out as circular structures. It is inferred that alkaline complexes accompanying carbonatites are generally small in scale, i.e., less than 1 km in diameter, and alkaline complexes having the shape of dykes or volcanic necks are not reflected topographically as circular structures.

It becomes clear that majority of the circular structures associated with carbonatites belong to the projected ring structure (type A). The structure is considered as concentric one 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 characteristic of carbonatites in this area is that most of them are associated with breccias and agglomerates. Syenite, nepheline syenite, trachyte, phonolite, nephelinite and so on are developed as alkaline rocks.

As most of the thorium anomaly detected through airborne radiometric survey reflect the existence of alkaline complexes associated with carbonatites, it is suggested that radiometric survey (especially for thorium) is effective in the exploration of carbonatites.

Tab. 6 Comprehensive result of compilation of previous works and LANDSAT image interpretation

Surveyed sector	LANDSAT Circular Structure		Chilwa alkaline complex			Airborne survey
	Number	Type	Lithology	Occurrence	Type	Thorium anomaly
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.

(after Garson, 1965)

Part Ⅲ Songwe sector

Chapter 1 Geology (Fig. 8)

Constituent rocks of this sector are as follows:

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa-Alkaline Province" Carbonatites (sovitic, 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.

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, a 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).

---

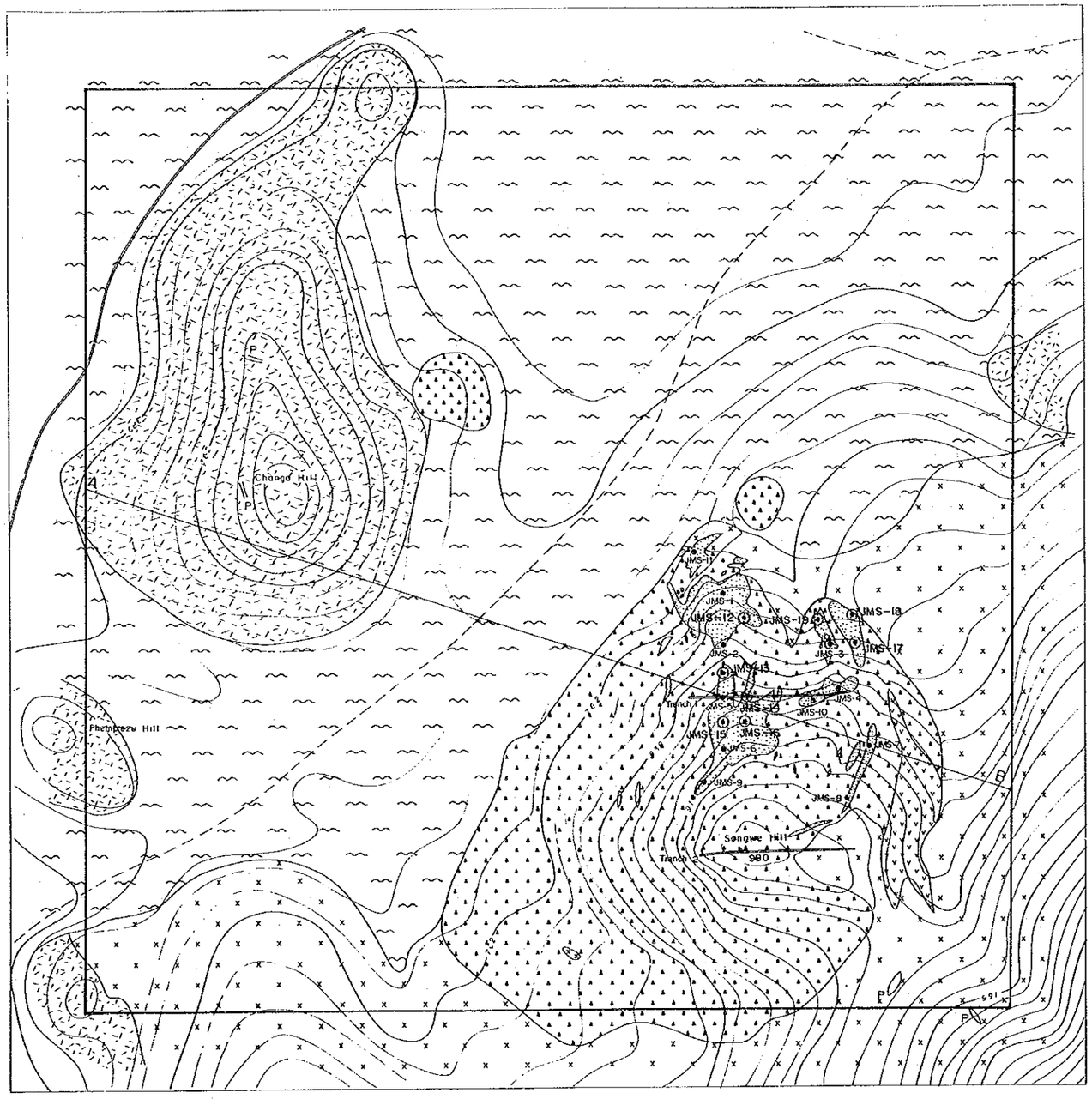
* Classification of carbonatite (by naked-eye)

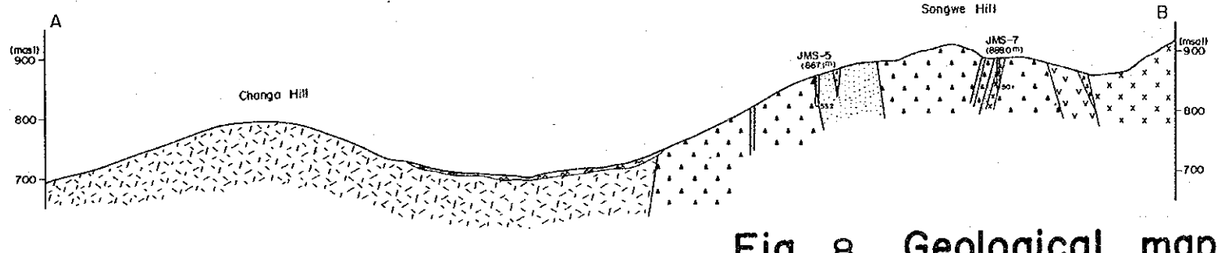
sovitic carbonatite: white to gray colored, composed mainly of fine- to medium-grained calcite
violently vesicating by the addition of dilute HCl (1:10)

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

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

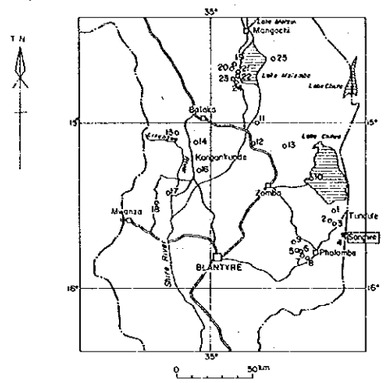
Comparison of results between of the naked-eye observation and of laboratory analyses will be shown later.





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

GEOLOGICAL MAP AND PROFILE OF SONGWE SECTOR



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1988

0m 250m 500m

LEGEND

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

Fig. 8 Geological map and profile of Songwe sector

Chapter 2 Results of geochemical survey

Geochemical samples collected were mostly carbonatites. 151 samples were collected and were assayed for 10 elements. The elements assayed and their detectable limit of each element are shown below.

Detectable limits

(ppm)

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

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

2-1 Statistical value

Statistical values of each element and REO of this sector as well as the crustal abundance are shown in Tab. 7.

Averaged contents of most elements analyzed in carbonatite here have over ten times higher than the crustal abundance. The contents of Sr in carbonatite is 7.7 times higher.

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

Tab. 7 Statistical values of geochemical survey, Songwe

(ppm)

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

2-2 Distribution of anomalies

The following methods are used to select geochemical anomalous values in Songwe sector.

The thresholds and anomalous are defined as:

the thresholds = M + 1S

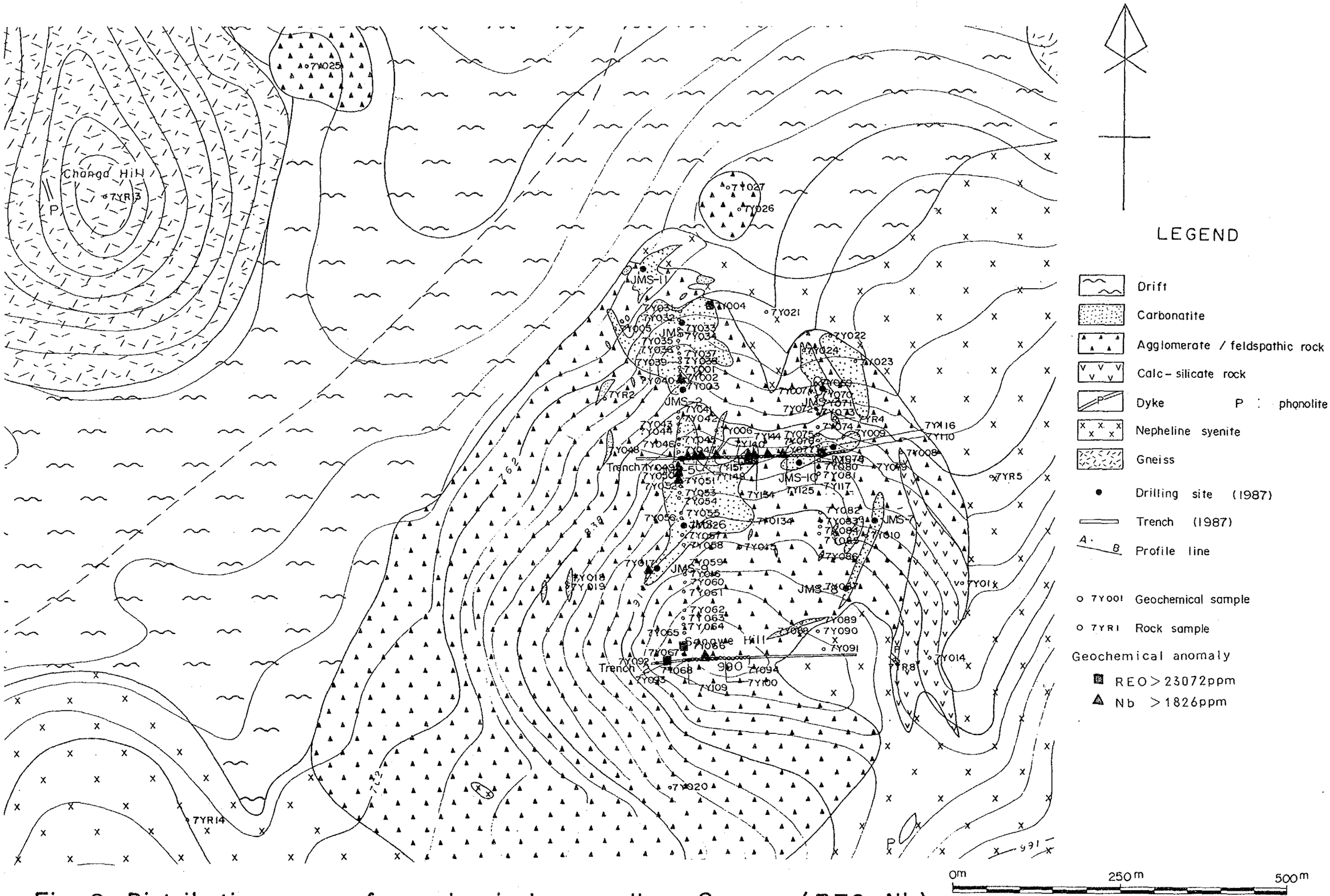
the anomalous values ≧ M + 1S

where M: mean value of elements

S: standard deviation

The thresholds and anomalous values are shown in Tab. 7 and their distribution is mapped in Fig. 9.

It is easily be seen from the figure, that distribution of anomalous values of REE and Nb is restricted on the northern slope of Songwe Hill.



LEGEND

- Drift
- Carbonatite
- Agglomerate / feldspathic rock
- Calc-silicate rock
- Dyke (P : phonolite)
- Nepheline syenite
- Gneiss
- Drilling site (1987)
- Trench (1987)
- A · B Profile line
- o 7Y001 Geochemical sample
- o 7YR1 Rock sample

Geochemical anomaly

- REO > 23072ppm
- Nb > 1826ppm

Fig. 9 Distribution map of geochemical anomalies, Songwe (REO, Nb)

Chapter 3 Results of drilling and discussion (PL. 1)

From the results of geological survey performed in Songwe sector, it has been clarified that carbonatites are developed showing an elliptical structure centering 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 100 m in width. Lineation of the carbonatite has rather random azimuth with a plunging angle ranging from 70° to 90°.

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

Based upon the results of geological and drilling surveys, a preliminary estimation of ore reserve has been made for the mineralized zones assuming the following:

cutoff grade ; REO 1.0% (REO represents total amount of 7 oxide 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 (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 sector.

The following is a list of dimension, ore reserve and grade of each body (Tab. 8 and Fig. 10).

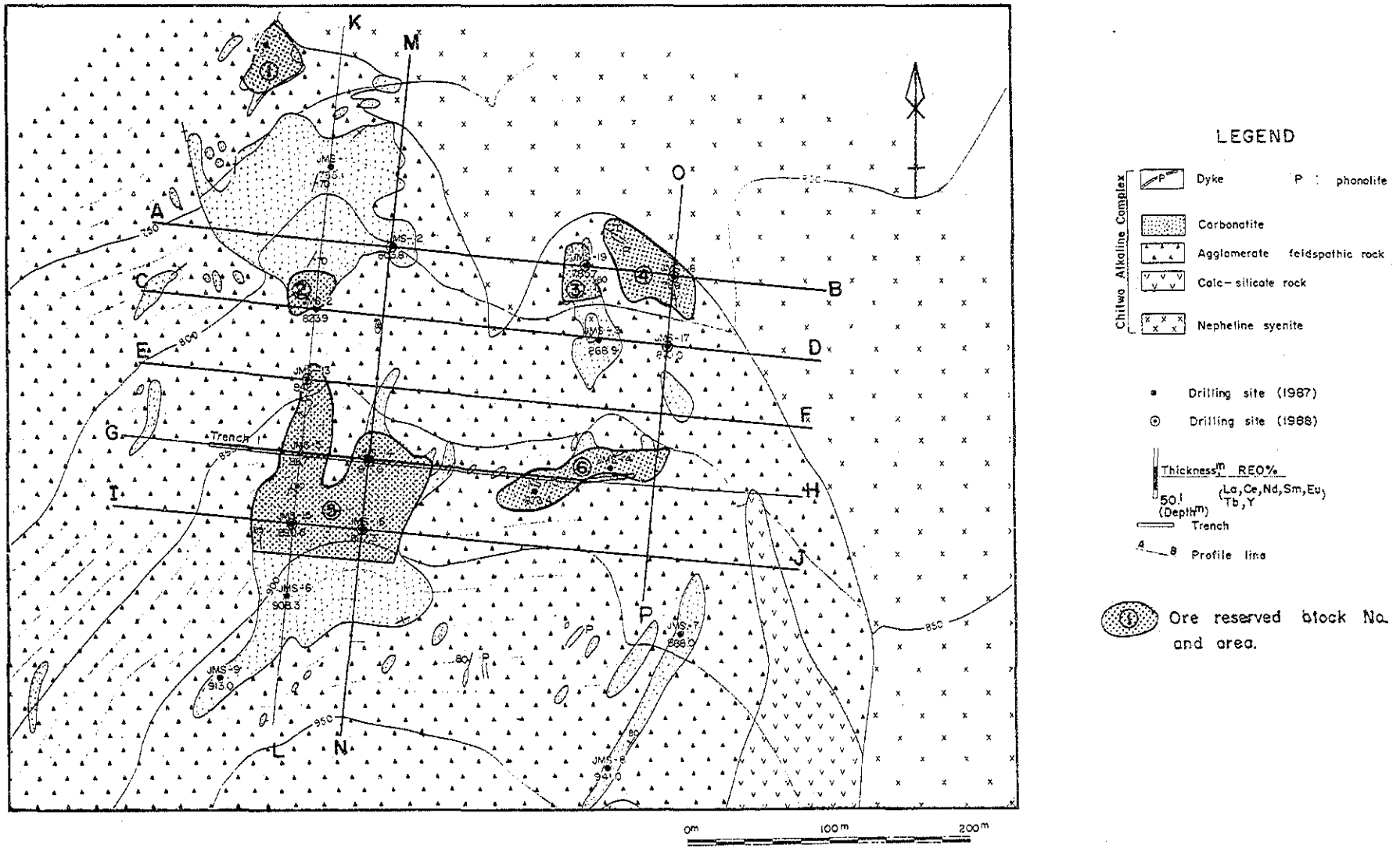


Fig. 10 – 1 Geological section of drill holes and map of ore reserves (REO), Songwe

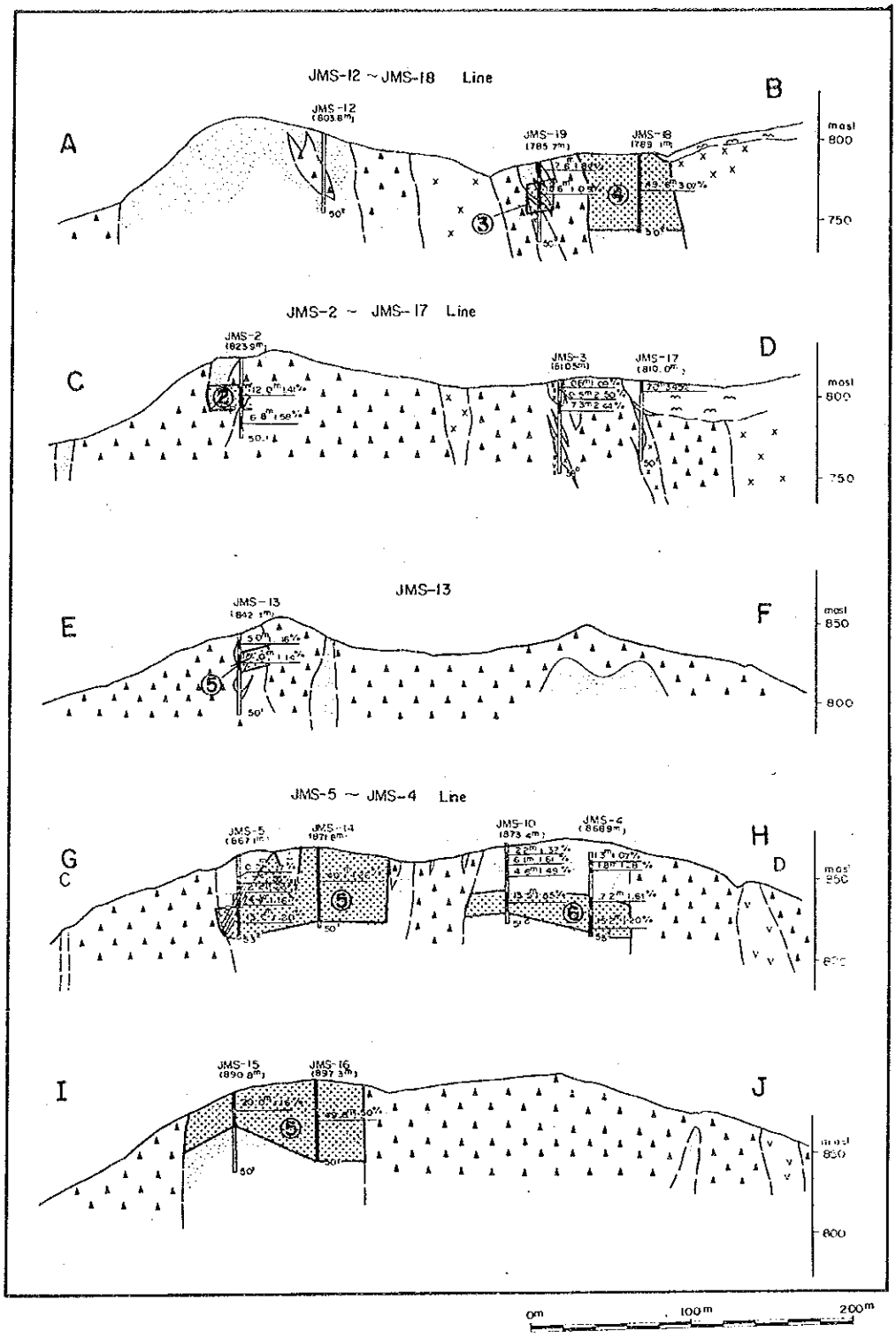


Fig.10-2 Geological section of drill holes and map of ore reserves (REO), Songwe

- W · E section -

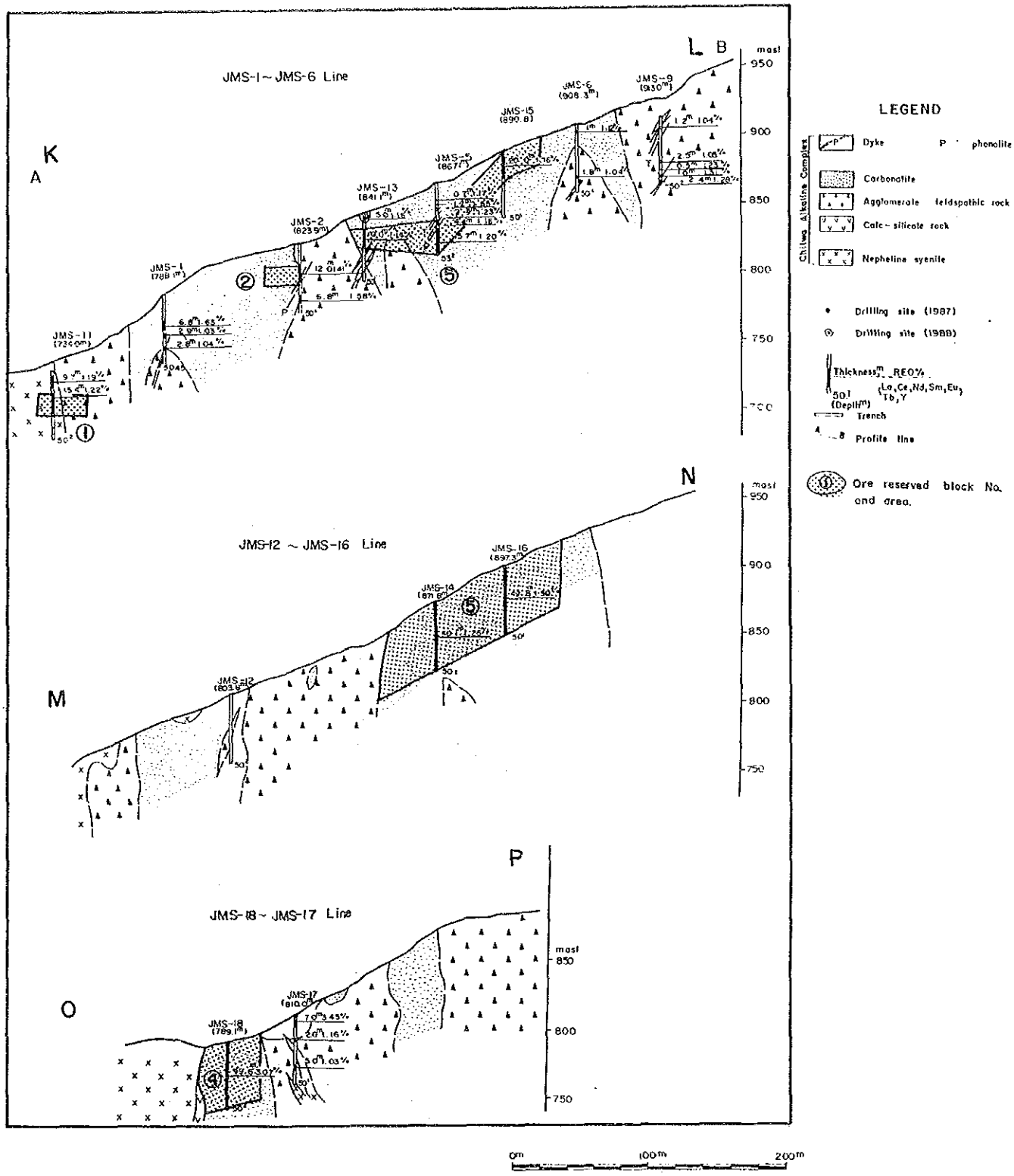


Fig.10-3 Geological section of drill holes and map of ore reserves (REO), Songwe
- N·S section -

Tab. 8 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 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 contents of 1.7% is rather lower as compared with that of Bayan Obo 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.

Part Ⅳ Tundulu sector

Chapter 1 Geology (Fig. 11)

Constituent rocks of this sector are as follows.

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa-Alkaline Province" Carbonatites (sovitic, ankeritic, 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.

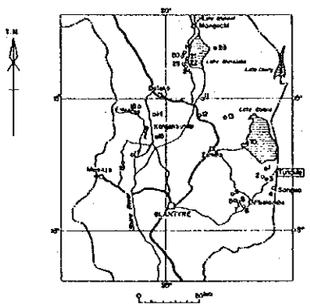
Sovite is mainly composed of fine to medium-grained whitish calcite. It is milky white in color, compact and rich in magnetite. Under the microscope, it is characterized by a mosaic texture constituted by calcite, dolomite, biotite, aegirine, apatite with lesser amounts of opaque minerals.

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

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

GEOLOGICAL MAP AND PROFILE OF TUNDULU SECTOR

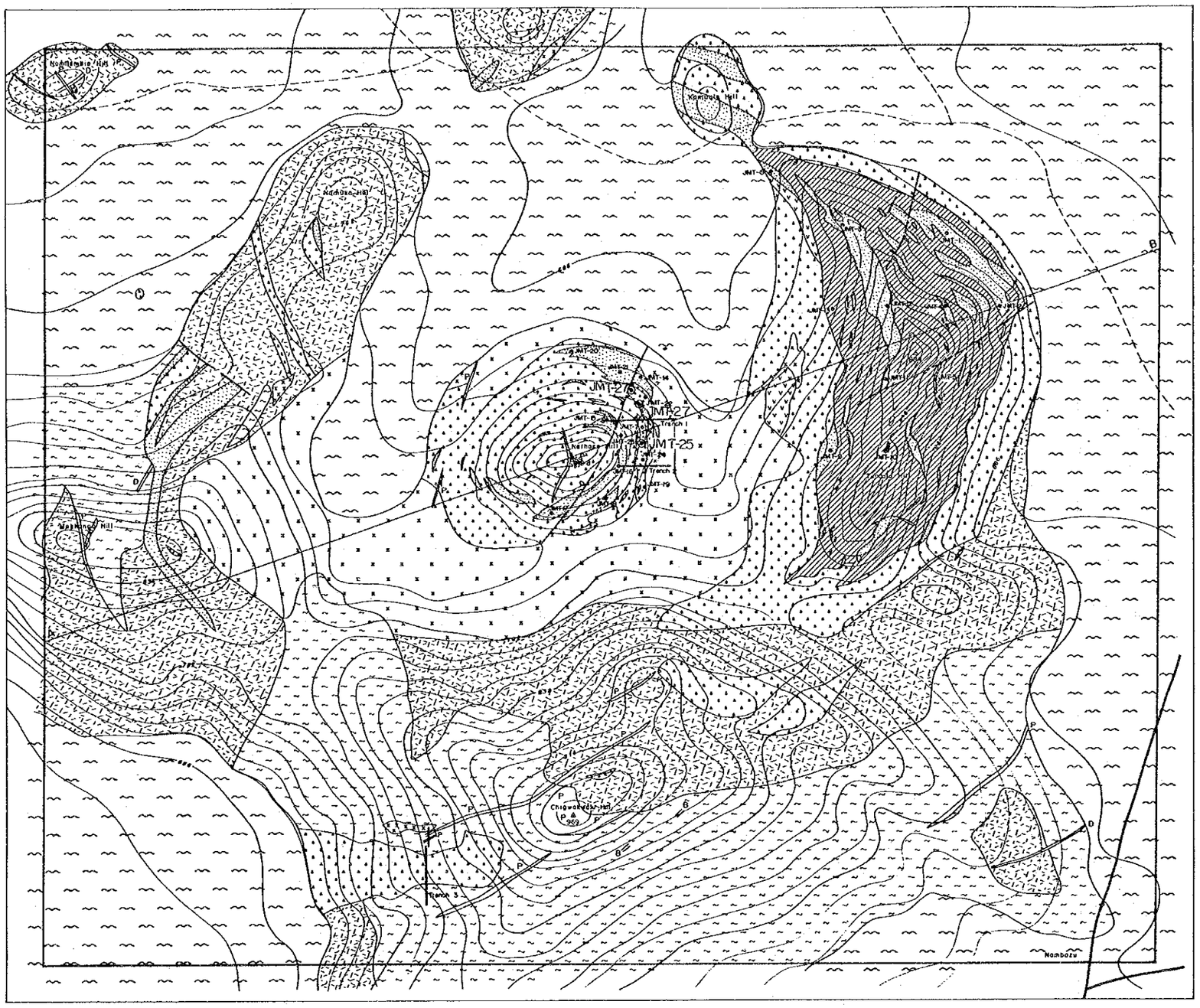


JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1988

0m 250m 500m

LEGEND

- Drift
- Carbonatite
- Apatite rock
- Carbonatite bearing agglomerate / feldspathic rock
- Agglomerate / feldspathic rock
- Calc-silicate rock
- Dyke / plug
  - P : phonolite
  - S : solvsbergite
  - T : trachyte
  - J : juvite
  - B : beforsite
  - D : dolerite
- Nepheline syenite
- Gneiss
- Syenite
- Fault
- Drilling site (1987) ⊙ Drilling site (1988)
- Trench (1987)
- A — B Profile line



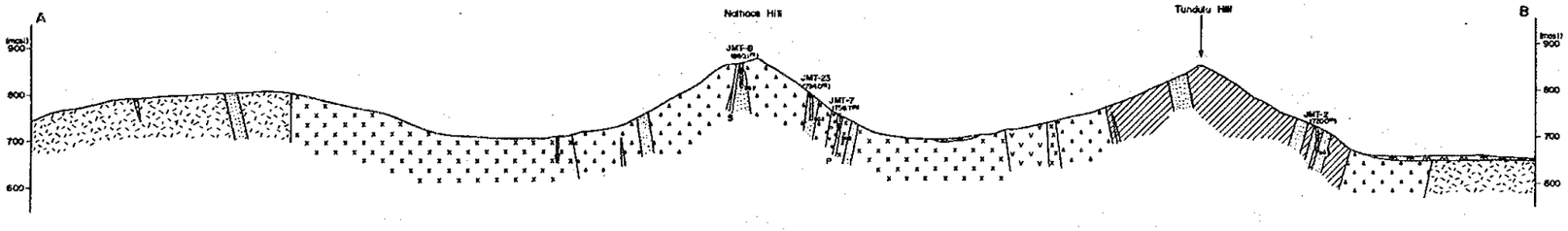


Fig. 11 Geological map and profile of Tundulu sector

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.

Chapter 2 Results of geochemical survey

Geochemical samples collected, analyzed elements, their detectable limit and procedure of statistical analyses are the same as those of Songwe sector.

152 samples are collected in this sector.

2-1 Statistical value

Statistical values of each element and REO of this sector as well as the crustal abundance are shown in Tab. 9.

Averaged contents of most elements analyzed in carbonatite here have over ten times higher than the crustal abundance. It suggests that these 10 elements can be used effectively as pathfinder element of carbonatites in Tundulu sector.

Tab. 9 Statistical values of geochemical survey, Tundulu

(ppm)

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

2-2 Distribution of anomalies

Anomalous values in this sector are calculated in the same manner as in the case of Songwe sector. The thresholds and anomalous values are shown in Tab. 9 and their distribution is mapped in Fig. 12.

It is easily be seen from the figure, that distribution of anomalous values of REE, Nb, Sr and P is restricted in the carbonatite body of Nathace Hill. While, the body in Tundulu Hill indicates almost no sign of anomaly.

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

Chapter 3 Results of drilling and discussion (PL. 2)

From the results of geological survey performed in Tundulu sector the following facts have been clarified.

Carbonatites are developed showing superposed double ring structure centering Nathace Hill. The outer ring constitutes Tundulu Hill. Generally

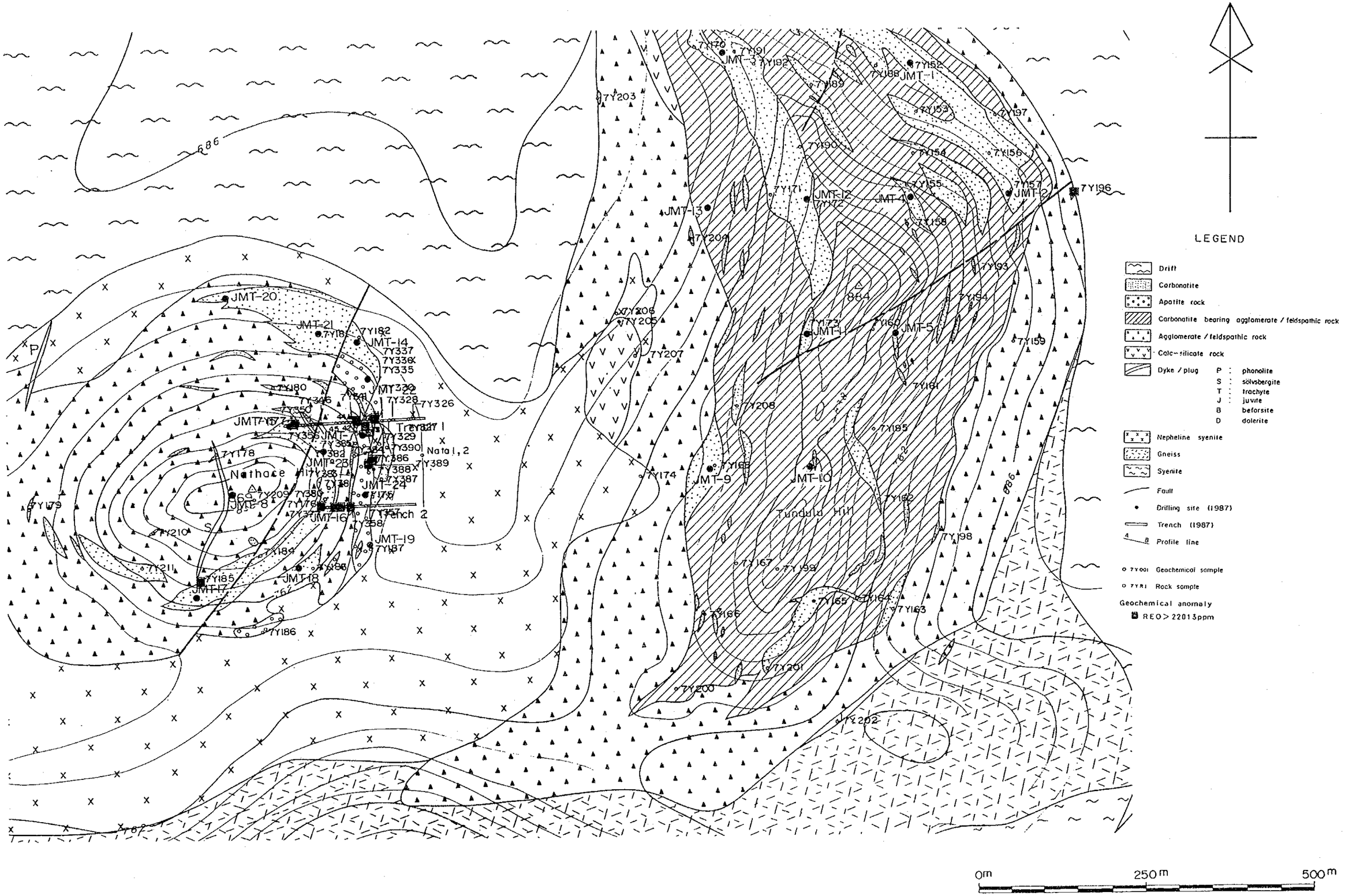


Fig. 12-1 Distribution of geochemical anomalies, Tundulu (REO)

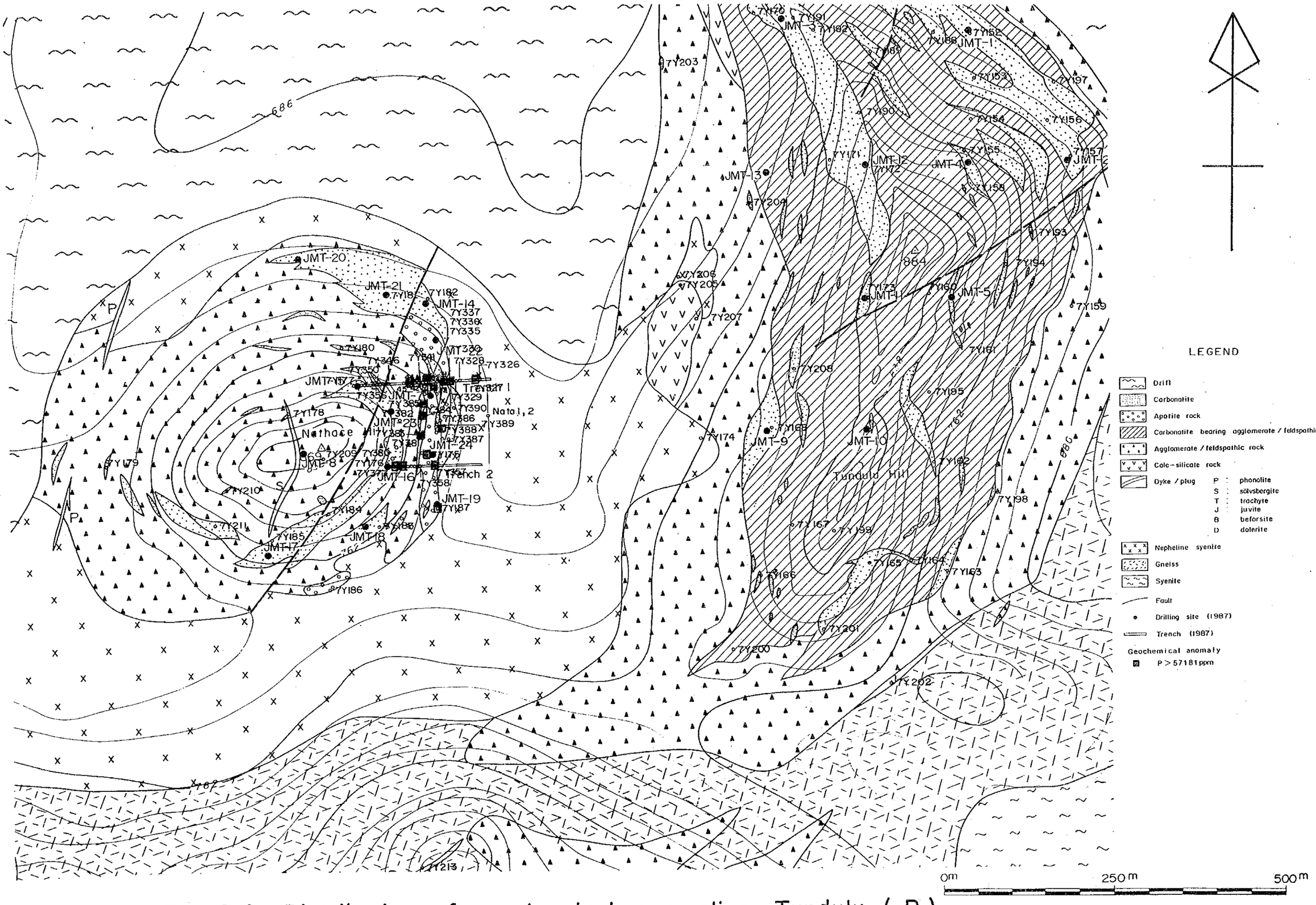


Fig. 12-2 Distribution of geochemical anomalies, Tundulu (P)

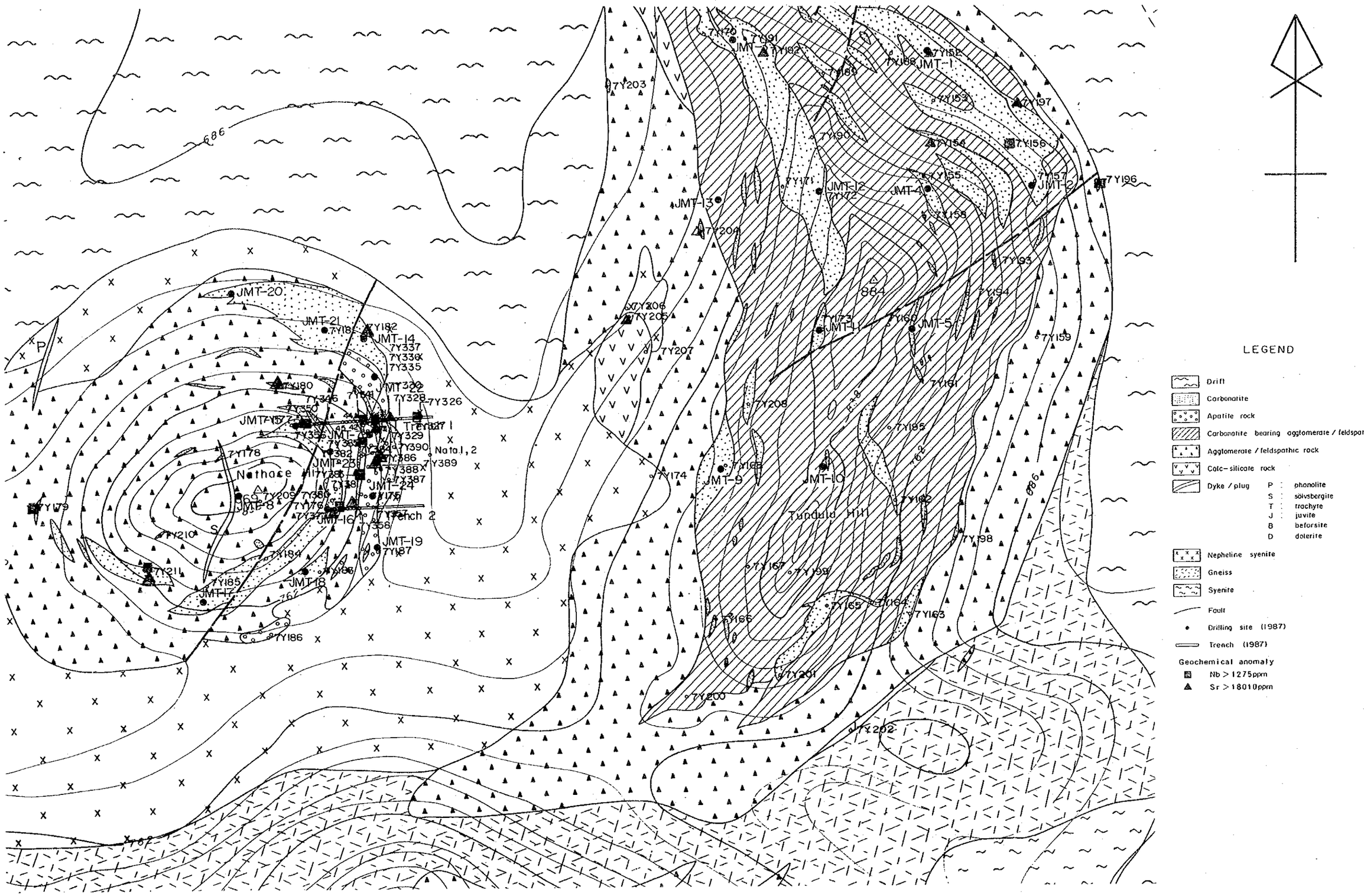


Fig. 12-3 Distribution of geochemical anomalies, Tundulu (Nb, Sr)

speaking, among the carbonatites showing the double ring structure, those of early intrusion constitutes the outer ring and are composed of sovitic one.

As carbonatites on Tundulu Hill are developed in the outer side than those on Nathace Hill and are composed of sovitic one, it is inferred that the former intrude comparatively in the earlier stage of the igneous activity.

Carbonatites on the Nathace Hill are sovitic, ankeritic and sideritic ones and apatite rock. Most of them are developed on the eastern slope of the Hill, showing a half ring structure. The following two litho-stratigraphic units have been discriminated for the carbonatites; namely, the upper unit is mainly sideritic and the lower one is apatite rock, sovitic and ankeritic carbonatites.

Carbonatites change the distribution pattern of strike to surround Nathace Hill and tend to dip 70° to 90° towards the top of the hill.

REE- and phosphorus- mineralized zones are recognized in both units on Nathace Hill.

Concentrated apatite rock is found in the lower unit as rather irregularly-shaped body, the dimension of which is 150m in length and 20 to 30m in width.

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 rocks, composed of apatite, quartz and calcite and for sideritic carbonatite, composed of ankerite and siderite, 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 results for carbonatites, composed of kutnahorite and calcite, are $\delta^{13}C$=-5.0‰ to -2.3‰ and $\delta^{18}O$=+20.7‰ to +22.0‰. Thus the rocks are inferred to have undergone alteration through contaminated by meteoric water.

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.

The estimation of ore reserves for REE-mineralized zone is made following the same method as in the case of Songwe sector. The estimation discriminates three ore bodies on the Nathace Hill. The following is a list of dimension, ore reserve and grade of each body (Tab. 10 and Fig. 13).

As in the case of Songwe sector, it is impossible to compare the value of ore reserves (0.6 million tons) with those of other mines. REO content is as high as those of Bayan Obo Mine.

Tab.10 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	18.6
Bayan Obo (China)				——	20,000	567	67	17

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

cutoff grade; P more than 2.2% (5% in P_2O_5 equivalent)

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

area; area of apatite rock and apatite-bearing carbonatite cropped out on the surface

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

The estimation discriminates a body in the present sector. The area with high potential for phosphorus deposit is generally identical with that for REE deposits shown above.

In Tab. 11, are shown ore reserves and grade of P, P_2O_5 and REO (Fig. 14).

As in the case of REO contents, it is impossible to compare the ore reserves of phosphorus with those of other mines.

The grade of phosphorus represented as P_2O_5 is 17.0%, higher than the value of Araxa Mine (P_2O_5 15.01%), suggests that the body has high potential for phosphorus deposits possible to be exploited.

Tab.11 Caluclation 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

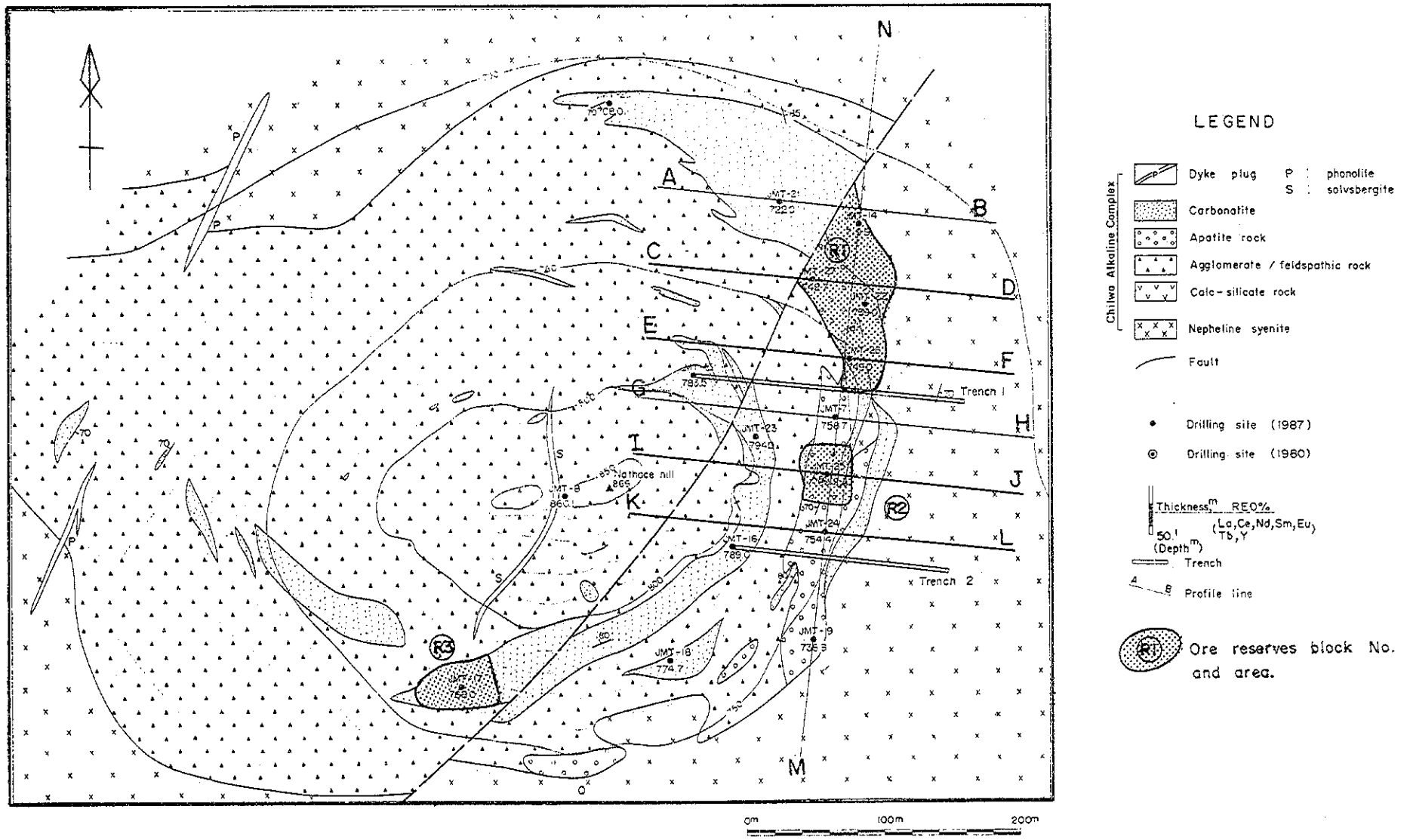


Fig. 13-1 Geological section of drill holes and map of ore reserves (REO), Songwe -Plain-

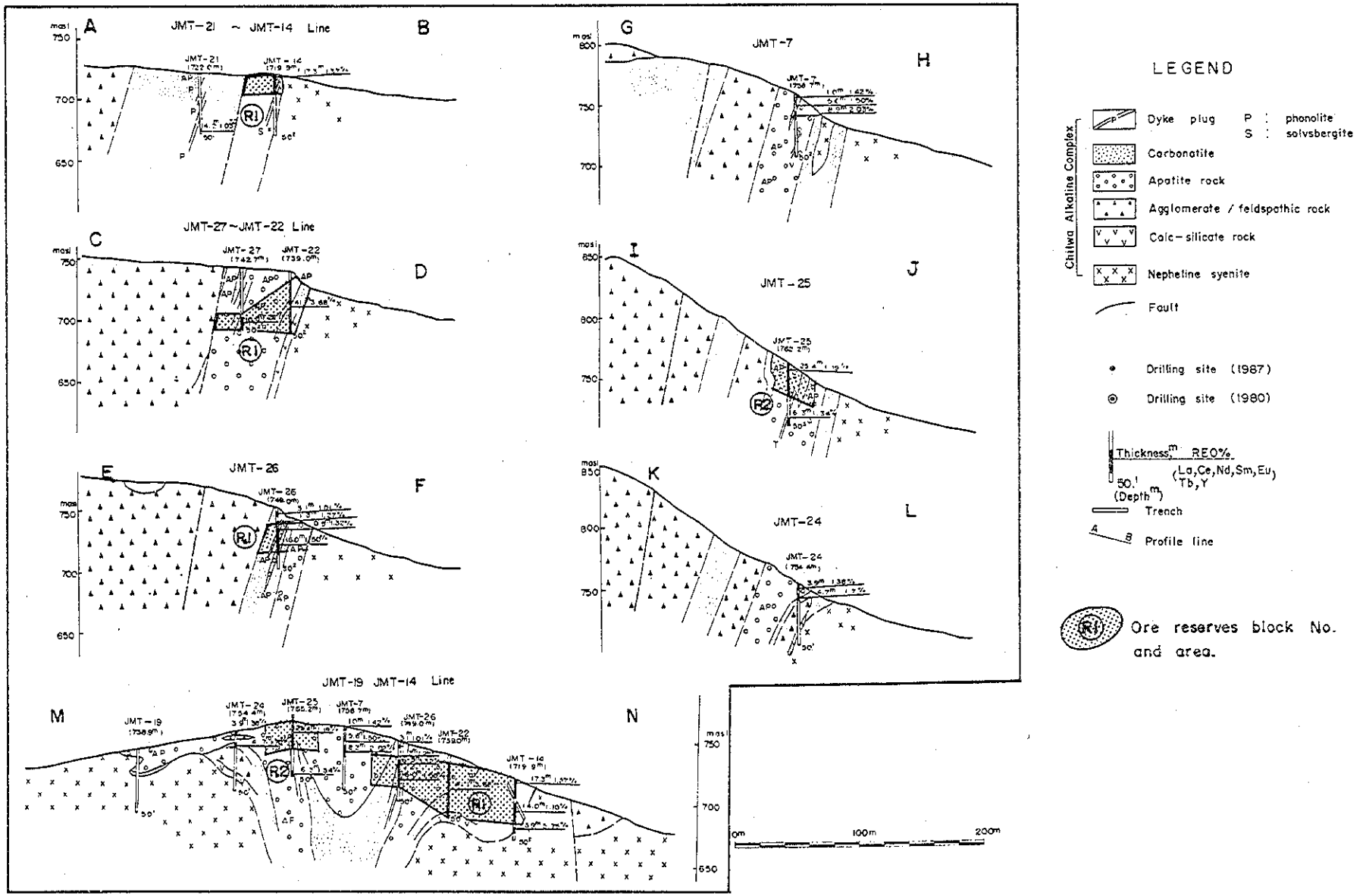


Fig. 13-2 Geological section of drill holes and map of ore reserves (REO), Tundulu
- Section -

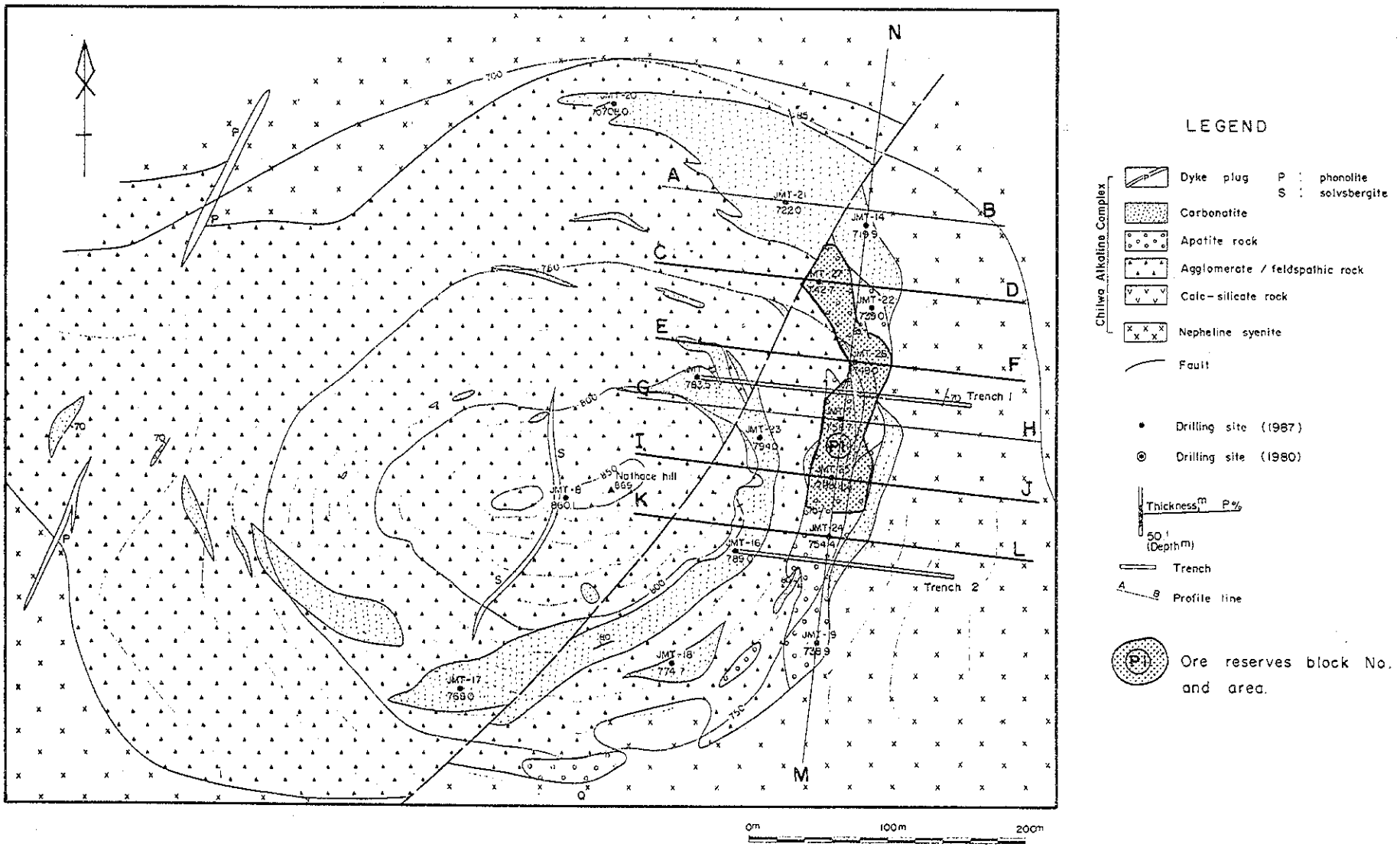


Fig. 14 - 1 Geological section of drill holes and map of ore reserves (P), Tundulu - Plain -

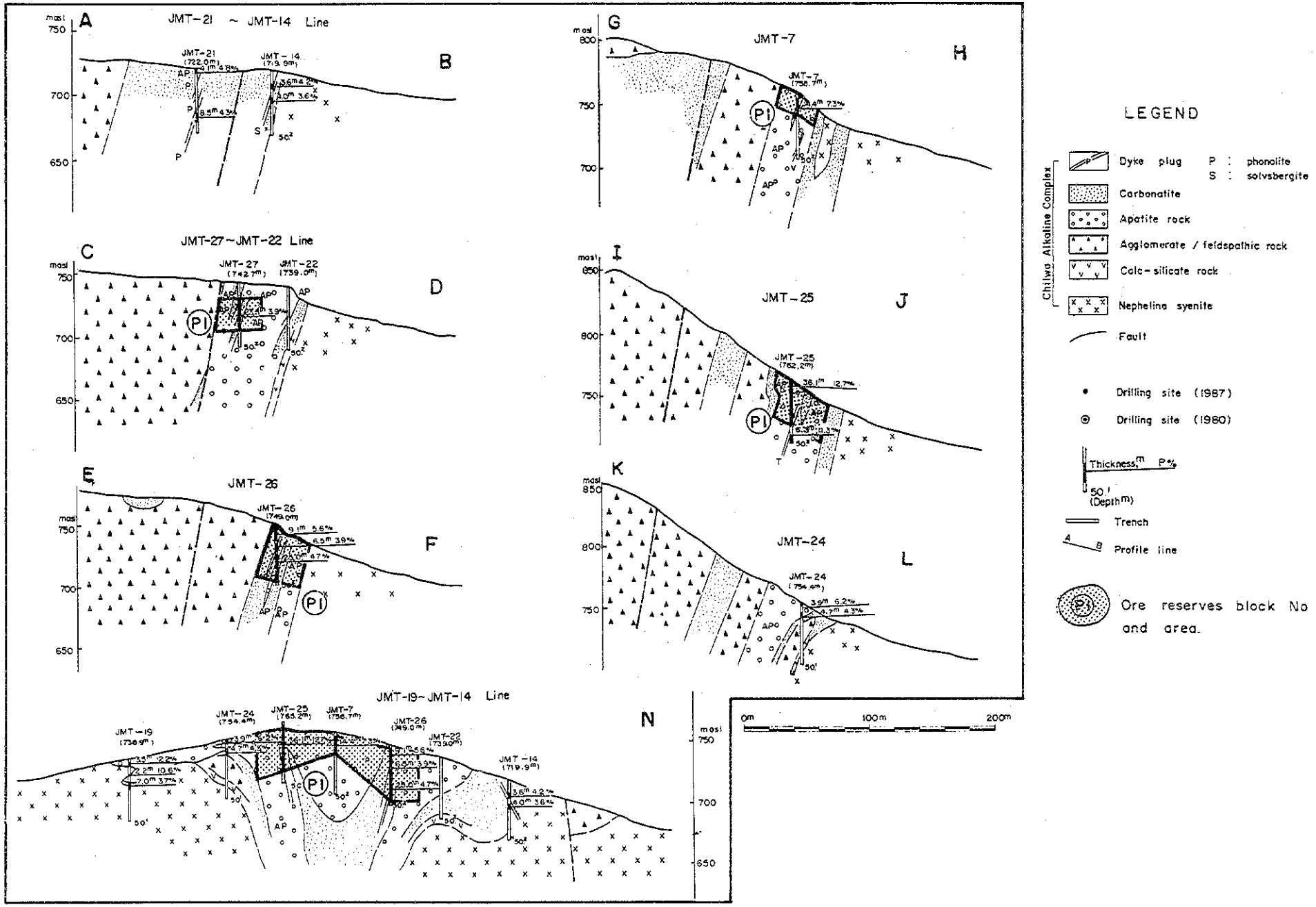


Fig. 14-2 Geological section of drill holes and map of ore reserves (P), Tundulu
- Section -

Part V Kangankunde sector