Chapter 1 Geology (Fig. 15)

Constituent rocks of this sector are as follows.

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa-Alkaline Province" Carbonatites (sovitic, ankeritic, and sideritic) Breccias (agglomerate, felspathic breccia) Nepheline syenite Dykes (phonolite, trachyte, nephelinite, lamprophyre etc.)
Late Precambrian to early Cambrian	Gneisses and syenites

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

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

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

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

Carbonatites in this sector are classified as dolomitic, sideritic, ankeritic and manganitic. Carbonatites are distributed mainly on the northern, eastern and western slopes of Kangankunde Hill.

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

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

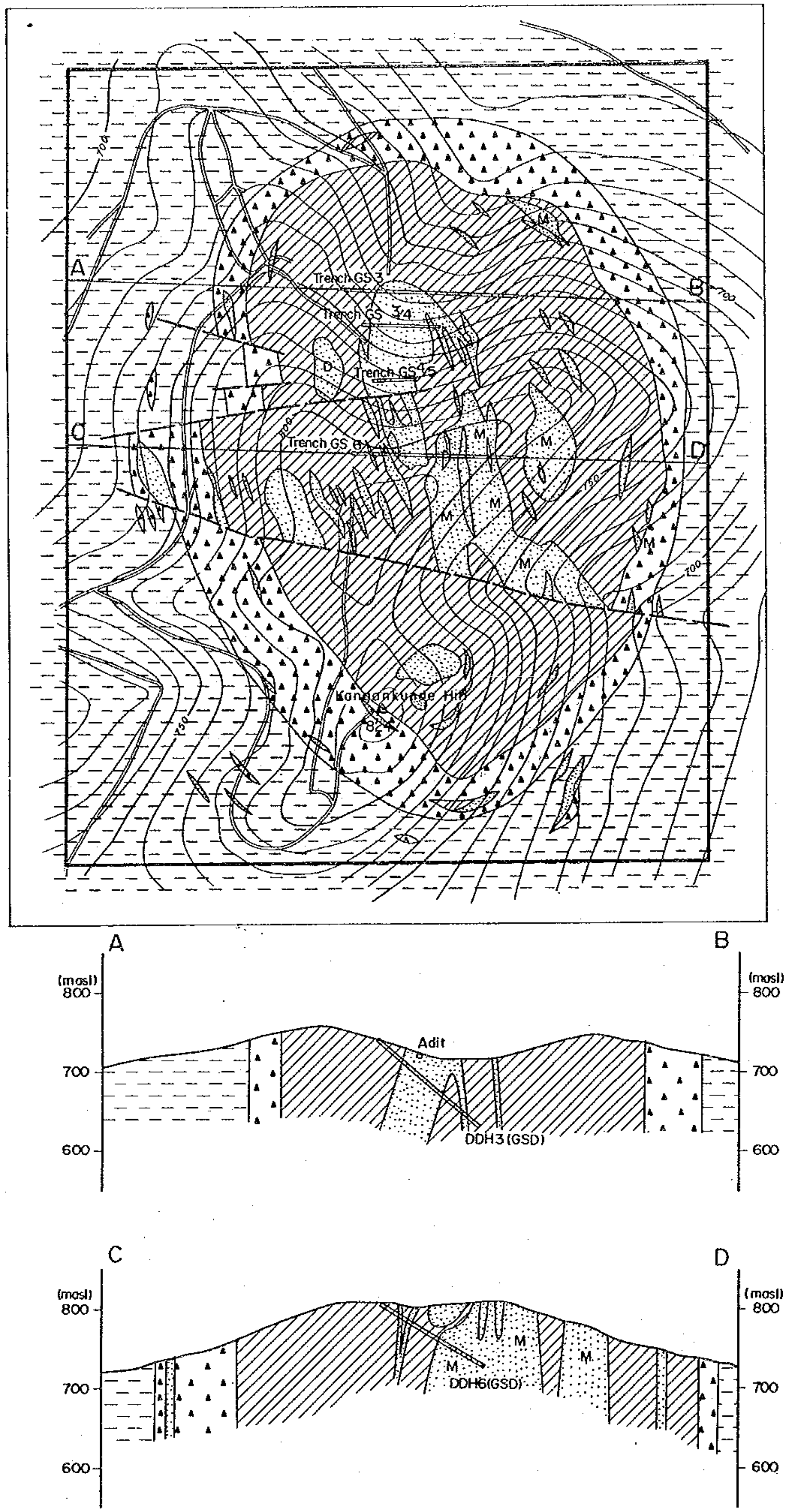
Manganese carbonatite is developed at the top and on the estern slope of the hill. It is melanocratic to dark brownish and massive, rich in iron and manganese oxides.

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

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

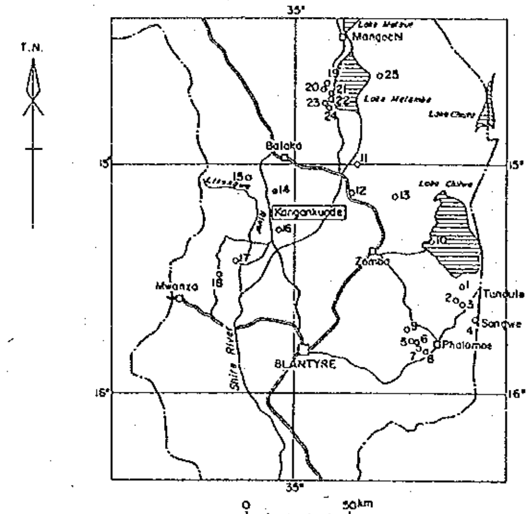
Main fault of E-W trend is found in the central part of the sector. By the fault, carbonatites and breccias are displaced.

Intensive erosion in the area has revealed carbonatite body to s considerable depth as opposed to Tundulu sector (Garson, 1965).



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

GEOLOGICAL MAP AND PROFILES OF KANGANKUNDE SECTOR



JAPAN INTERNATIONAL COOPERATION AGENCY
METAL MINING AGENCY OF JAPAN
FEBRUARY 1988

0m 250m 500m

LEGEND

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

Fig. 15 Geological map and profiles of Kangankunde sector

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 Tundulu and Songwe sectors.

102 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. 12.

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

It suggests that these 8 elements can be used effectively as pathfinder element of carbonatites in this sector.

Tab.12 Statistical values of geochemical survey, Kangankunde

(ppm)

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

2-2 Distribution of anomalies

Anomalous values in this sector are calculated in the same manner as in the case of Tundulu and Songwe sectors. The thresholds and anomalous values are shown in Tab. 12 and their distribution is mapped in Fig. 16.

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 on the northern slope of Kangankunde Hill.

Therefore, it is concluded that the carbonatite body on the northern slope of Kangankunde Hill has the highest potential for REE, Nb, Sr and P resources.

Chapter 3 Discussion

From the results of geological, geochemical, drilling and previous surveys done by the Geological Survey Department, the following facts on Kangankunde Hill have been established:

1. Carbonatites are distributed mainly in Kangankunde Hill. Small outcrops of carbonatites are found to the south and north of Kangankunde Hill.

2. Constituent rocks are almost the same as those of Tundulu and Songwe sectors except the absence of nepheline syenite.

3. Geochemical survey suggests that REE and phosphorus mineralized zones are concentrated on the northern slope of Kangankunde Hill.

4. REE patterns of carbonatites in this sector have tendency to decrease from La to Tb (Fig. 25).

5. In Kangankunde Hill, drilling, trench survey and underground survey have been conducted by Geological Survey of Malawi and private enterprises, especially in the area where the anomalous values are known to be concentrated. Holt (1965) reported that considerable REE reserves of 324.500t, in which monazite and strontianite had grade of 5.58% and 17.90% respectively, were concentrated to the depth of 33m.

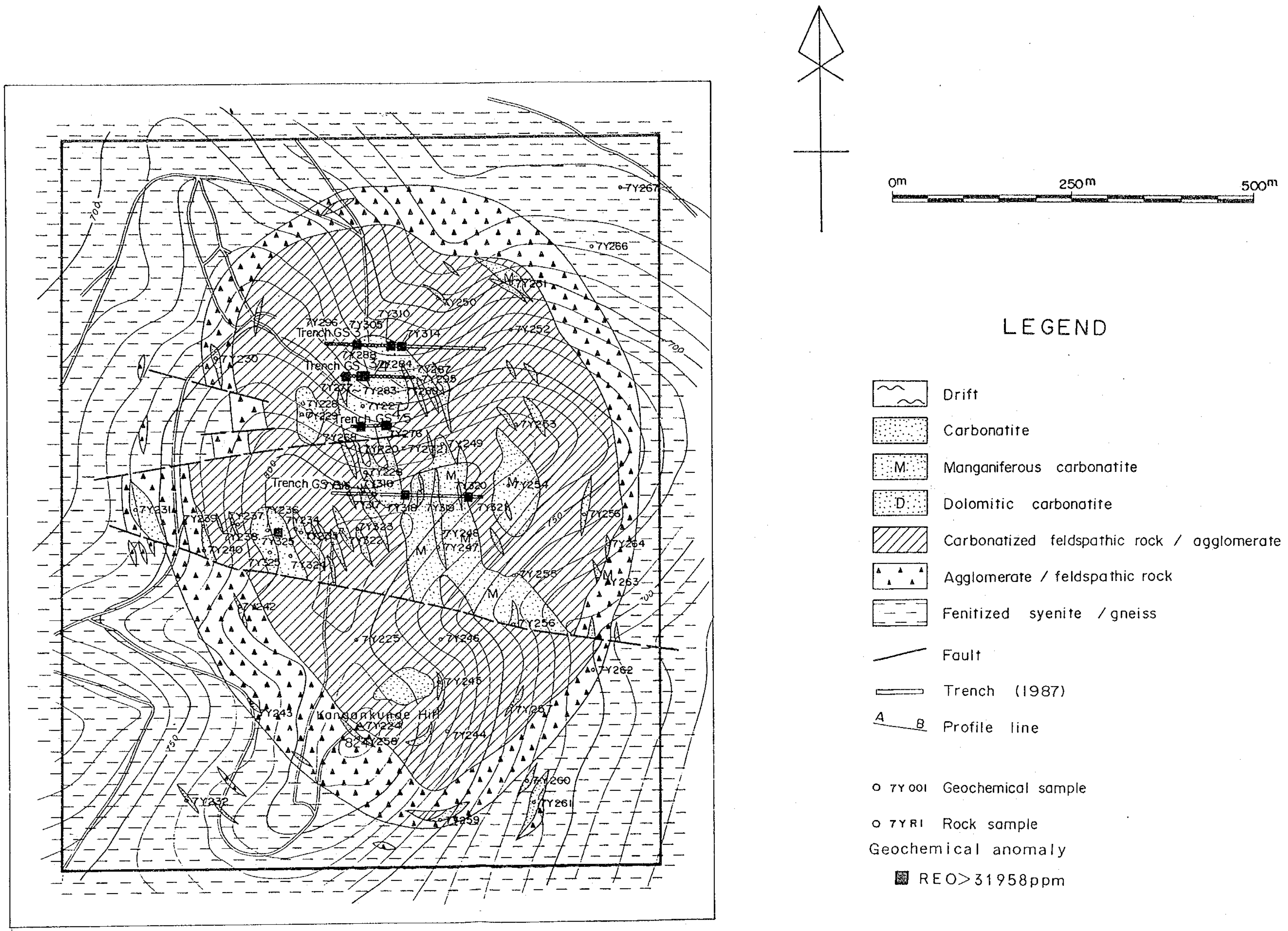


Fig. 16-1 Distribution map of geochemical anomalies, Kangankunde (REO)

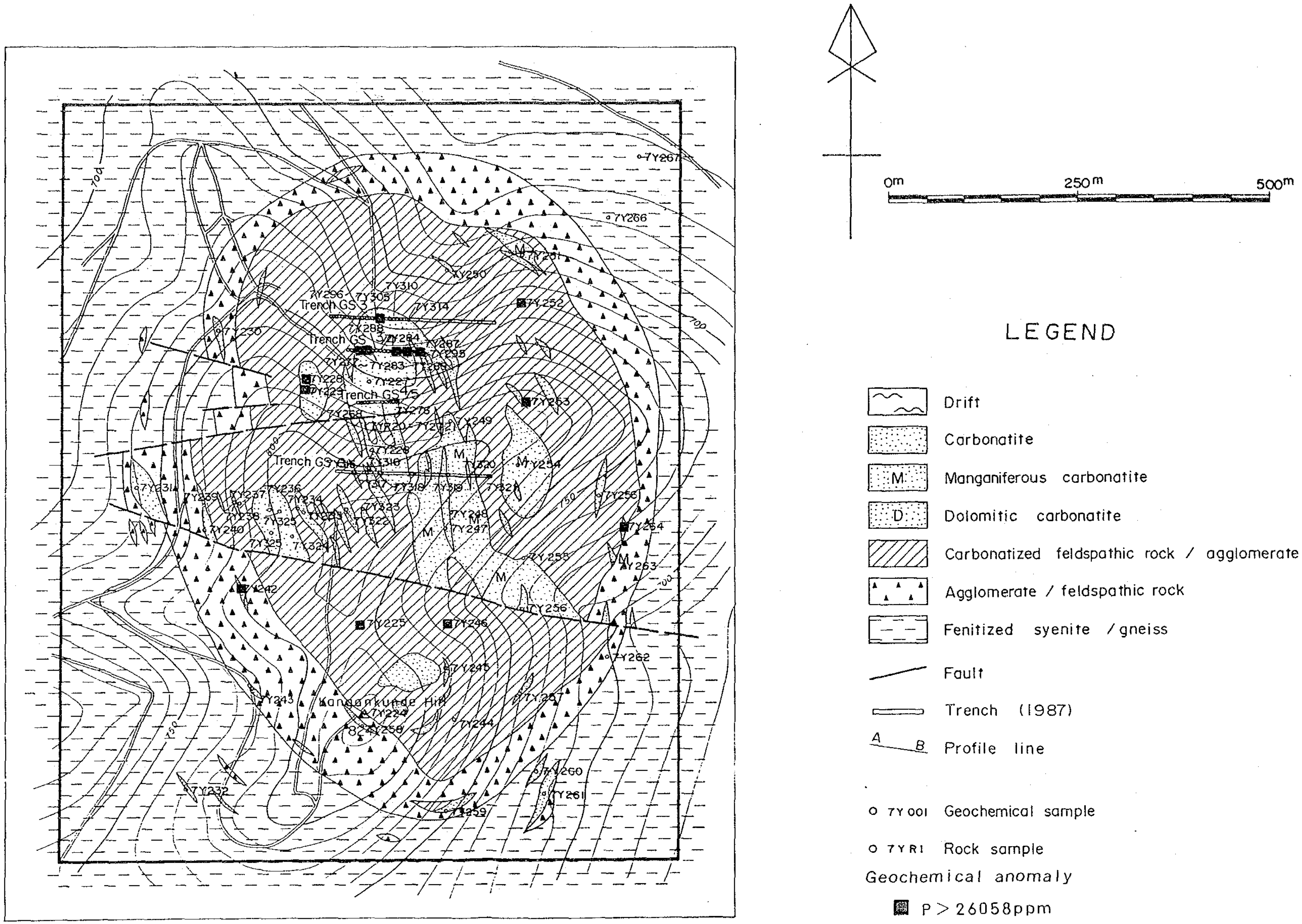


Fig. 16-2 Distribution map of geochemical anomalies, Kangankunde (P)

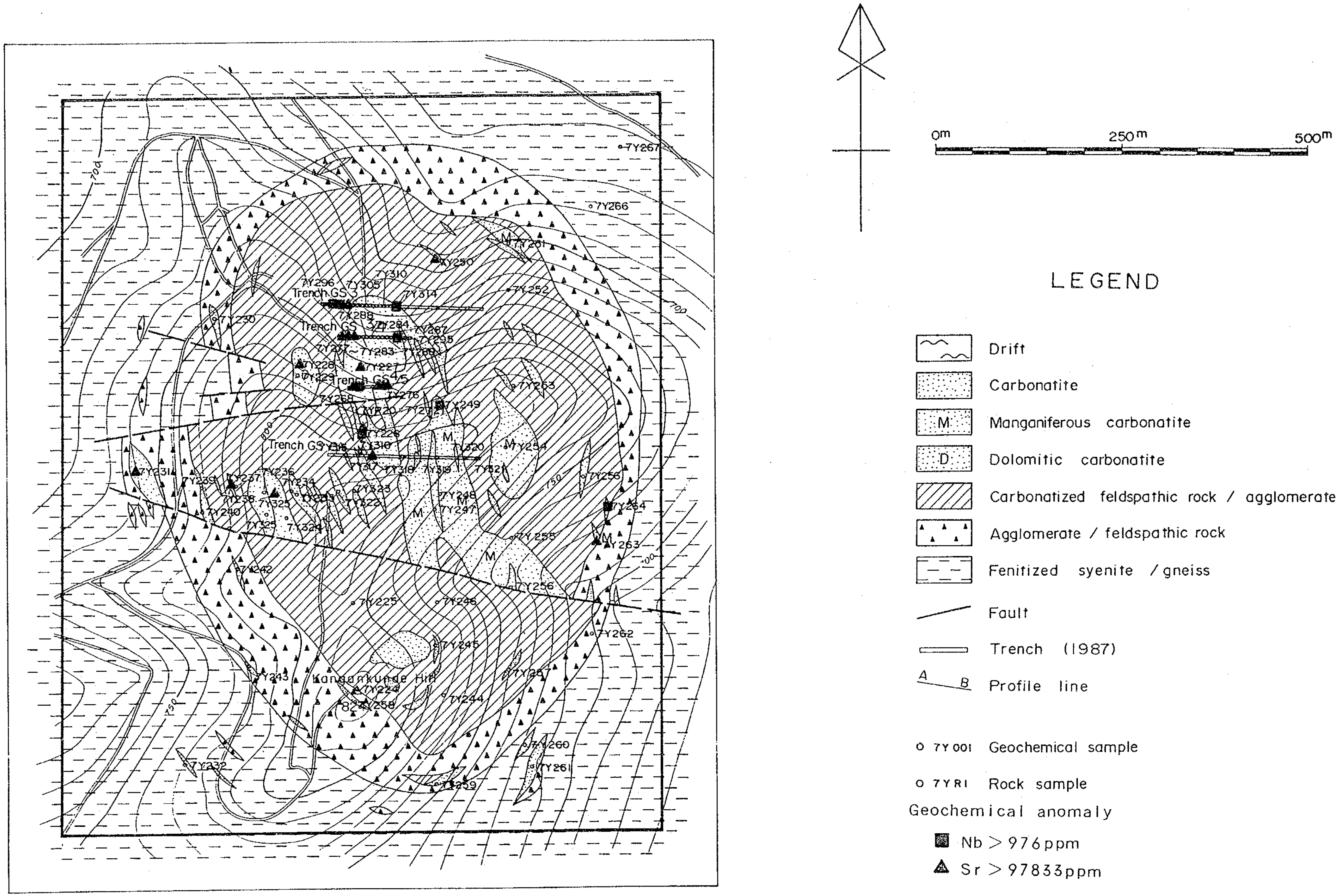


Fig. 16-3 Distribution map of geochemical anomalies, Kangankunde (Nb, Sr)

Part VI Chilwa Island sector

Chapter 1 Geology (Fig. 17, 18, PL. 3)

Constituent rocks of this sector are as follows.

Age	Rocks
Late Jurassic to early Cretaceous	"Chilwa-Alkaline Province" Carbonatites (sovitic, ankeritic, and sideritic) Breccias (agglomerate, feldspathic breccia) Nepheline syenite Dykes (phonolite, trachyte, nephelinite, lamprophyre etc.)
Late Precambrian to early Cambrian	Gneisses and syenites

Late Precambrian to early Cambrian basement rocks of gneisses and syenites are distributed in the outermost part of the sector and have undergone intense fenitization.

Gneisses are gray to grayish green in color, composed mainly of K-feldspar, plagioclase, quartz, clinopyroxene, common hornblende and biotite. Accessory minerals are apatite, ilmenite and magnetite.

Syenites have coarse-grained grayish K-feldspar and fine-to medium-grained clinopyroxene, plagioclase and quartz. Accessory minerals are apatite, pyrite and magnetite.

Igneous rocks of "Chilwa Alkaline Province" are developed throughout the island showing a ring structure, where the lithofacies are changed, from the outermost side inward, breccias, sovitic carbonatite, ankeritic and sideritic carbonatites. The diameter of the ring is approximately 2 km.

Nepheline syenite occurs around Michulu and Chinyombi Hills, situated in the northwestern part of the sector. It is leucocratic to pale pink in color, showing medium-grained equigranular texture.

Breccias occur as a small body in the carbonatite and as a layer of 100m to 700m width along boundary between carbonatite and basement rocks. Breccias are classified into feldspathic breccia and agglomerate and the former is predominant in the sector.

Those rocks found in and adjoining to carbonatite tend to undergo carbonitized alteration. They are reddish brown to dark brown in tint and often intruded by small veins of dark manganese minerals. Breccias with interstitial carbonate always have diameter ranging from several centimeters to several meters.

Carbonatites in this sector are classified into sovitic, ankeritic and sideritic. Sovitic carbonatite is developed on and around the top of the island from Mbirikwi, Michulu and Chinyobi Hills through Northern and Southern summits to Mulinde Hill.

Sovitic carbonatite is mainly composed of medium- to coarse-grained whitish to grayish calcite. Around Chinyombi Hill it is rich in pyroxenes and is gray to dark gray in color. Apatite, fluorite and pyrite are found as accessory minerals in places. X-ray powder diffraction analysis, has shown pyrochlore, synchysite, strontianite and apatite. This carbonatite shows a ring structure, dipping steeply outward.

Ankeritic and sideritic carbonatites are developed in the inner side of sovitic carbonatite, showing a ring structure with 1km diameter centered in the central part of Chilwa Island. The outer part of the ring is constituted by ankeritic and the inner part by mixed zone of sideritic and ankeritic ones. Ankeritic carbonatite is medium- to fine-grained and dark gray to dark brown or yellowish brown in color. Fine-grained pyrite and fluorite are visible. Main constituent minerals are ankerite and calcite and X-ray powder diffraction examination has detected bastnaesite, calkinsite, strontianite, synchysite, pyrochlore, betafite and apatite.

Dyke rocks are phonolite and lamprophyre. The former is several meters in width and the latter is found in the scale of 50m X 100m around JMC-23.

The geological structure of rocks of "Chilwa-Alkaline Province" is characterized by a ring structure.

Based upon the analyses of distribution pattern of stress, Garson et al. (1958) has assumed that the igneous activity occurred at three places of around 1,700m, 1,000 and 300m below the ground surface, each of them are arranged vertically.

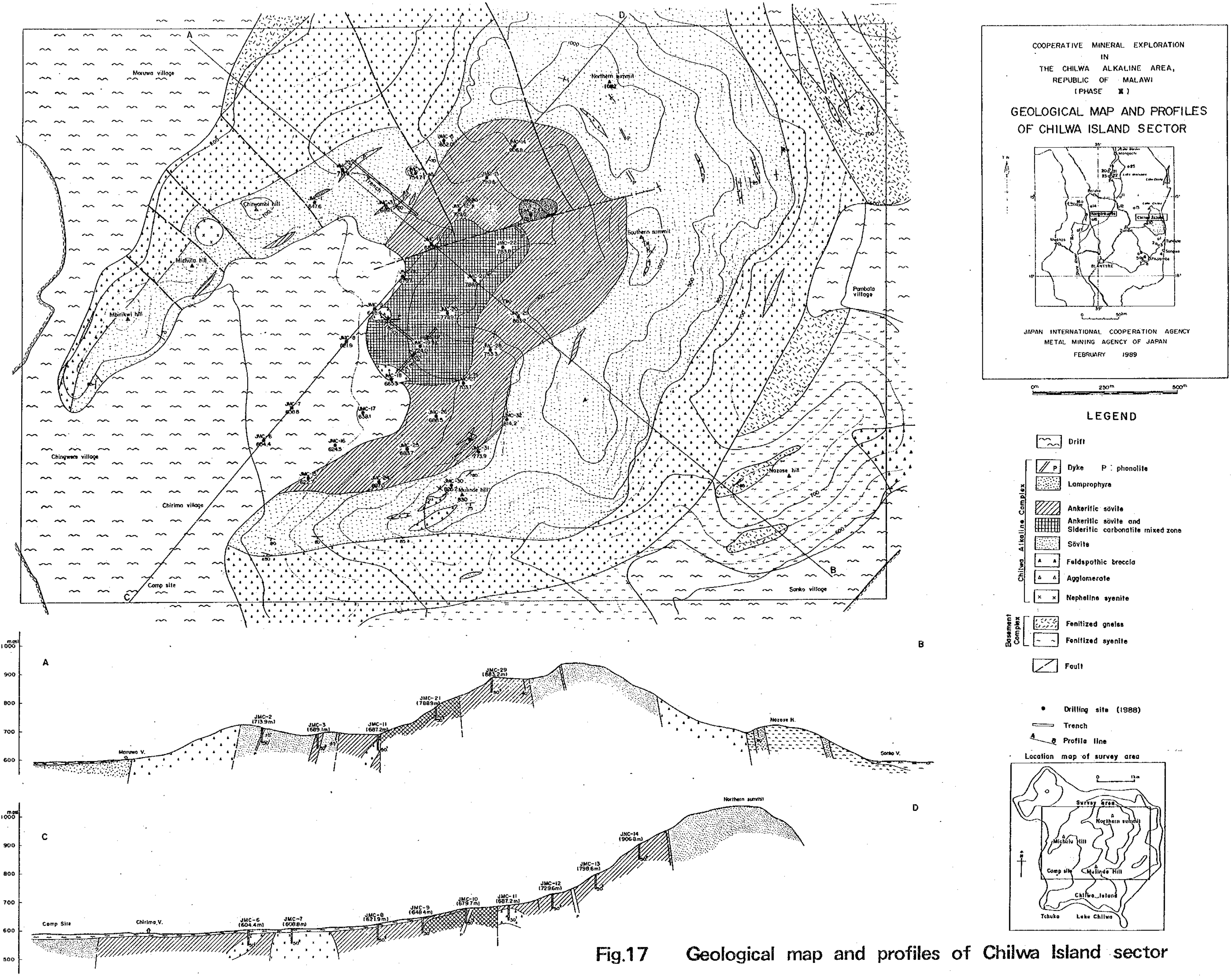


Fig.17 Geological map and profiles of Chilwa Island sector

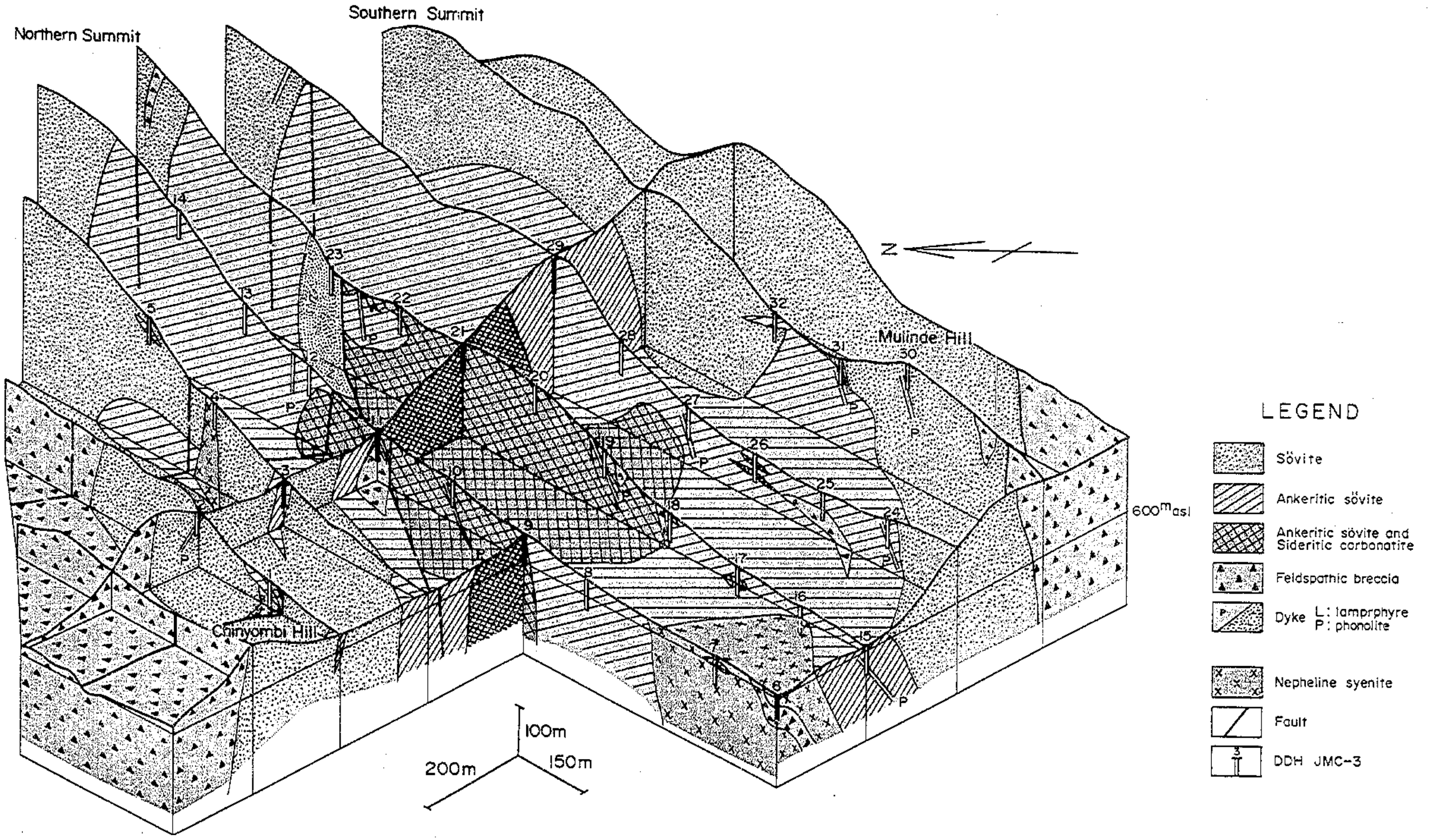


Fig. 18 Panel diagram of the Chilwa Island carbonatite complex

Chapter 2 Results of geochemical survey

Geochemical samples collected were mostly carbonatites. 151 samples were collected

2-1 Statistical value

Statistical values of each element and REE oxides (REO) of this sector as well as the crustal abundance are shown in Tab. 13.

Averaged contents of nearly all 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 Chilwa Island sector.

Tab.13 Statistical values of geochemical survey, Chilwa Island

(ppm)

Element	Rock Type	No. of Samples	Max.	Min.	Geometrical Mean (M)	M+1S	Abundance (Earth Crust)
La	Carbonatite	117	29505	63	1309	4033	25
	Others	34	6163	51	512	1871	25
Ce	Carbonatite	117	33400	95	2544	7543	81
	Others	34	14979	79	968	3942	81
Nd	Carbonatite	117	8031	16	845	2482	20
	Others	34	5426	14	313	1531	20
Sm	Carbonatite	117	1233	0.05	87.9	680	4
	Others	34	971.5	0.05	46.4	394	4
Eu	Carbonatite	117	292.5	1	31.0	80	0.8
	Others	34	170.1	0.05	10.9	81	0.8
Tb	Carbonatite	117	87.2	0.05	2.7	35	0.5
	Others	34	59.5	0.05	1.3	20	0.5
Nb	Carbonatite	117	9155	0.5	121	1207	20
	Others	34	2539	6	214	857	20
Sr	Carbonatite	117	15088	116	3181	7823	300
	Others	34	11782	64	1529	5223	300
Y	Carbonatite	117	947	24	173	360	38
	Others	34	818	20	110	294	38
P	Carbonatite	117	61403	34	2046	8723	900
	Others	34	164631	206	2672	9467	900
REO	Carbonatite	117	83009	249	6186	17863	
	Others	34	31762	251	2457	9531	

2-2 Distribution of anomalies

The thresholds and anomalous values are shown in Tab. 13 and their distribution is mapped in Fig. 19.

It is inferred that ankeritic carbonatite and mixed zone of ankeritic and sideritic ones indicate anomalous values of REE and Sr. While Nb-anomaly is found in sovitic carbonatite and P-anomaly in sovitic and ankeritic carbonatites.

Therefore, it is concluded that the central part occupied by ankeritic carbonatite and its mixed zone with sideritic carbonatite have higher potential for REE, while the outer part occupied by sovitic carbonatite for Nb and P.

3-4 results of drilling survey and discussion (Fig. 20)

Geology and characteristics of carbonatites in Chilwa Island have been summarized as follows (Garson et al., 1958; JICA and MMAJ, 1988):

1. The area of 3.5km X 2.6km of Chilwa Island is occupied by Alkaline rocks and carbonatites.
2. Basement rocks near carbonatites have undergone intense fenitization.
3. Carbonatites body shows a ring structure, which consists of breccias, sovitic, ankeritic and sideritic carbonatites from outer side inward.
4. In the ring, the stage of igneous activity of carbonatites becomes younger inward.
5. The igneous activity occurred at three places of around 1,700m, 1,000 and 300m below the ground surface, each of them is arranged vertically.

During the third phase, geological, geochemical and drilling surveys were carried out together with laboratory experiments. The purpose of this phase survey was to elucidate the geological conditions and petrogenesis of the carbonatite body in Chilwa Island.

Through the field works, carbonatites were preliminarily classified into sovitic, ankeritic and sideritic. The comparison among the results of

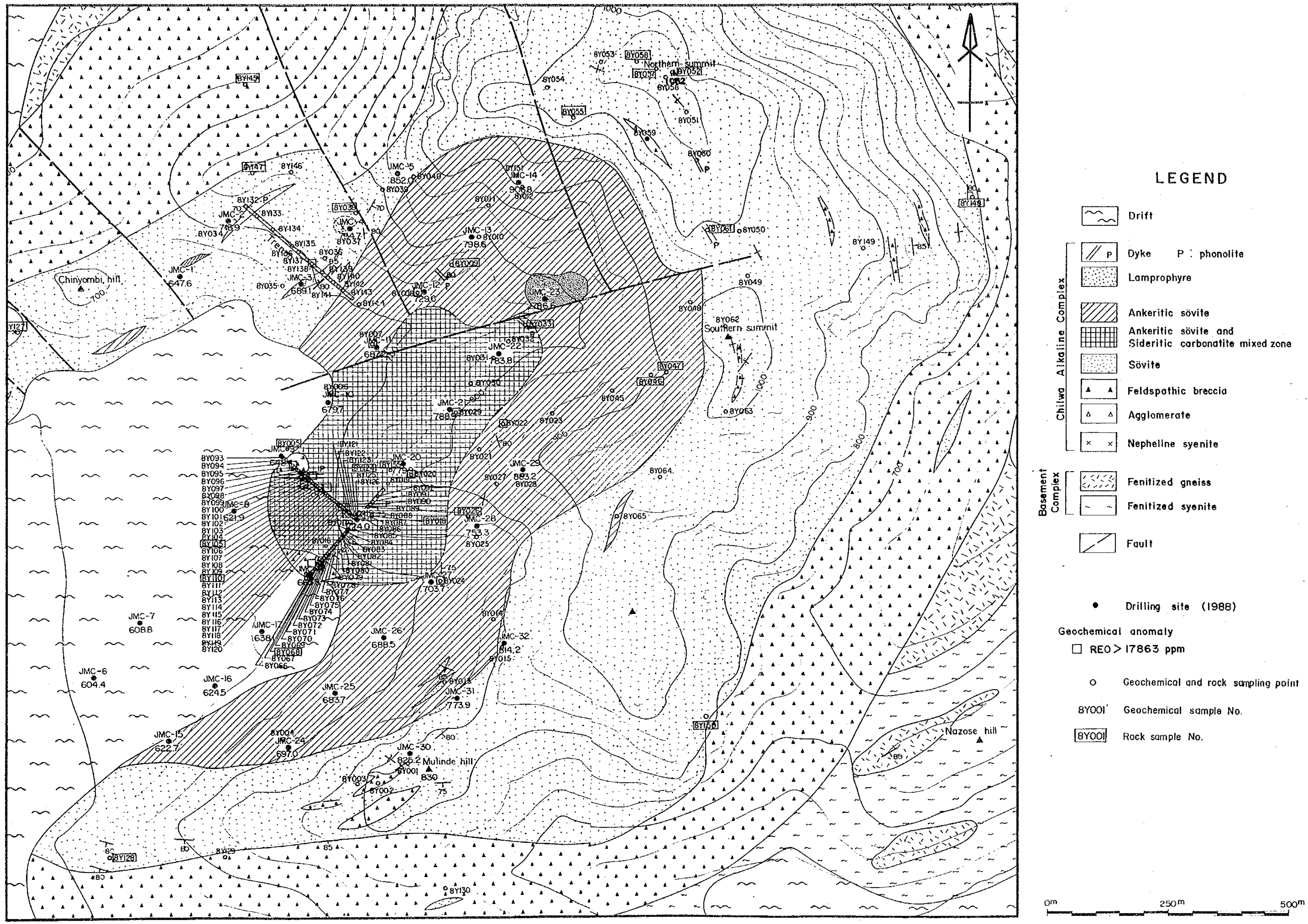


Fig. 19-1 Distribution of geochemical anomalies, Chilwa Island (REO)

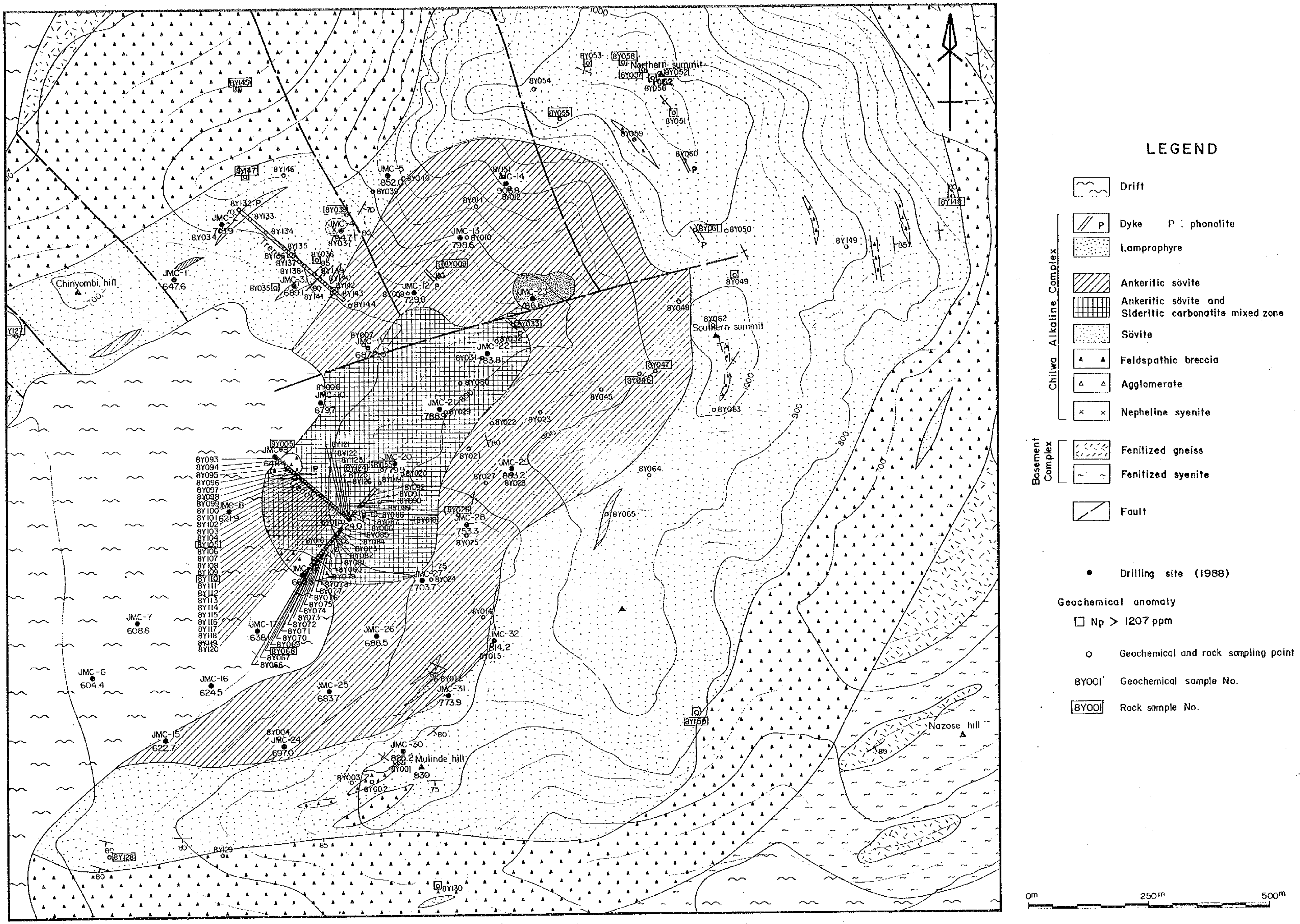


Fig. 19-2 Distribution of geochemical anomalies, Chilwa Island (Nb)

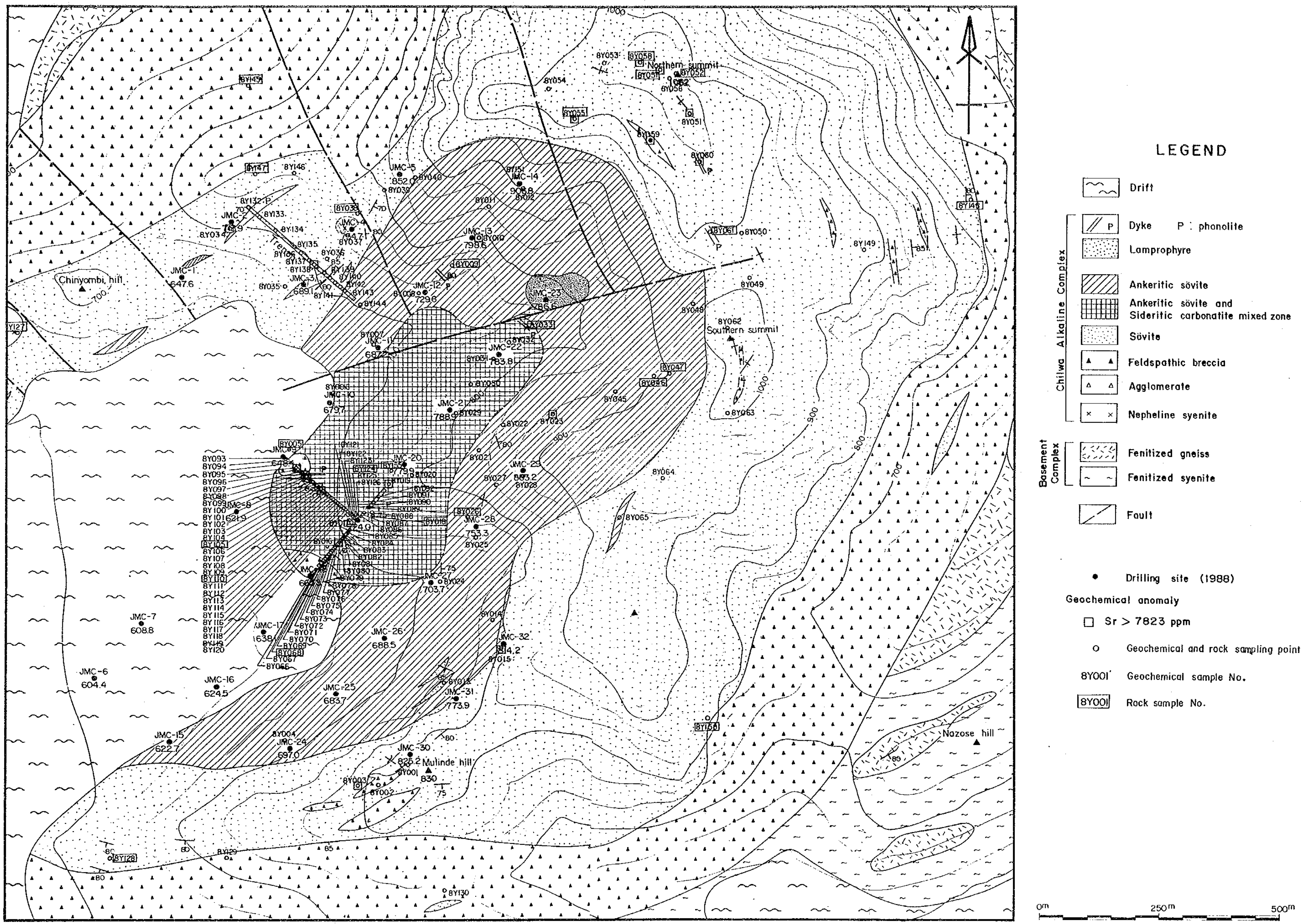


Fig. 19-3 Distribution of geochemical anomalies, Chilwa Island (Sr)

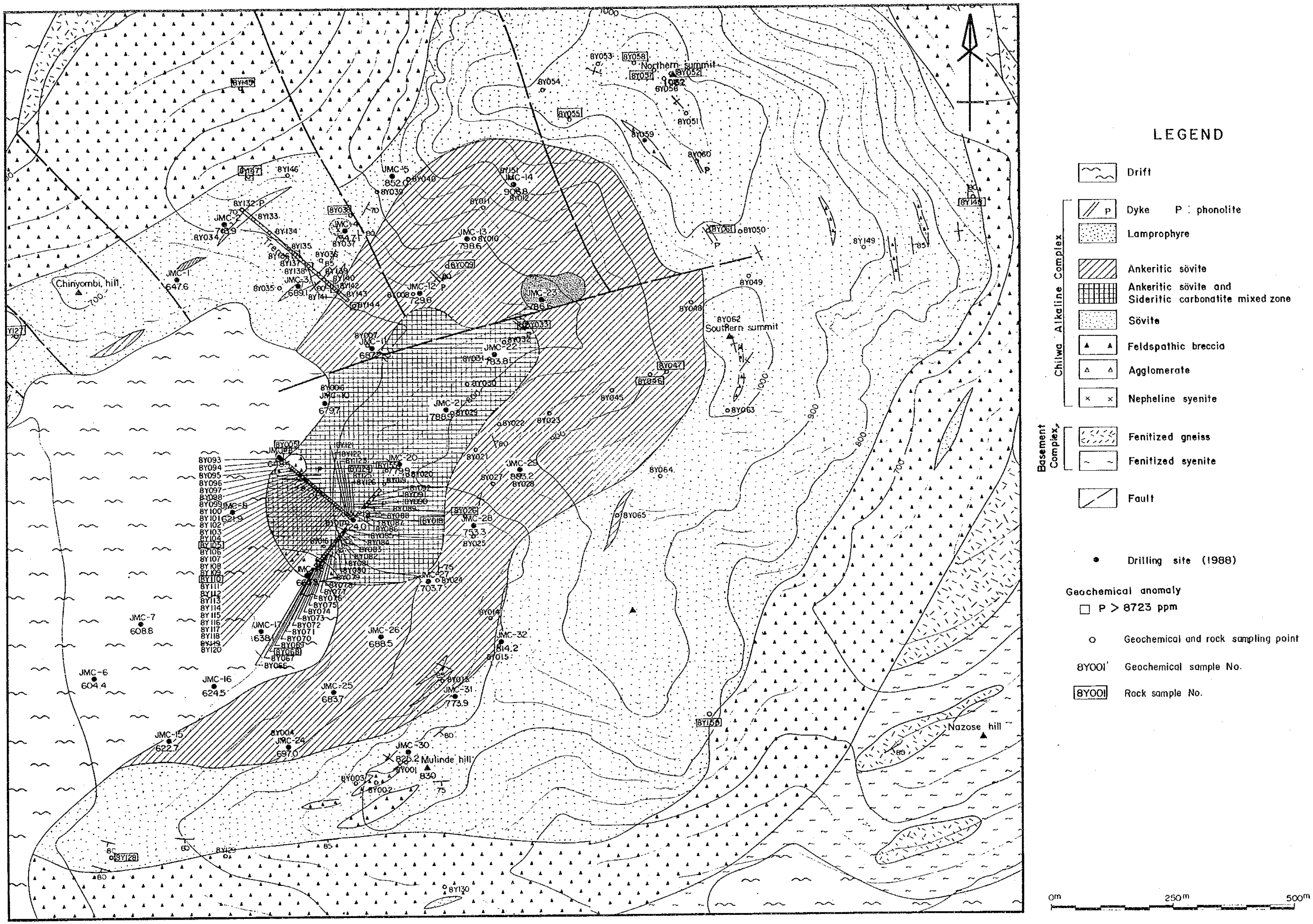


Fig.19-4 Distribution of geochemical anomalies, Chilwa Island (P)

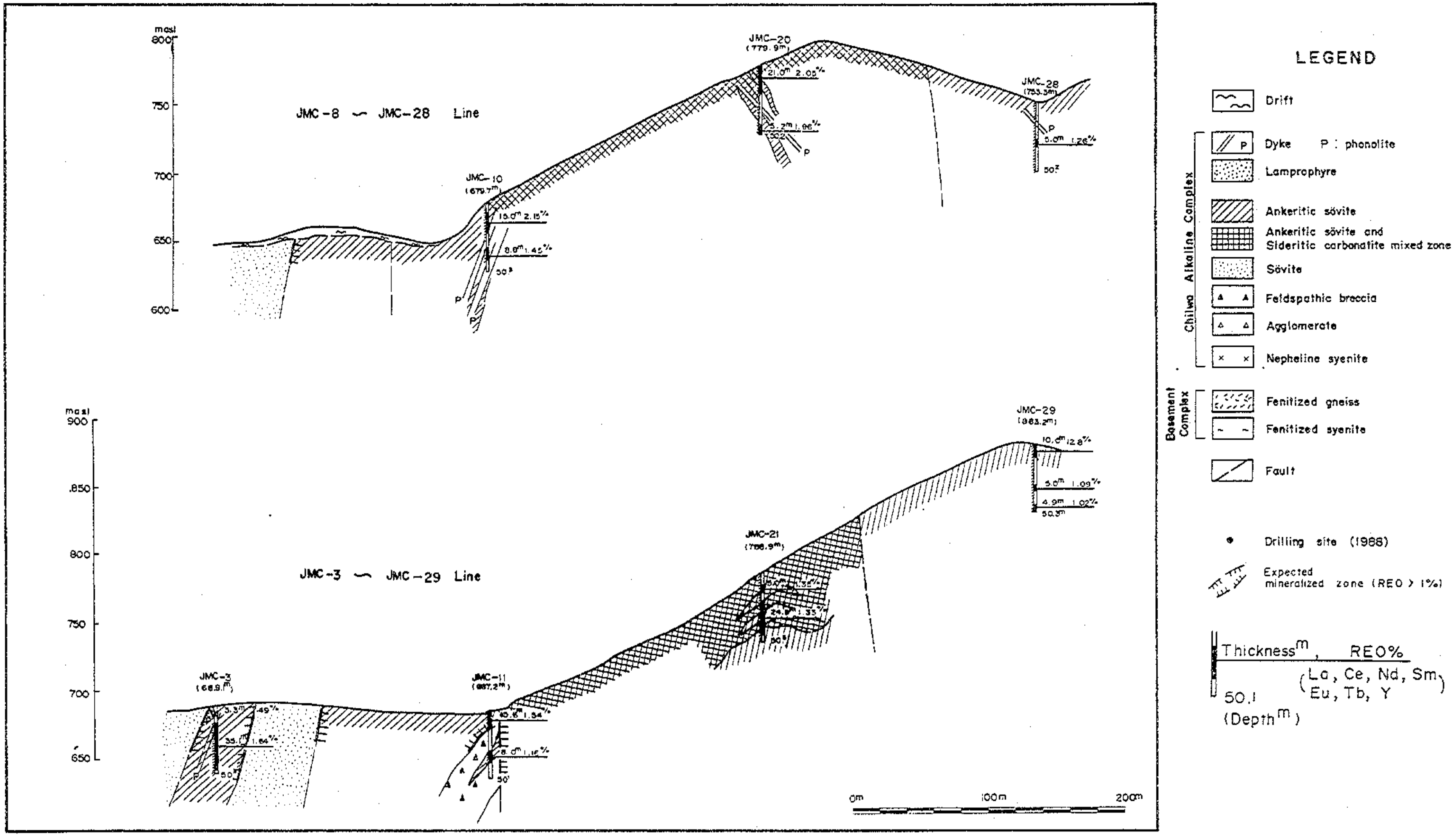


Fig.20 - 1 Geological section of drill holes, Chilwa Island

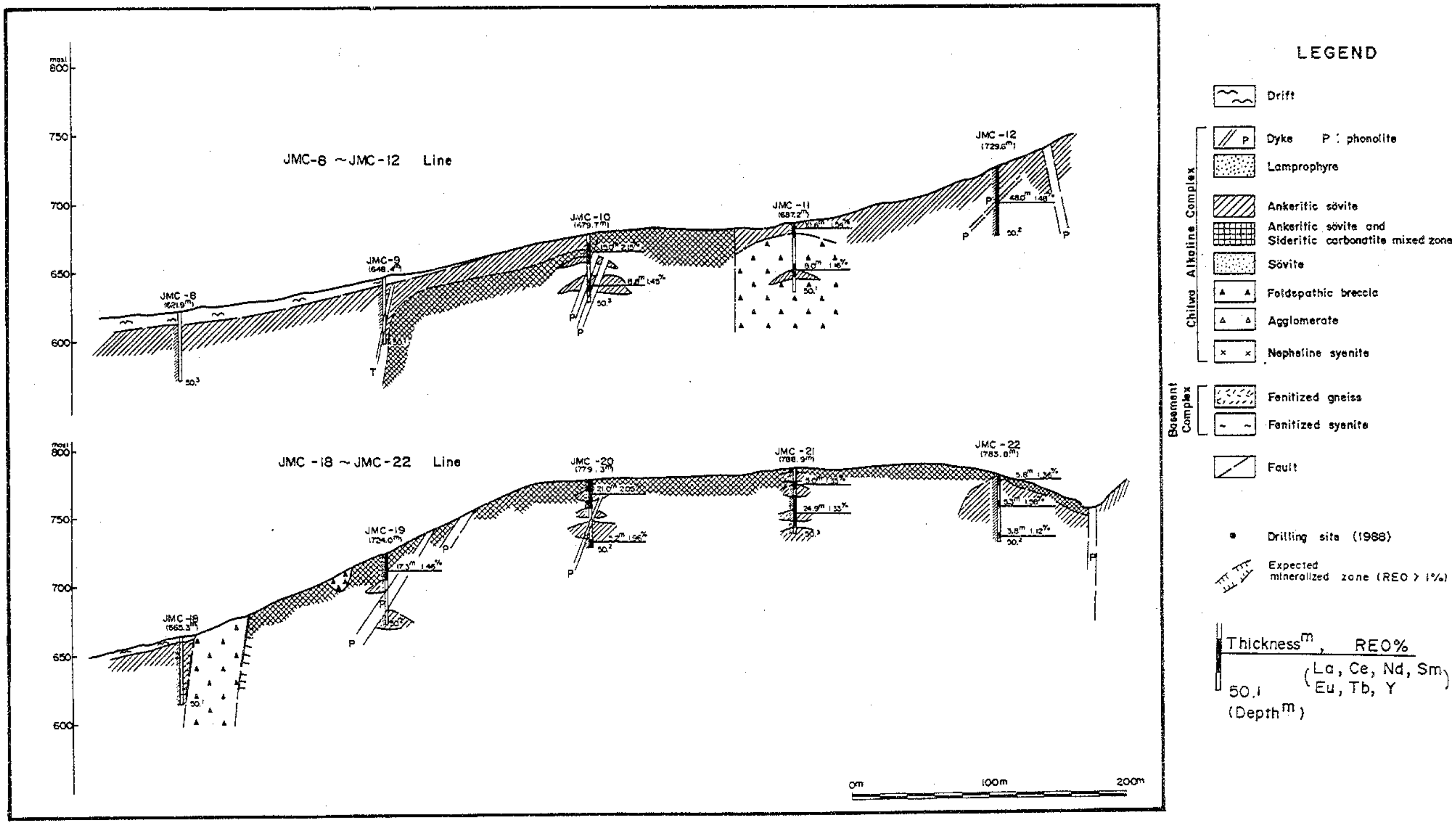


Fig.20 - 2 Geological section of drill holes, Chilwa Island

field observation, microscopic analysis and X-ray diffraction examination for these three types are shown in Tab. 14.

It has been clarified that sovitic and ankeritic carbonatites contain dolomite and that magnetite and goethite are abundant in sideritic one. Siderite is considered to be partly altered to goethite.

As the results of previous works, central part and its adjoining part of the carbonatite body have been considered to be sideritic and ankeritic, respectively. Through the survey of third phase, however, ankeritic carbonatite is recognized in sideritic one, (JMC-19, 20 and 21), thus ankeritic carbonatite where sideritic carbonatite is often associated is discriminated as mixed part of both carbonatites.

As shown before, the geological structure of Chilwa Island sector is characterized by a ring structure. Although constituent rocks in the inner part of the ring dip in rather random direction, in the outer part they tend to dip steeply outward.

Minerals such as apatite and pyrochlore were analysed by EPMA to estimate the contents of REE and other elements. As a result of the analysis, it has been clarified that apatite contains La (7.12%), Ce (13.7%) and Th (1.21%) and pyrochlore has Nb (33.1-47.4%), and Ce (1.33-2.76%).

Carbon and oxygen isotopic ratios are analyzed for carbonatites in order to elucidate the petrogenesis of these rocks.

Analyzed results for sovitic and ankeritic ones, composed of calcite, ankerite and dolomite, are $\delta^{13}C$=-4.5‰ to -2.4‰ and $\delta^{18}O$=+8.2‰ to +12.1‰. The values are rather higher than those of apatite rocks and carbonatites in Nathace Hill, but suggest that these rocks are igneous in origin.

The result for sideritic carbonatite, though it shows no sign of containing carbonate through X-ray diffraction examination, has $\delta^{13}C$=-6.6‰ to -6.7‰ and $\delta^{18}O$=+18.3‰ to +20.3‰. Thus the rocks are inferred to have undergone alteration through contamination by meteoric water. It might be stated that during the alteration carbonate minerals and goethite replace siderite. The carbonate may be amorphous one.

As a result of geological, geochemical and drilling surveys, it is inferred that ankeritic carbonatite and its mixed zone with sideritic one in the central part of Chilwa Island sector have the highest potential in this sector for REE mineralized zone. As for Nb resources, sovitic carbonatite around Northern Summit and around the JMC-3 is considered to have the highest potential.

Tab.14 Observation of the Chilwa Island carbonatites

Sample No.	Field		Thin section		X-ray diffractometer
	Name	Description	Name	Description	Mineral
C3003	sövite	medium-grained white to brown calcite	sövite	calcite (0.05-0.7mm) with amount of barite, quartz and pyrite, mosaic texture	calcite ≫ dolomite = quartz = = barite
C1304	ankeritic sövite	fine-grained reddish brown carbonate	ankeritic sövite	carbonate (-0.15mm), porphyritic texture	ankerite > dolomite
C2208	ankeritic sövite	fine-grained white and reddish brown carbonate	ankeritic sövite	carbonate (0.2-1.0mm), porphyritic texture	ankerite = siderite ≫ quartz = pyrite
C2810	ankeritic sövite	pyrite bearing fine-grained white carbonate	ankeritic sövite	carbonate (0.1-1.25mm) with K-feldsper, quartz, pyrite, fluorite and barite, mosaic texture	ankerite ≫ siderite > quartz > barite
C2904	ankeritic sövite	fine-grained gray carbonate	ankeritic sövite	carbonate (0.1-0.7mm) with quartz pyrite, magnetite, and goethite	ankerite ≫ K-feldspar > quartz
C2106	sideritic carbonatite	black to dark brown coase-grained carbonate	altered carbonatite	euhedral to subhedral magnetite and goethite (1.5 - 7mm) with quartz, carbonate and K-feldspar	calcite = goethite > calkinsite = Synchysite = K-feldspar
C2408	ankeritic sövite	fluorite bearing medium-grained carbonate	sideritic carbonatite	euhedral to subhedral siderite (0.2-1.75mm) with quartz, barite and fluorite	siderite > fluorite > quartz > kutnahorite = barite

Part VII Comprehensive discussion

Part VII Comprehensive discussion

Based upon the analyses for samples collected during the phases from 1986, are discussed depth of formation, isotopic ratio, bulk chemistry and REE contents of carbonatites in the Chilwa Alkaline area.

Chapter 1 Depth of formation of carbonatite bodies

Generally speaking, the variation in mode of field occurrence of the carbonatite is considered to depend on the depth of consolidation of magma (GSJ and DNPM, 1987). Thus it may be possible to estimate the depth of consolidation based upon the mode of occurrence (Garson, 1965 and 1966).

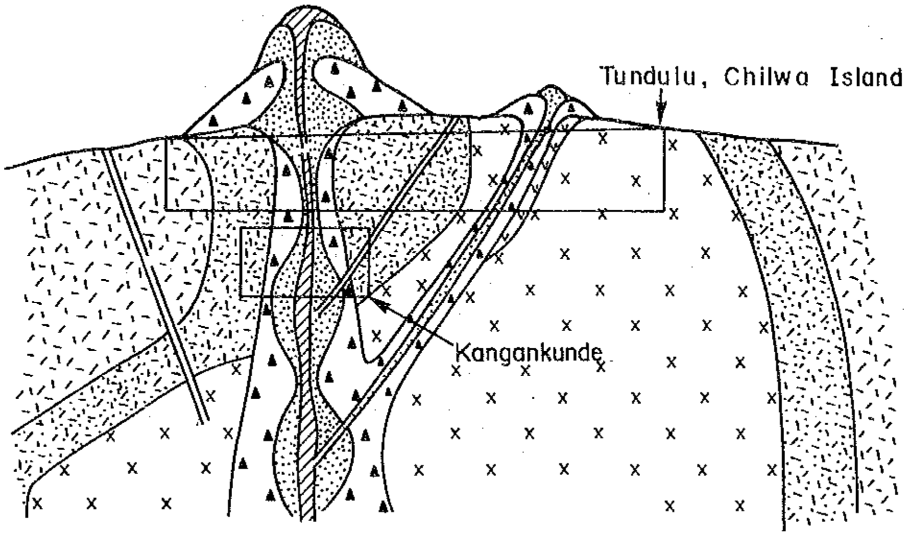
During the third phase survey, schematic cross sections for carbonatites bodies in Tundulu, Songwe, Kangankunde and Chilwa Island sectors were drafted in order to compare the depth of formation of the bodies in each sector.

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 steeply 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).

As the carbonatite body in Kangankunde sector contains carbonatized breccias and shows ovoidal ring structure, it is inferred to be formed in rather deeper level than those of other sectors (Fig. 21).



LEGEND

Upper Jurassic to Lower Cretaceous
- Dike
- Ankertic, sideritic carbonatite, apatite rock
- Sövite
- Agglomerate, feldspathic breccia
- Nepheline syenite
  - Carbonate silicate rock
  - Fenitized rock

Upper Precambrian To Lower Cambrian
- Basement complex

Fig.21 Schematic diagram of the carbonatite complex in the Chilwa Alkaline area

Chapter 2 Isotopic ratios of Carbon and oxygen

Carbon and oxygen isotopic ratios are analyzed for carbonatites and apatite rocks in "Chilwa-Alkaline Province" in order to elucidate their petrogenesis.

CO_2 generated through the decomposition reaction of carbonates with phosphates were analyzed with a mass spectrometer.

The procedure is as follows:

1) weigh 30 to 40 mg of previously ground samples (minus 200 mesh)
2) phosphoric acid (100%) is added to decompose samples in vacuum and at 25°C for 1 to 7 days
3) collect CO_2 generated and remove mixed H_2O by the aid of ethyl alcohol as a freezing mixture
4) contents of $\delta^{13}C$ and $\delta^{18}O$ in CO_2 are analyzed with mass spectrometer (Finnigan Mat Delta-E) at the Central laboratory of Mitubishi Metal Corporation.

The working standard, used is fossil coral CK-13 (aragonite of $\delta^{13}C_{PDB}$=+0.54‰ and $\delta^{18}O_{PDB}$=-1.75‰). The contents of $\delta^{18}O$ are further corrected for the kinetic fractionation in the phosphoric acid reaction with different minerals.

The relationship between $\delta^{18}O_{PDB}$ and $\delta^{18}O_{SMOW}$ is as follows:

$$\delta^{18}O_{SMOW} = 1.03086\ \delta^{18}O_{PDB} + 30.86‰$$

Tab. 15 shows isotopic ratios of carbonates in Chilwa Island and Tundulu sectors.

Tab.15 Isotopic composition of the carbonatites

No	Sample No	Sector	Rock name	Mineral	$\delta^{13}C$ (PDB)	$\delta^{18}O$ (PDB)	$\delta^{18}O$ (SMOW)
1	8Y009	Chilwa Is	ankeritic sövite	ankerite	-4.5	-22.0	+ 8.2
2	8Y026	"	"	dolomite > calcite	-2.4	-20.1	+10.1
3	8Y038	"	sövite	calcite > dolomite	-3.8	-19.7	+10.6
4	8Y058	"	"	calcite > ankerite	-3.2	-18.2	+12.1
5	8Y068	"	sideritic carbonatite	fluorite > Fe	-6.6	-10.2	+20.3
6	8Y124	"	"	fluorite > Fe	-6.7	-12.2	+18.3
7	8Y153	Tundulu	apatite rock	apatite > quartz > calcite	-6.2	-24.7	+ 5.4
8	8Y154	"	"	"	-7.4	-21.5	+ 8.7
9	JMT-7	"	sideritic carbonatite	kutnahorite > calcite	-2.3	- 9.9	+20.7
10	JMT-22	"	ankeritic sövite	ankerite > siderite	-5.4	-23.3	+ 6.8
11	JMT-26	"	sideritic carbonatite	kutnahorite > calcite	-5.0	- 8.6	+22.0

Analyzed results are plotted on the figure in comparison with those of various rock types (Fig. 22).

$\delta^{13}C$ in carbonatites from "Chilwa Alkaline Province" are distirubted in the range of -7.4‰ to -2.3‰ and $\delta^{18}O$ are in two ranges of +5.4‰ to 12.1‰ and +18.3‰ to 22.0‰. The values of $\delta^{13}C$ are similar to those from common carbonatites and diamond. While the values of $\delta^{18}O$ are plotted in the area of such igneous rocks as basalt and granite. Analyzed samples with higher $\delta^{18}O$ ranging from 18.3‰ to 22.0‰ are plotted in the are of sedimentary rocks, but it is inferred that these samples have undergone low-temperature hydrothermal alteration.

The relationship between $\delta^{13}C$ and $\delta^{18}O$ is shown in Fig. 23. The square labeled as Oka Box in the figure represents the isotopic ratios of carbonatites from Oka, Canada (Deines, 1970). The ratios of Mbeya carbonatites of Tanzania are also plotted after Suwa et al. (1969).

As shown in the figure, among the samples of apatite rock, sovitic and ankeritic carbonatites of "Chilwa Alkaline Province", two are plotted in

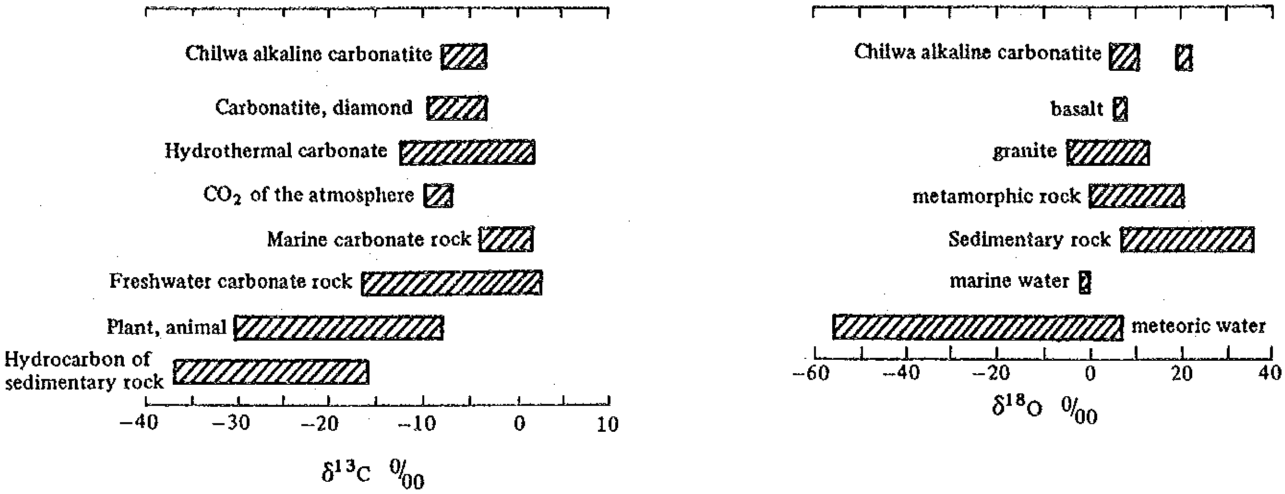


Fig.22 The carbon and oxygen isotopic ratios of the materials

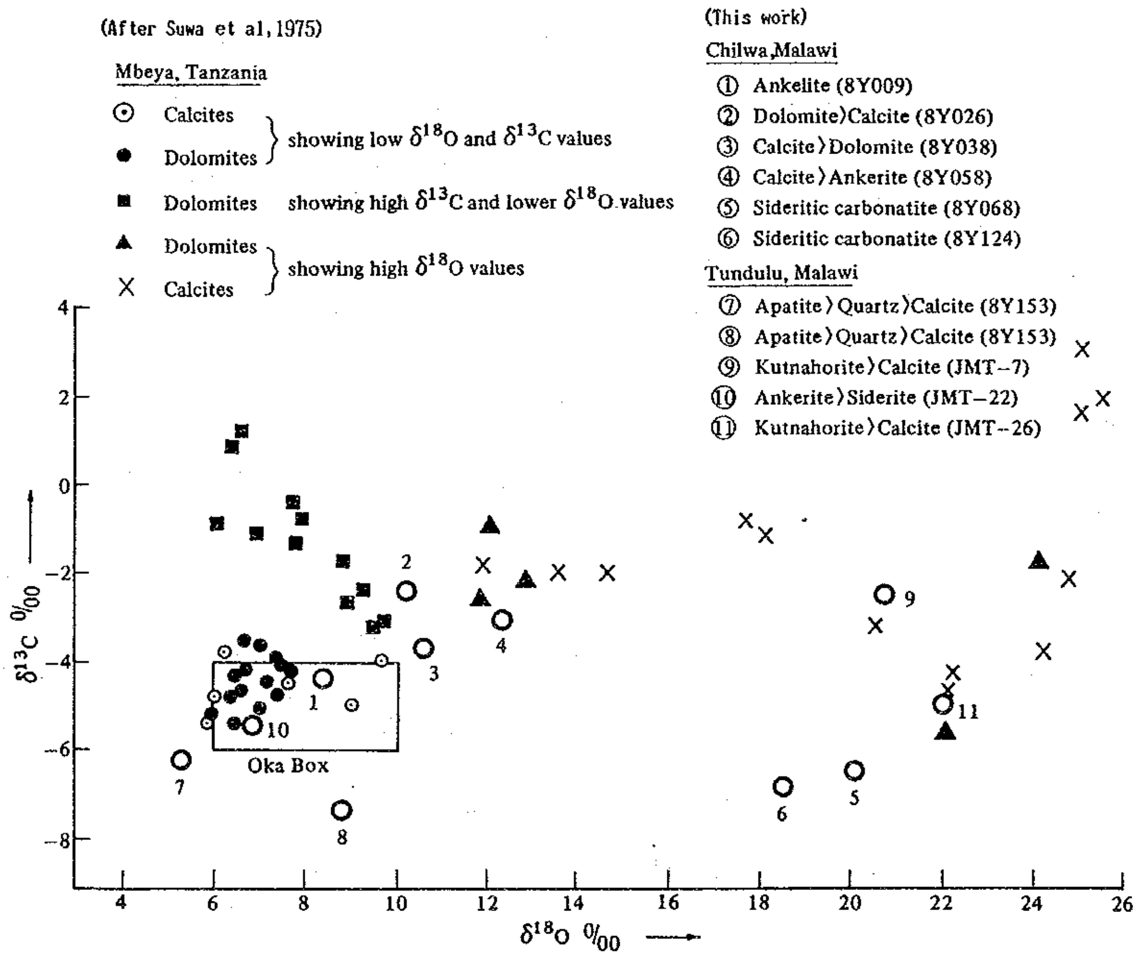


Fig.23 The oxygen and carbon isotopic ratios of carbonatites in Chilwa alkaline area carbonatite, southern Malawi and Mbeya carbonatite, southern Tanzania

the Oka Box and five out of it but around the Box. These seven samples are inferred to be of magmatic origin, because it has generally been assumed that the values of $\delta^{13}C$ and $\delta^{18}O$ of igneous rocks are low. The rest four of samples show higher $\delta^{18}O$ and low $\delta^{13}C$. Bulk chemical analysis for these rocks show that Fe-oxides content ranges from 13.55% and 47.38%. There is a large possibility that, in rocks showing high $\delta^{18}O$ and low $\delta^{13}C$, metal oxides hold a high concentration of $\delta^{18}O$. The enrichment in $\delta^{18}O$ is inferred to be related to the interaction of magmatic oxygen with that of the atmosphere and meteoric water.

Chapter 3 Bulk chemical composition of carbonatites

In order to elucidate the chemical characteristics of carbonatites whose classification have been made based upon field observation, ten of sovitic one, six of ankeritic one, seven of sideritic one and two of apatite rock were analyzed (Tab. 16).

Fig. 24 is a triangular diagram of molar MgO, CaO and, FeO and MgO, CaO, SiO_2. Among the analyzed carbonatites, all of sovitic one and one of ankeritic (8Y005) are plotted in sovitic field. Two (JMT-7 and JMT-26) out of seven sideritic ones are plotted in ankeritic field. Samples of 8Y030 and 8Y110 are inferred to be sideritic ones mixed with ankeritic and sovitic, respectively.

Chapter 4 REE contents in carbonatites

It has been found out that La and Ce are enriched in carbonatites. High contents of these elements are solely due to the occurrence of bastnaesite, synchysite and parisite in carbonatites.

Besides these elements, Nb, Sm, Eu and Tb have been analyzed for carbonatites in the survey area to summarize their abundance and distribution.

To research for a major host phase in the carbonatites, rare elements in such minerals as pyrochlore, bastnaesite, rutile and apatite were analyzed. Fig. 25 shows REE pattern for the representative rocks from each sector. It is seen from the figure that samples from Songwe sector are more enriched in medium REE than those from Tundulu, Kangankunde and Chilwa

Island sectors as well as from Mountain Pass Mine. Eu and Tb contents of Songwe samples are higher as compared with those of Bayan Obo Mine.

Analyzed results using EPMA show that Th content in bastnaesite from Songwe and Tundulu sectors is 0.01 to 0.19 weight % and that in apatite from Chilwa Island it is 1.21 weight % (Tab. 17).

In Tab. 18 are presented a comparison of ore reserves and grade of carbonatites ore deposits from Songwe and Tundulu sectors with those in the world.

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 REO and P_2O_5 with those of other mines.

REO contents in Songwe and Tundulu sectors, the values of which are 1.7% and 2.1% respectively, are rather lower as compared with the value of 2.0% of Bayan Obo Mine, but the content of medium REE in Songwe sector is 1.5 to 2 times higher than that of Bayan Obo Mine.

Recently, the total amount of consumption of REE has steadily decreased after the peak of 1983, but that of REE with high purity tends to increase. Light REE are in overstock while medium to heavy REE are in deficiency of supply.

The grade of phosphorus (P_2O_5) in Tundulu sector is estimated to be as high as 17.0%. This ore grade is higher than Araxa (P_2O_5 15%) or Sukulu (P_2O_5 13%). This phosphorus deposit is possible to be exploited for the phosphatic fertilizer. It is inferred that one way of using the phosphorus resources could be for the production of fused magnesium phosphate (50,000 tons/year, approximately 10,000 tons in P_2O_5 equivalent) by the aid of domestic resources of ultrabasic rocks or dolomitic rocks as well as electric power.

Tab.16 Chemical composition of the carbonatites

Rock	2	2	3	2	3	1	1	2	1	1	1	1
Sample	8Y005	8Y009	8Y018	8Y026	8Y030	8Y038	8Y041	8Y046	8Y047	8Y052	8Y055	8Y058
SiO2	2.63	13.08	0.16	1.05	0.99	1.56	1.99	2.57	1.37	2.39	2.38	4.59
TiO2	<0.01	0.01	<0.01	0.02	0.03	<0.01	0.01	0.04	0.02	0.02	0.02	0.19
Al2O3	1.31	0.41	0.12	0.25	0.09	0.23	0.52	0.47	0.05	0.19	0.20	0.12
Fe2O3	11.52	0.01	49.30	0.06	29.53	4.20	2.25	7.57	0.37	5.41	0.83	2.44
FeO	<0.01	7.76	<0.01	4.92	<0.01	0.21	0.49	0.64	2.39	<0.01	2.76	1.60
MnO	5.38	2.88	8.03	1.28	6.76	0.84	0.28	2.35	0.09	0.79	0.52	0.19
MgO	0.16	12.49	0.41	18.29	4.94	0.37	0.10	17.19	0.89	0.17	0.92	0.27
CaO	37.69	21.15	22.64	25.10	23.21	45.65	47.61	23.16	47.71	46.30	43.82	42.81
SrO	0.83	0.50	0.09	0.34	0.15	0.86	1.09	0.47	0.63	0.28	0.96	0.98
BaO	1.50	0.40	1.45	0.98	0.50	0.26	0.14	0.29	0.18	0.18	0.56	0.03
K2O	0.04	0.04	0.02	0.08	0.01	0.07	0.11	0.08	0.01	0.04	0.10	0.02
Na2O	0.04	0.02	<0.01	0.02	<0.01	0.08	0.03	0.05	0.07	0.02	0.07	0.08
P2O5	14.07	0.44	0.04	0.03	0.04	1.34	3.31	0.24	0.03	0.39	0.62	1.41
Nb2O5	0.01	0.20	0.00	0.08	0.00	0.04	0.01	0.05	0.16	0.08	0.11	1.31
REO	1.63	0.61	1.43	0.59	0.87	0.23	0.12	0.87	0.24	0.15	0.32	0.12
LOI	22.35	40.47	16.07	46.73	32.71	43.13	41.18	43.93	45.71	43.24	44.98	43.48
CO2	9.65	34.58	8.24	38.74	22.17	33.43	31.41	35.13	36.61	35.19	37.18	33.42
S	0.10	0.02	0.03	0.03	0.01	0.03	<0.01	0.01	0.06	<0.01	0.54	<0.01
ToTal	99.17	100.47	99.78	99.82	99.84	99.07	99.24	99.97	99.93	99.65	99.17	99.64

Rock	3	3	2	3	1	1	1	1		4	3	2	3
Sample	8Y068	8Y103	8Y110	8Y124	8Y128	8Y147	8Y148	8Y150	8Y153	8Y154	JMT07	JMT22	JMT26
SiO2	15.46	1.96	24.12	0.40	2.66	13.99	16.16	3.95	25.94	30.13	1.16	10.60	2.54
TiO2	<0.01	0.01	0.31	0.03	<0.01	0.66	0.46	0.02	0.01	<0.01	0.05	0.06	<0.01
Al2O3	5.27	0.17	6.56	1.58	0.27	0.53	2.82	0.33	0.33	0.21	0.21	0.09	0.03
Fe2O3	47.38	32.34	19.12	48.64	2.04	14.29	7.11	1.50	0.56	1.62	14.66	5.48	13.55
FeO	<0.01	<0.01	<0.01	<0.01	0.69	1.21	0.80	0.44	0.19	0.13	<0.01	8.97	<0.01
MnO	5.59	10.97	2.51	8.64	0.35	0.30	0.71	0.30	0.07	0.17	3.45	2.69	3.70
MgO	0.38	0.54	0.40	0.34	0.19	0.16	1.73	0.18	0.02	0.02	9.50	7.81	6.83
CaO	8.57	21.40	20.32	25.99	48.26	38.05	32.57	46.56	39.51	28.75	26.29	17.83	22.30
SrO	0.13	0.21	0.28	0.11	0.66	0.66	0.18	0.91	0.71	0.63	4.47	6.74	8.12
BaO	1.62	0.99	0.89	1.39	0.21	0.08	0.74	0.57	0.04	0.62	1.16	1.97	2.85
K2O	3.27	0.04	2.46	0.25	0.15	0.07	2.22	0.21	0.05	0.01	0.15	0.02	0.01
Na2O	0.02	<0.01	0.03	<0.01	0.04	0.43	0.07	0.04	0.54	0.45	0.02	0.08	0.02
P2O5	0.27	0.16	0.45	0.09	1.21	4.29	0.08	0.80	29.71	26.14	0.02	<0.01	<0.01
Nb2O5	0.00	0.01	0.04	0.01	0.01	0.18	0.07	0.21	0.00	0.00	0.02	0.07	<0.01
REO	1.13	2.93	0.52	0.34	0.13	0.12	0.18	0.13	0.49	0.36	2.38	3.87	4.51
LOI	10.82	27.96	21.60	11.83	42.47	24.18	33.89	43.53	1.03	10.78	37.26	33.93	36.90
CO2	0.60	17.47	12.04	3.52	32.59	17.31	26.73	35.12	0.99	1.63	26.14	27.86	26.81
S	0.23	0.03	0.07	0.12	<0.01	<0.01	0.30	0.12	<0.01	0.02	0.21	1.85	0.42
ToTal	99.92	99.70	99.62	99.64	99.34	99.20	99.78	99.68	99.19	100.03	100.80	100.22	101.38

Mole %

Sample	8Y005	8Y009	8Y018	8Y026	8Y030	8Y038	8Y041	8Y046	8Y047	8Y052	8Y055	8Y058
SiO2	3.58	11.73	0.26	0.92	1.23	1.55	1.99	2.40	1.28	2.31	2.23	4.56
TiO2	0 01	0.01	0.01	0.01	0.03	0.00	0.01	0.03	0.01	0.01	0.01	0.14
Al2O3	1.05	0.22	0.11	0.13	0.07	0.13	0.31	0.26	0.03	0.11	0.11	0.07
Fe2O3	5.91	0.00	29.72	0.02	13.76	1.57	0.85	2.66	0.13	1.96	0.29	0.91
FeO	0.01	5.82	0.01	3.60	0.01	0.17	0.41	0.50	1.87	0.00	2.16	1.33
MnO	6.21	2.19	10.90	0.95	7.09	0.71	0.24	1.86	0.07	0.65	0.41	0.16
MgO	0.33	16.70	0.98	23.87	9.12	0.55	0.15	23.89	1.24	0.24	1.28	0.40
CaO	55.04	20.32	38.86	23.55	30.80	48.61	50.99	23.13	47.90	47.88	43.94	45.55
SrO	0.65	0.26	0.09	0.17	0.10	0.50	0.63	0.26	0.34	0.16	0.52	0.57
BaO	0.80	0.14	0.91	0.34	0.24	0.10	0.05	0.11	0.07	0.07	0.21	0.01
K2O	0.03	0.02	0.02	0.04	0.01	0.04	0.07	0.05	0.01	0.02	0.06	0.01
Na2O	0.05	0.02	0.01	0.02	0.01	0.08	0.03	0.05	0.06	0.02	0.06	0.08
P2O5	8.12	0.17	0.03	0.01	0.02	0.56	1.40	0.09	0.01	0.16	0.25	0.59
Nb2O5	0.00	0.04	0.00	0.02	0.00	0.01	0.00	0.01	0.03	0.02	0.02	0.29
CO2	17.96	42.34	18.02	46.30	37.49	45.36	42.87	44.71	46.83	46.37	47.50	45.31
S	0.26	0.03	0.09	0.05	0.02	0.06	0.01	0.02	0.11	0.01	0.95	0.01

Sample	8Y068	8Y103	8Y110	8Y124	8Y128	8Y147	8Y148	8Y150	8Y153	8Y154	JMT07	JMT22	JMT26
SiO2	28.08	2.73	30.61	0.65	2.61	15.75	16.39	3.76	30.94	39.47	1.27	10.64	2.88
TiO2	0.01	0.01	0.30	0.04	0.00	0.56	0.35	0.01	0.00	0.00	0.04	0.05	0.00
Al2O3	5.64	0.14	4.91	1.52	0.16	0.35	1.69	0.19	0.23	0.16	0.14	0.05	0.02
Fe2O3	32.38	16.95	9.13	29.92	0.75	6.05	2.71	0.54	0.25	0.80	6.04	2.07	5.79
FeO	0.01	0.01	0.01	0.01	0.57	1.14	0.68	0.35	0.19	0.14	0.00	7.53	0.00
MnO	8.60	12.94	2.70	11.96	0.29	0.29	0.61	0.24	0.07	0.19	3.20	2.29	3.56
MgO	1.03	1.12	0.76	0.83	0.28	0.27	2.62	0.26	0.04	0.04	15.50	11.69	11.56
CaO	16.68	31.94	27.63	45.52	50.66	45.90	35.40	47.52	50.49	40.35	30.84	19.19	27.12
SrO	0.13	0.17	0.21	0.10	0.37	0.43	0.10	0.50	0.49	0.48	2.84	3.92	5.34
BaO	1.15	0.54	0.44	0.89	0.08	0.04	0.29	0.21	0.02	0.32	0.50	0.78	1.27
K2O	3.79	0.04	1.99	0.26	0.09	0.05	1.44	0.13	0.04	0.01	0.10	0.01	0.01
Na2O	0.04	0.01	0.04	0.01	0.04	0.47	0.07	0.04	0.62	0.58	0.02	0.08	0.02
P2O5	0.21	0.09	0.24	0.06	0.50	2.04	0.03	0.32	15.00	14.49	0.01	0.00	0.00
Nb2O5	0.00	0.00	0.01	0.00	0.00	0.05	0.02	0.05	0.00	0.00	0.01	0.02	0.00
CO2	1.49	33.23	20.86	7.86	43.59	26.61	37.02	45.67	1.61	2.92	39.07	38.20	41.54
S	0.78	0.08	0.17	0.37	0.01	0.01	0.57	0.21	0.01	0.05	0.43	3.48	0.89

Mole ratio (%)

	8Y005	8Y009	8Y018	8Y026	8Y030	8Y038	8Y041	8Y046	8Y047	8Y052	8Y055	8Y058
MgO	0.56	34.26	2.44	49.38	22.16	1.08	0.28	48.34	2.46	0.48	2.70	0.79
CaO	93.37	41.68	96.91	48.72	74.85	95.86	95.97	46.80	95.00	94.94	92.60	90.18
SiO2	6.07	24.06	0.65	1.90	2.99	3.06	3.75	4.86	2.54	4.58	4.70	9.03

	8Y068	8Y103	8Y110	8Y124	8Y128	8Y147	8Y148	8Y150	8Y153	8Y154	JMT07	JMT22	JMT26
MgO	2.25	3.13	1.29	1.77	0.52	0.44	4.82	0.50	0.05	0.05	32.56	28.16	27.82
CaO	36.43	89.24	46.83	96.85	94.60	74.13	65.06	92.20	61.97	50.53	64.78	46.22	65.26
SiO2	61.32	7.63	51.88	1.38	4.87	25.44	30.12	7.30	37.98	49.42	2.67	25.63	6.93

Mole ratio (%)

	8Y005	8Y009	8Y018	8Y026	8Y030	8Y038	8Y041	8Y046	8Y047	8Y052	8Y055	8Y058
MgO	0.54	38.98	1.41	46.77	16.99	1.08	0.29	47.61	2.42	0.48	2.69	0.83
CaO	89.80	47.43	55.86	46.14	57.37	95.50	97.31	46.09	93.66	95.61	92.18	94.52
FeO	9.66	13.59	42.73	7.09	25.65	3.42	2.40	6.30	3.91	3.91	5.14	4.65

	8Y068	8Y103	8Y110	8Y124	8Y128	8Y147	8Y148	8Y150	8Y153	8Y154	JMT07	JMT22	JMT26
MgO	2.06	2.24	2.03	1.09	0.54	0.51	6.33	0.53	0.08	0.10	29.59	28.88	26.00
CaO	33.29	63.85	73.62	59.67	96.94	86.02	85.49	97.64	99.06	97.63	58.88	47.41	60.98
FeO	64.65	33.91	24.35	39.24	2.53	13.47	8.19	1.83	0.86	2.27	11.53	23.72	13.02

Rock	Field name
1	Sövite
2	Ankeritic sövite
3	Sideritic carbonatite
4	Apatite rock

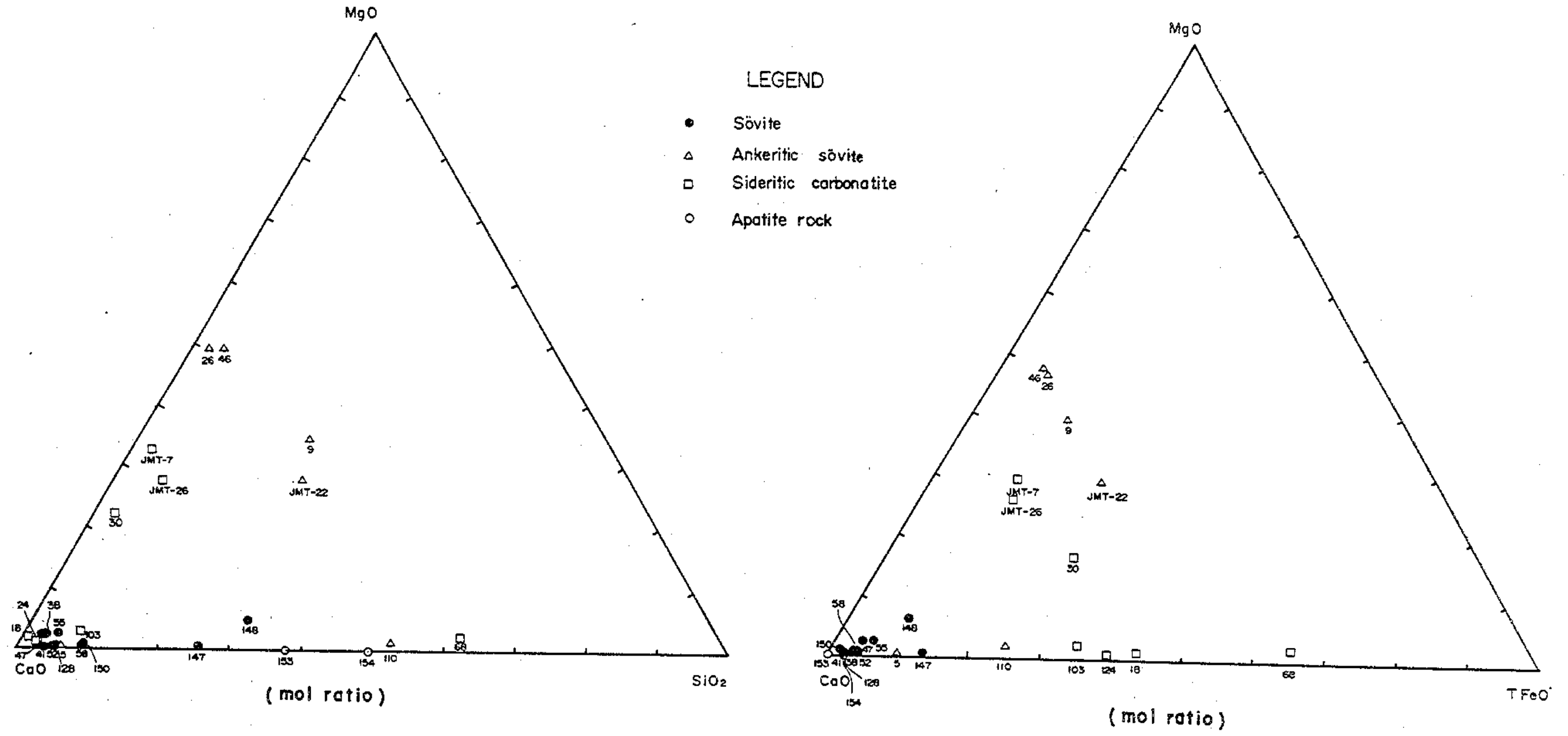


Fig 24 Ternary Diagrams of the Carbonatites

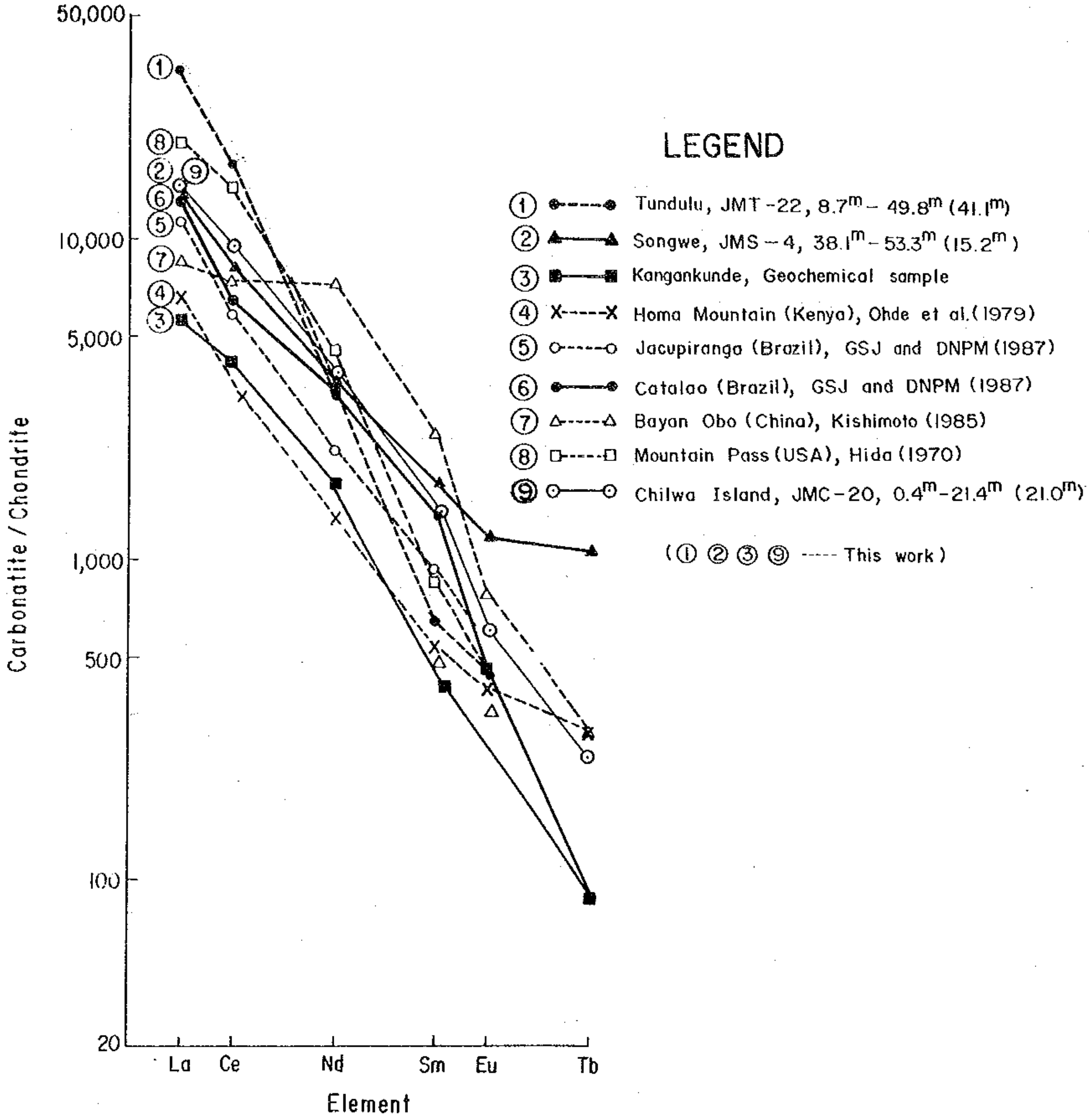


Fig. 25 Chondrite normalized rare earth concentration

Tab.17 Result of quantitative EPMA analysis

No.	Sample No.	Sector	Locality	Rock name	Mineral	Element (wt %)											
						La	Ce	Sm	Gd	Dy	Nb	Y	Na	Ca	Ti	Th	Zr
1	C1306	Chilwa Island	JMC-13 30.2m	Apatite sövite	Rutil	0	9.68	0	0	0	4.43	0	0.14	1.19	69.6	0	0.29
2	C1306	"	"	"	Apatite	7.12	13.7	0	0.29	0	0	2.44	0.12	0.83	0	1.21	1.58
3	C3211	"	-32 47.4m	Sövite	Pyrochlore	0	2.76	0	0	0	47.4	2.50	1.06	14.0	1.70	0	4.13
4	S1604	Songwe	JMS- 4 14.0m	Iron oxide ore	Bastnaesite (?)	38.5	29.3	5.39	0.58	0	0.16	0	0.21	9.01	0	0.01	0
5	T2501	Tundulu	JMT-15 3.2m	Apatite rock	Pyrochlore	0	0.53	2.76	0	1.62	18.7	1.28	4.07	6.32	1.21	0	2.19
6	T2501	"	"	"	Bastnaesite	9.62	14.1	2.58	0.69	0	1.21	0	0.19	7.66	0	0	0
7	T2607	"	MJT-26 28.9m	Apatite rock	Pyrochlore	0	0.16	0.59	0	0.32	19.1	0.82	0.61	6.22	0.90	0	1.44
8	T2607	"	"	"	Bastnaesite	15.0	17.1	4.67	0.20	0	0	0	0	5.90	0	0.19	0
9	8Y058	Chilwa Island	Surface	Sövite	Pyrochlore	0	1.33	3.90	0	0	37.8	1.82	1.03	11.0	1.68	0	3.26
10	8Y058	"	"	"	Pyrochlore	0	1.69	0	0.84	0	33.1	3.01	1.06	12.8	1.28	0	3.70

Tab.18 REO & P_2O_5 resources related carbonatite/alkaline complex

Name of complex	Type of carbonatite	REO (Mil.t) Reserves	REO (%) Ore grade	REO (Th.t) Metal	P_2O_5 (Mil.t) Reserves	P_2O_5 (%) Ore grade	P_2O_5 (Th.t) P_2O_5
Songwe, (Malawi) (This work)	sövite, ankeritic	1.4	1.7	23.8			
Tundulu, (Malawi) (This work)	ankeritic, sideritic, apatite	0.6	2.1	12.6	0.5	17.0	85.0
Araxa, (Brazil)	beforsite, sövite				460	15.01	69,046
Tapira (Brazil)	sövite				921	8.32	76,627
Catalao (Brazil)	beforsite,	2	12.20	244	306	7.96	24,358
Jacupiranga (Brazil)	sövite, beforsite				89	6.15	5,474
Ipanema (Brazil)	Sövite				117	6.73	7,874
Oka (Canada)	sövite	122	0.2	244			
Sukulu (Uganda)	carbonatite				200	13.0	26,000
Siilinjarvi (Finland)	sövite				465	4.0	18,600
Mountain Pass	(USA)	100	5-10				
Rayan Obo	(China)	(REO) 35	1.9-13.5				

(after GSJ and DNPM, 1987)

Part Ⅷ Conclusion and recommendation

Part VIII Conclusion and recommendation

Chapter 1 Songwe sector

1-1 Conclusion

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 of 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.

1-2 Recommendation for the future

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.

Chapter 2 Tundulu sector

2-1 Conclusion

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 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 of 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.

2-2 Recommendation for the future

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.

Chapter 3 Kangankunde sector

3-1 Conclusion

Constituent rocks in this sector is almost the same as those in Tundulu and Songwe sectors.

Igneous rocks in "Chilwa Alkaline Province" are mainly composed of carbonatites and breccias. Nepheline syenite is absent.

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

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

Carbonatites are composed mainly of sideritic, ankeritic and dolomitic, which are widely distributed on the northern and western slopes of Kangankunde Hill. Manganese carbonatite occurs on the top and eastern slope of the hill.

Useful minerals in carbonatites are monazite, strontianite and apatite.

Geology of this sector is almost the same as those of Tundulu and Songwe sectors except the absence of nepheline syenite.

REE- or phosphorus-mineralized zones in carbonatite or apatite rock are recognized on the northern slope of Kangankunde hill, having the highest potential for REE resources.

3-2 Recommendation for the future

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

Chapter 4 Chilwa Island sector

4-1 Conclusion

<u>Geological survey</u>

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.

4-2 Recommendation for the future

Through the 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.