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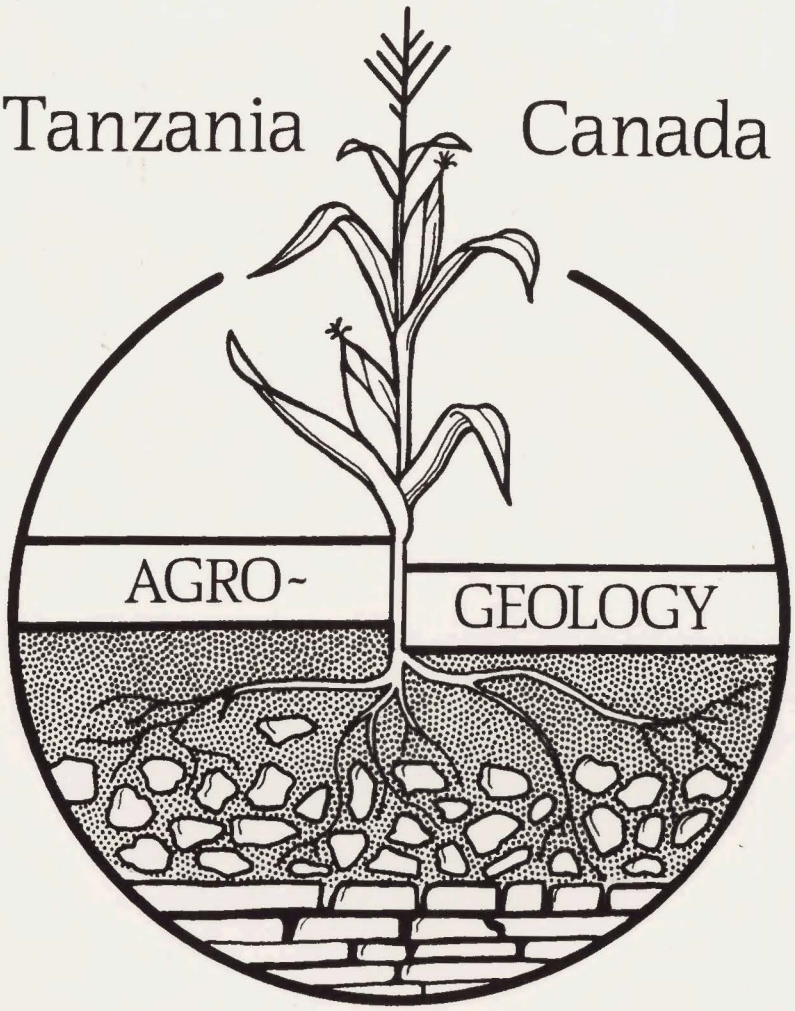

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TANZANIA-CANADA AGROGEOLOGY PROJECT

REPORT ON COMPLETION OF THE FIRST PHASE

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March 1988

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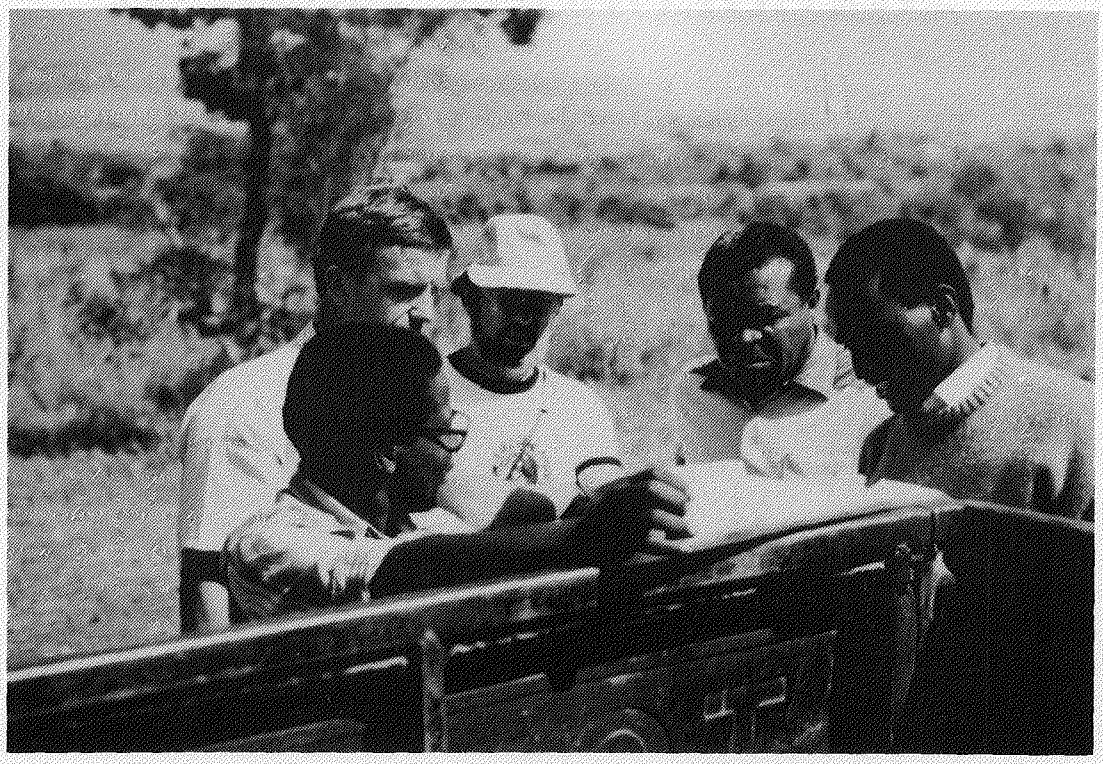

Representatives of the 5 organizations involved in the project. From left to right J.M.R. Semoka (Sokoine University of Agriculture), Peter van Straaten (University of Guelph), Calvin Pride (I.D.R.C.), J.A.M. Kamasho (Uyole Agricultural Centre) and E.P. Mchihiyo (Ministry of Minerals and Energy, Madini).

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CHAPTER 1

INTRODUCTION

1.1 AGROGEOLOGY: GEOLOGY IN THE SERVICE OF AGRICULTURE

The farmer and the forester alike, treat soil as a nutrient mine. They exploit the ability of soil to provide much of the chemical sustenance a plant needs to flourish (Chesworth and van Straaten 1988). Unlike more familiar mines however, it is a renewable resource at least while the earth remains an active planet. Tectonic, igneous and sedimentary processes combine in the internal and external geochemical cycles, to add fresh nutrient-laden rock continually to the biosphere. If this were not so, the land surface of the earth would long ago have been reduced to a uniform low fertility (Chesworth 1982).

Unfortunately, the rate of renewal by natural geological processes is slower by up to two orders of magnitude, than the rates at which farmers exhaust the soil. Consequently, an important part of the historical evolution of farming has involved the development of practices that enable the soil to recover its fertility after cropping. These range from low-input methods such as shifting cultivation to high-input techniques that support monoculture in modern industrial farming. No technique has been entirely successful, though in geologically favoured environments, the Nile Valley and northern China for example, thousands of years of continuous cultivation have been achieved. However, even in the favoured cases, problems such as salinisation and soil erosion arise and the history of cultivating the soil is perhaps more a history of crisis control than of unadulterated progress.

The process of weathering is crucial to the fertilization of soils. The principal reaction, or complex of reactions, is a massive overtitration of bases (contained in and on the land surface) against aqueous solutions of acids obtained from atmospheric and biospheric sources. The result is a release of nutrient elements from the minerals of rock and soil and, at least in humid climates, the gradual acidification of the weathering regime towards relatively infertile compositions buffered by phases in the system SiO_2-Fe_2O_3- organic acids - CO_2- H_2O (see Chesworth 1973). Generally, the release rates are not fast enough to support continued cropping so that the weathering of ordinary minerals and rocks cannot be expected to sustain a crop. Yet in certain environments, the humid tropics for example, and with certain materials (e.g. apatite in acid soils), natural minerals do indeed weather fast enough for the agronomist's purposes. In most cases however, a farmer relies upon materials more soluble than the common minerals to replenish the nutrients of arable land. Even so, everything the plant needs except N, H_2O and CO_2 is ultimately derivable from rocks of one kind or another.

The conversion of geological raw materials into more soluble fertilizers is energy intensive and the eventual price of the fertilizer is proportionately high. Unless credit (as in the Cameroons) or subsidies (as in Zimbabwe) are available, Third World farmers cannot afford the fertilizers that developed world agriculturalists rely upon. Thus, to have a truly self sustaining agriculture in the developing world cheaper inputs than those that support industrialised farming are needed. In terms of fertilizer, this means finding locally available raw materials that require little or no processing. This is the fundamental idea behind the Tanzania-Canada Agrogeology Project.

1.2 THE TANZANIA-CANADA AGROGEOLOGY PROJECT

The Tanzania-Canada Agrogeology Project is a joint venture betweenthe Ministry of Minerals and Energy (Madini, Tanzania Geological Survey; and Stamico), the Sokoine University of Agriculture in Morogoro, and the Uyole Agricultural Centre in Mbeya, all of which are in Tanzania, and the University of Guelph in Canada. Funding is provided by the International Development Research Centre (IDRC), Ottawa, and by the Tanzania Government. Two areas were chosen for study: one centred on Mbeya and another centred on Morogoro (Fig. 1.1).

The *GENERAL OBJECTIVE* of the project, targeted particularly at the small scale farmer, is to increase soil productivity using locally available geological and organic materials. *SPECIFIC OBJECTIVES* to accomplish the general objective are as follows:

(i) To specify the soil fertility problems known to exist in two selected test areas (Mbeya region and Morogoro region) and to identify soils that are susceptible to improvement.

(ii) To locate and assess locally available materials needed to ameliorate the problems identified.

(iii) To carry out a thorough chemical and mineralogical characterization of all soils and geological materials of interest.

(iv) To carry out weathering experiments and mineralogical characterization of all soils and geological materials of interest.

(v) To carry out glasshouse and field tests, and evaluate promising materials in order to formulate fertilizer recommendations to the local, especially the small farmer.

(vi) To adapt and develop a grinder for the geological materials, appropriate for local use.

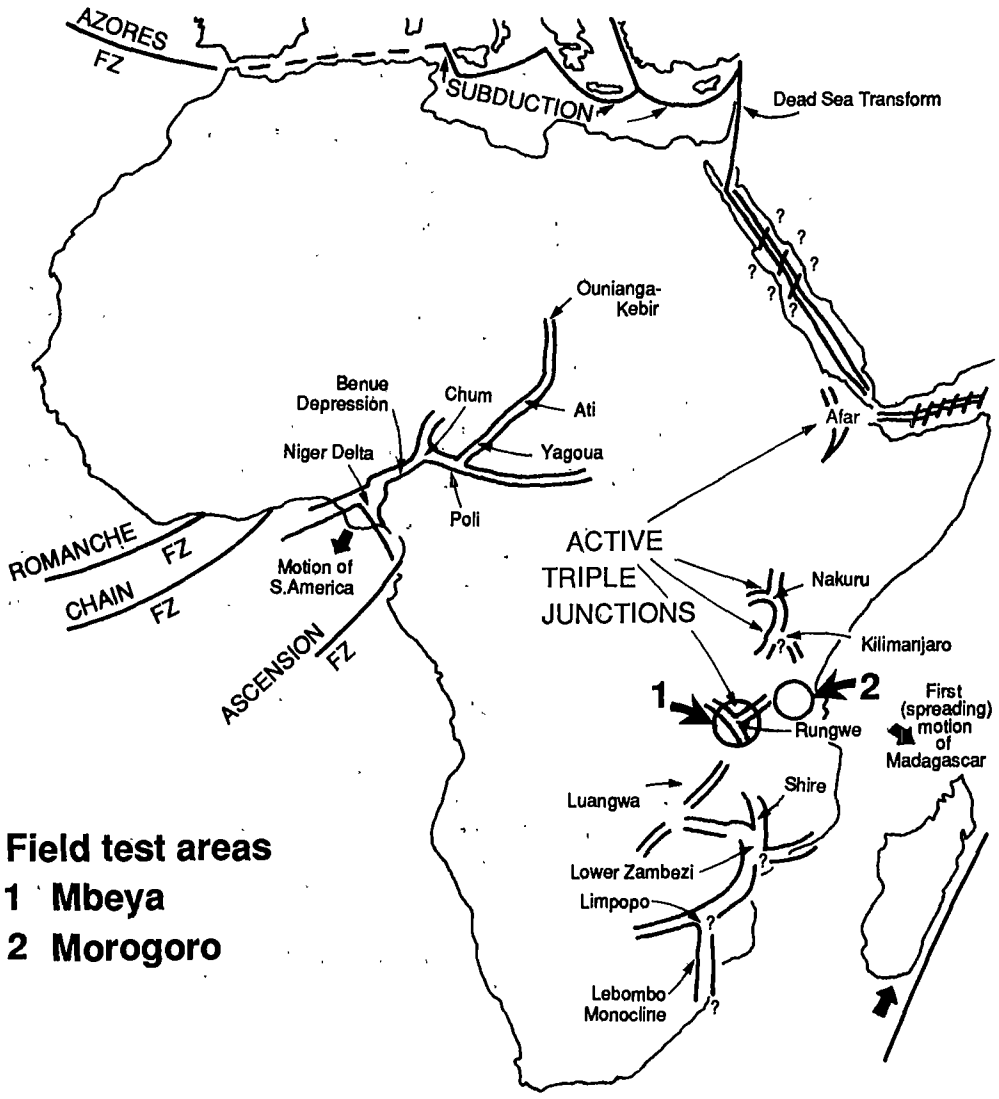

Fig. 1.1 Location of field test areas.

1.3 PARTICIPATING INSTITUTIONS AND PERSONNEL

The institutions and personnel involved in the Tanzania-Canada Agrogeology Project are as follows:

1. Ministry of Mincrals and Encrgy:
MADINI - Gcological Survey of Tanzania,

Messrs.	E.P. Mchihiyo	geologists
	F.T. Mtuy	
	P.M. Masao	
	M.M. Makweba	
	O.W. Kiranga	
	M.Z. Mbasha	
	V.B. Ntulanalwo	geophysicists
	G.J. Mbalwa	
	E. Willa	technicians
	A.E. Mbuya	
	A.M. Tengia	
	E.O. Mmari	

STAMICO - State Mining Corporation,
Mr. G. Mwakalukwa

2. Sokoine Agricultural University:

Dr. J.M.R. Scmoka	soil scientists
Dr. P.N.S. Mnkeni	
Mr. J. Mihalu	technicians
Mr. M. Malekela	

3. Uyole Agricultural Centre:

Mr. J.A.M. Kamasho	soil scientist
Mr. F. Mindasi	chemist
Mr. D. Kisandu	technicians
Mr. P. Ngowi	

4. University of Guclph:

Dr. W. Chesworth	geologists
Dr. P. van Straaten	
Mr. P. Smith	technician
Mr. D. Crabtrce	graduate student

The project would not have been possible without the wholehearted support of Mr. D. Chao, Commissioner of Research and Laboratories, Ministry of Minerals and Energy (Madini), Prof. G.V. Mmari, Vice-Chancellor, Sokoine University of Agriculture, of Dr. M.P. Salema, incoming chairman of the Department of Soil Science at Sokoine University of Agriculture, Dr. J. Liwenga, Director of the Uyole Agricultural Centre, Dr. C.D. Madata, Chief Scientific Officer, Uyole Agriculture Centre, and Dr. B.D. Kay, chairman of the Department of Land Resource Science at Guclph.

It goes without saying that the personnel of IDRC's cooperative programs division played a considerable role in the success of this project.

1.4 GENERAL OUTLINE OF THE REPORT

After this brief introduction, the second chapter of the report examines the general geochemistry of the soils of the target areas in Mbeya and Morogoro regions. The topic is approached via a study of the weathering systems developed on the geological parent materials. We have made the first chemical and mineralogical analyses of such systems and are able to define many of the soil related problems that are likely to occur in this region. The chemically related problems are:

a. Low pH,
b. Low fertility,
c. Al and Mn toxicities,
d. Phosphate fixation,
e. Cu deficiency.

In addition we recognize the principal physical problems to be associated with:

a. Erosion,
b. Water conservation.

The third chapter describes the work of the geological team in prospecting for agricultural raw materials that could be useful in treating the pathological conditions identified by the soil investigators.

So far, the geologists have located materials useful as phosphate fertilizers, as general purpose fertilizers, as Cu-amendments, for liming, for nitrogen conservation, and for water conservation. Almost all of these geological resources are amenable to labour intensive small scale mining. In addition, many are strategically located close to the targeted user, thus obviating long distance transport with its associated costs.

Chapters four and five describe the testing of the raw materials for agronomic use. Tests were accomplished in the laboratory, the greenhouse and the field, and the results of the tests lead into chapter six which examines the extent to which our original objectives were achieved.

The final chapter presents an outline of the second phase of the project, which grew out of, and builds upon the first phase.

CHAPTER 2

SOILS IN SOUTHERN TANZANIA

2.1 THE REGIONAL SETTING

Although having prominent mountainous regions most of Tanzania is flat lying, from the hot, humid, coastal plain, to the semi-arid interior plateau. The East African Rift system cuts through the country, bifurcating north from Lake Nyasa into eastern and western branches. The extremes of elevation are marked by the bottom of Lake Tanganyika in the western rift (358 metres below sea level), and by Africa's highest mountain, Kilimanjaro (5,895 metres), in the northeast. Kilimanjaro, and many of the mountainous tracts in Tanzania, are volcanic in origin, the volcanism being associated with the rift system. In the south of the country, the principal volcanic pile is provided by Mount Rungwe (2,967 metres), near the city of Mbeya. It forms the centre of one of our two test areas.

Block faulting has also produced mountains in Tanzania and in the south, the Uluguru mountains are a prominent example, with the second of our two test areas situated at their foot, on the outskirts of the city of Morogoro.

Details of the geological setting will be dealt with in the next chapter but a few facts are necessary here as a prelude to a discussion of the soils. The geological core of the country is the Archaean, Tanzania Craton. Typically, it is a granite-greenstone terrain, similar to Archaean blocks on other continents. Draped around it are so-called mobile belts, Proterozoic in age, containing quartzo-feldspathic gneisses and granitoids, as well as pelitic and amphibolitic rocks. In the south and west, the Ubendian supergroup belongs to this category of formations. To the east, the late Proterozoic to early Paleozoic Mozambique belt of metamorphics and granitoids, which further east are overlain by Karroo and younger sediments. Permo-Triassic and younger, continental sediments are also found within the rifts.

The most dramatic, geological imprint of later times is undoubtedly produced by the rift-related volcanism of Tertiary and Quartenary eras. In the Mbeya region for example basaltic flows, phonolitic domes and extensive pyroclastics form the basis of a beautiful landscape that supports one of the richest farming areas in the whole country.

Clearly, Tanzanian soils have a wide variety of lithologies on which to form, and to judge by the FAO soils map of Africa, Tanzania has perhaps a wider variety of soils than any other country on the continent. Bedrock variability alone cannot account for this. At least an equally important factor is the climatic one, which varies from humid, tropical in the coastal strip, through hot and semi-arid in the interior plateau, to Alpine on the volcanic massifs, and including, on the summit of Kilimanjaro, conditions similar to the polar desert. These vast extremes, with accompanying variability of vegetation, combine with the many kinds of geological parent materials, and with different landforms and drainage conditions, to give the large number of soil types referred to earlier.

As far as the mineralogical and geochemical nature of the soils is concerned, most of our effort has gone into characterising materials and weathering systems in the Mbeya region. This work will be described first, after which, data on the soils of the Morogoro region will be provided. The chapter ends with a discussion of the general geochemical nature of the soil systems studied and the inherent soil problems that farmers are faced with in our study areas, in their efforts to grow food. This will also form the basis of the geologists' efforts to find ways and materials to combat the problems.

2.2 GEOCHEMISTRY OF SOIL FORMATION IN THE MBEYA REGIONS

There exists a wide range of parent material types and compositions in the Mbeya region, but only two groups of materials are of major extent where arable farming is practised. These are Precambrian quartzo-feldspathic gneisses, and Tertiary to Recent volcanics. Weathering and soil formation on the volcanic rocks will be emphasized here, since the most productive soils are in fact on these deposits.

2.2.1 WEATHERING OF VOLCANIC MATERIALS

Figure 2.1 shows the distribution of volcanic parent materials in the Mbeya region. In the central part of the volcanic massif the predominant soil-forming materials are massive alkali basalt and phonolite-trachyte ash. The extent of the ash cover is indicated on the map. New analyses of these dominant volcanics are given in Table 2.1.

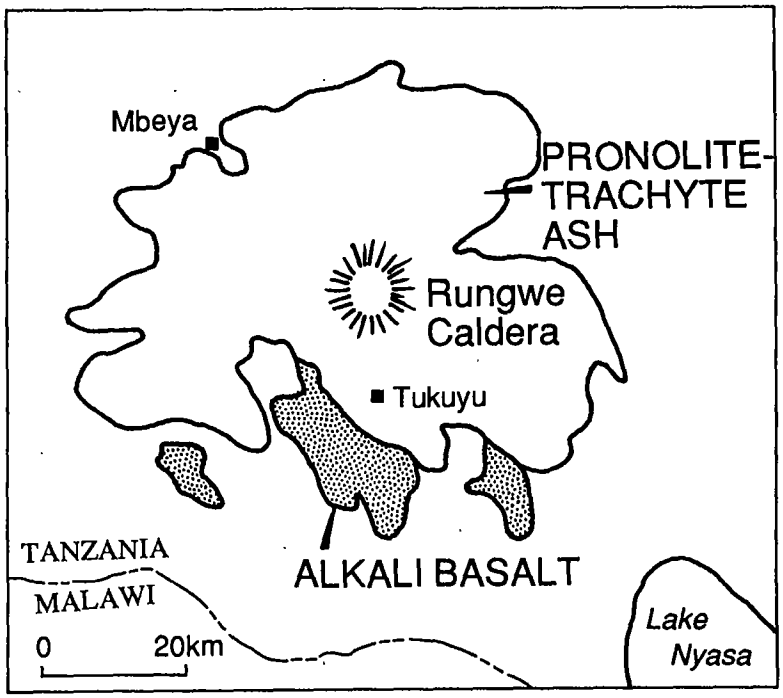

Fig. 2.1 Soil parent materials associated with the Rungwe volcanic complex.

Table 2.1 Chemical anlayses of volcanic rock parent material of soils in and around the Rungwe massif.

	1	2	3	4	5	6	7	8
SiO_2	41.56	41.35	43.80	43.36	43.48	62.31	61.51	60.15
Al_2O_3	15.23	15.10	14.74	14.83	16.25	17.08	18.90	18.38
Fe_2O_3	14.26	14.52	13.00	12.44	12.08	4.79	3.45	3.36
MgO	7.44	7.17	9.51	9.87	7.49	.38	.40	.49
CaO	13.20	13.28	12.22	12.05	12.28	.97	.73	.86
Na_2O	1.22	1.20	1.00	.92	1.43	4.91	5.87	5.29
K_2O	1.05	1.04	1.18	1.15	1.58	5.05	5.54	5.35
TiO_2	2.39	2.46	2.23	2.23	2.03	.67	.62	.82
MnO	.28	.29	.21	.18	.24	.32	.27	.23
P_2O_5	2.39	2.37	1.10	1.11	1.61	.12	.09	.14
LOI	.98	1.22	1.00	1.87	1.54	3.39	2.61	4.66

1-2 Signal Hill, 3-5 Mitalula, 6 Ngozi, 7-8 Rungwe. LOI = Loss on ignition.
XRF analyses, McMaster University, Hamilton, Ontario, Canada

Basaltic materials

The basalts are alkaline olivine basalts, with olivine, clinopyroxene and plagioclase as the dominant minerals. They are best exposed, uncontaminated by younger ash deposits, south and south-west of Tukuyu. Near Signal Hill, columnar basalts have a thin regosol developed on them. At the Mitalula experimental sub-station a deep ferralitic soil has formed. Table 2.2 gives analyses of the appropriate rocks and weathered products.

Table 2.2 Chemical analyses of weathered materials developed on basalt.

	1	2	3	4	5	6	7	8
SiO_2	18.48	17.20	29.16	26.76	36.66	34.52	37.09	78.52
Al_2O_3	10.32	15.66	26.40	24.85	20.92	25.99	25.34	12.27
Fe_2O_3	37.67	39.50	24.26	24.85	17.89	15.22	14.69	2.56
MgO	5.93	1.81	.17	.19	.64	.68	1.43	.19
CaO	3.70	.17	.14	.11	1.92	.02	2.72	.02
Na_2O	.15	.13	.05	.05	.16	.09	.41	.32
K_2O	.25	.18	.15	.15	.81	.81	.94	1.15
TiO_2	7.56	8.09	3.42	3.81	3.25	2.73	2.52	.24
MnO	.27	.20	.12	.14	.41	.41	.51	.03
P_2O_5	3.58	2.72	.95	.96	.89	1.00	1.03	.11
LOI	12.10	14.35	15.16	18.10	16.45	18.52	13.33	4.57

1-2 Signal Hill, 3-5 Mitalula, 6 Ngozi, 7-8 Rungwe.
XRF analyses, McMaster University

The weathered products of the Signal Hill rocks are the more immature of the two samples. They show a major trend of Si-loss, relative to Al and Fe, and a minor trend in two of the samples, of Fe-enrichment (Fig. 2.2). The simple trend of Si-loss is exhibited by all weathered samples in contact with air, or water in equilibrium with air. The Fe-enrichment trend is seen in internal rims around unweathered basalts, a local geochemical environment protected from the air-contact environment by an outer weathered rim. The major trend indicates that the early stages of weathering involve negligible loss of Al and Fe to the system.

The Mitalula samples on the other hand, have evolved further than the Signal Hill ones, and show a trend away from the fresh basalt compositions that implies loss of Al and Fe as well as Si. The overall trend is ferrallitic with the soils richer in Al and Fe than the parent materials.

All major components can be examined in terms of the diagram shown in figure 2.3. Weathering produces a progressive simplification of the system towards the residua system of weathering (SiO_2-Al_2O_3-Fe_2O_3-H_2O). Accompanying this trend the mineralogy is progressively simplified through assemblages containing 2:1 sheet silicates, finally to the most mature state in which kaolinite-quartz-goethite constitute the stable assemblage. This ultimate assemblage represents the acid, relatively infertile, end point of the system.

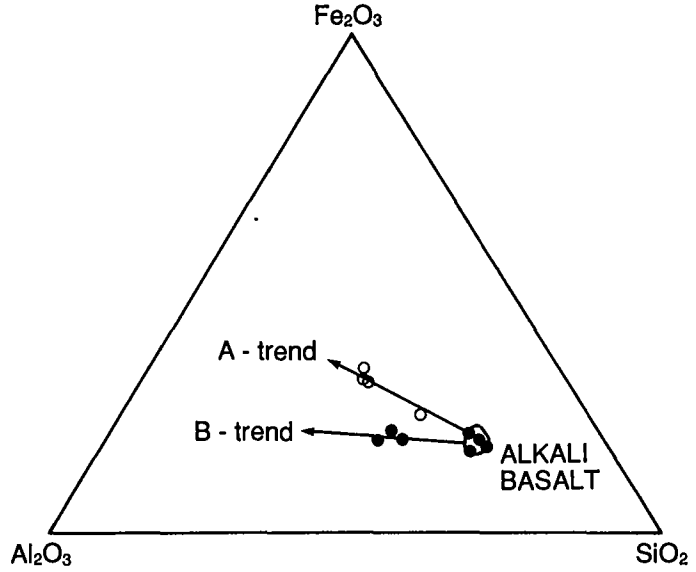

Fig. 2.2 Ferralitic weathering trends of alkali basalt.

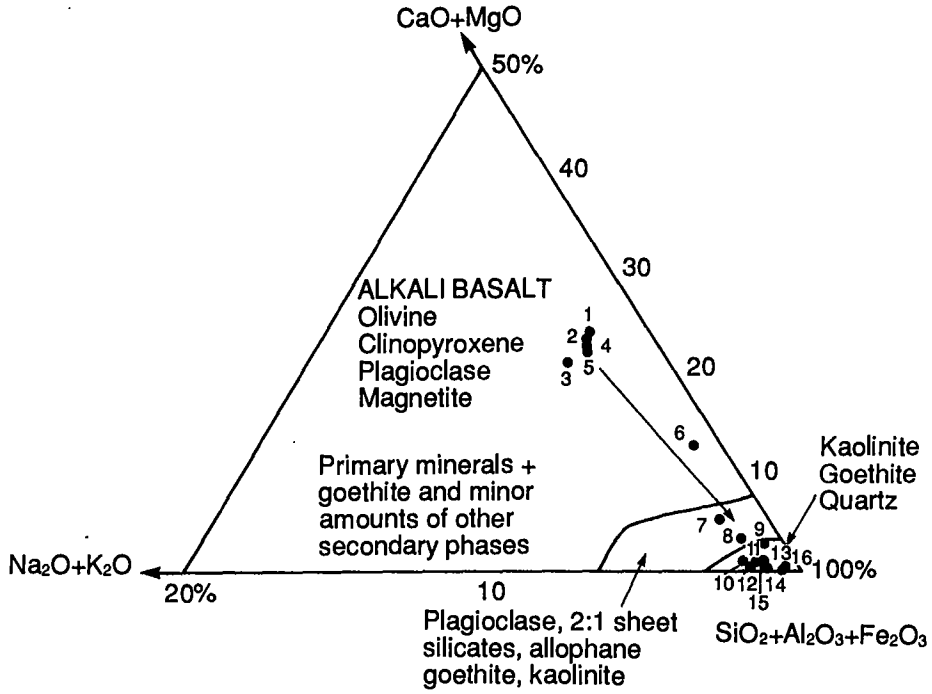

Fig. 2.3 Chemical and mineralogical changes in weathering and soil formation on alkali basalt.

Ash materials

North of Tukuyu, the massive volcanics are overlain by pyroclastic rocks emanating principally from two centres: Ngozi and Rungwe. These ashes form the basis of the most productive soils of the region. They are of phonolite-trachyte composition and develop into andosols on weathering. Chemical analyses of weathered materials are shown in Table 2.3.

Table 2.3 Chemical analyses of weathered materials developed on volcanic ash.

	1	2	3	4	5	6
SiO_2	41.68	50.91	58.16	67.22	49.34	47.87
Al_2O_3	17.93	21.46	19.41	17.45	27.24	29.43
Fe_2O_3	5.84	6.16	4.22	3.38	5.52	7.36
MgO	.54	.55	.20	.03	.02	.02
CaO	1.35	1.98	1.02	.11	.09	.09
Na_2O	2.63	3.56	4.35	4.18	.75	.35
K_2O	3.22	4.32	5.51	5.62	1.30	.91
TiO_2	1.32	1.39	.91	.59	.95	1.28
MnO	.27	.25	.23	.21	.18	.38
P_2O_5	.24	.17	.10	.04	.06	.06
LOI	24.97	9.24	5.89	1.17	14.55	12.25

1-2 Signal Hill, 3-5 Mitalula, 6 Ngozi, LOI = loss on ignition
XRF analyses, McMaster University

As with the basalts the weathering trend is a ferralitic one (Fig. 2.4) and as expected the overall tendency is to take compositions to a residua system end point (Fig. 2.5). In other words the ultimate soil will be as acid and

infertile as those developed from basalt. However, the ash deposits are younger than the basalts and the profile is less mature, generally lacking a recognizable B horizon. Consequently, the rooting zone still contains weatherable phases, including glass, which accounts in part for the higher fertility of the soils formed on these materials. In addition the ash deposits appear to conserve water more easily than the basaltic soils and this too could account for the relatively high productivity of these soils.

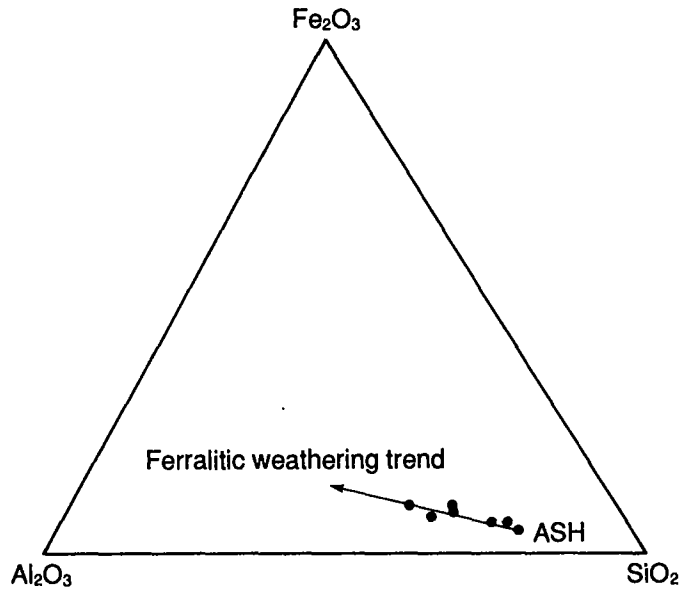

Fig. 2.4 Ferralitic weathering trend of volcanic ash.

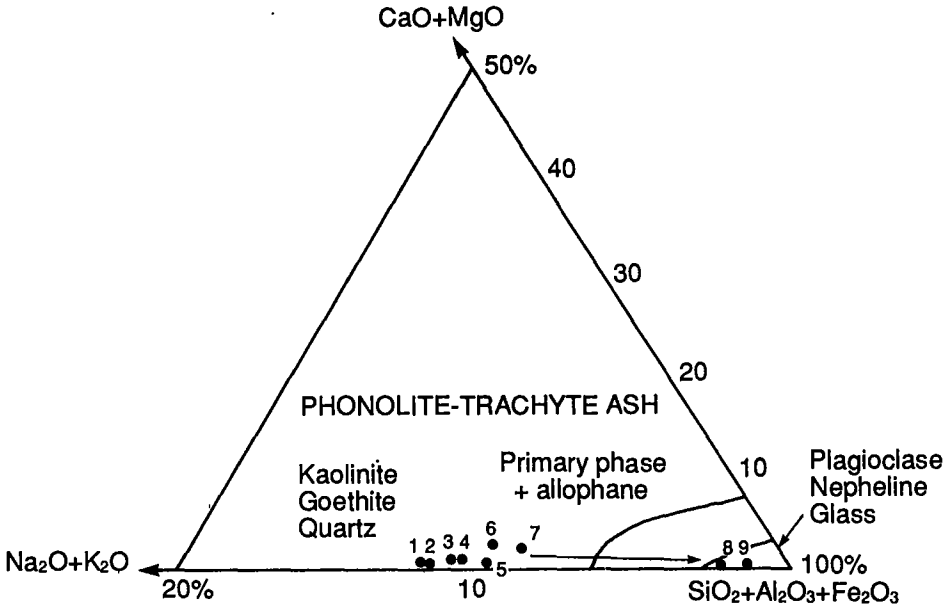

Fig. 2.5 Chemical and mineralogical changes in weathering and soil formation on volcanic ash.

2.2.2 WEATHERING OF PRECAMBRIAN BASEMENT

The Ubendian,Precambrian basement of the Mbeya region is dominated by quartzo-feldspathic rocks in which biotite and hornblende are the usual ferromagnesian constituents. In road cuts, on the western edge of the rift system, it is possible to find fresh bedrock and the initial saprolitic stage of weathering. At the other extreme, on the edges of the Rungwe volcanic massif, ultisolic soils produced by the long term weathering of Ubendian

materials can be sampled though not as far as the bedrock parent material. Intermediate stages between the early saprolite and the late ultisol can only be sampled by deep drilling. Consequently these stages are not represented in our data.

Table 2.4 presents analyses of Ubendian materials and the saprolite and soils developed on them. The same tendency for the chemical compositions to simplify towards the residua system of weathering (SiO_2-Al_2O_3-Fe_2O_3-H_2O) is seen here, as it was with the volcanic materials.

Table 2.4 Ubendian rocks and saprolites.

	Ubendian Paragneiss	Saprolite developed on Ubendian Rocks			
SiO_2	79.40	46.43	47.40	45.04	61.81
Al_2O_3	10.25	12.15	12.51	13.66	15.87
Fe_2O_3	3.51	10.93	10.76	11.54	9.93
MgO	0.49	16.48	13.53	13.33	1.31
CaO	0.27	9.34	9.39	9.15	0.25
Na_2O	0.04	1.00	1.30	1.09	0.04
K_2O	1.78	1.71	1.34	1.95	2.47
TiO_2	0.96	0.20	0.27	0.26	0.96
MnO	0.03	0.15	0.16	0.17	0.18
P_2O_5	0.16	0.06	0.07	0.06	0.06
LOI	3.08	1.54	3.26	3.73	7.12

XRF analyses, McMaster University

2.3 GEOCHEMISTRY OF SOIL FORMATION IN THE MOROGORO REGION

The difficulty in studying the geochemistry of soil formation in the Morogoro district is that the test soils are on flat lying land underlain by ancient rock. Neither recent movements nor volcanism have intervened to give fresh, weathering systems so that the soils have generally weathered over a long period and the profiles are consequently very deep. Thus only A and B horizons are generally accessible and parent material types (C horizons in other words) must be inferred from what is known of the local geology. The dominant parent material is quartzo-feldspathic metamorphics similar to those occurring within the Precambrian mobile belts of Tanzania, and the best profile we have on this comes from outside the area, near Dodoma (table 2.5), which confirms the same tendency towards the residua system of weathering noted in the Mbeya region.

Table 2.5. Ferralitic profile 851030.1, Dodoma region.

	0-30 cm	30-70 cm	70-130 cm	130 cm
SiO_2	67.64	60.04	59.40	59.82
Al_2O_3	10.96	21.24	20.98	20.76
Fe_2O_3	2.52	4.44	4.64	4.70
MgO	0.55	0.43	0.52	0.59
CaO	2.58	0.57	0.38	0.44
Na_2O	0.32	0.22	0.28	0.30
K_2O	1.53	1.59	1.69	1.78
TiO_2	0.29	0.75	0.76	0.76
MnO	0.11	0.03	0.02	0.11
P_2O_5	1.05	0.05	0.02	0.03
LOI	12.34	10.62	11.29	10.71

XRF analyses, McMaster University

2.4 THE GENERAL GEOCHEMICAL NATURE OF THE SOIL SYSTEMS

All the data presented show that all parent materials studied lead to compositions enriched in SiO_2, Al_2O_3, Fe_2O_3 and H_2O relative to other major components. In addition, figures 2.2 amd 2.4 indicates a loss of SiO_2 relative to Al_2O_3 and Fe_2O_3. This leads to the conclusion, an unremarkable one, considering the climatic regime studied, that the weathering system is generally, in Pedro's (1968) terminology, of ferralitic type. Stated differently, there is a marked tendency for Al and Fe amongst the non-volatile components, to accumulate at the weathering surface. Given a long enough weathering period this would produce laterites and/or bauxites, and in fact Fe- and Al-rich duricrusts are common on the older erosional surfaces of this and other parts of Africa.

By way of summary, figure 2.6 shows the chemical trends and the resulting soil mineralogies, of the weathering materials that we have studied in southern Tanzania. The impulse towards weathered systems dominated by quartz-kaolinite-goethite assemblages is very clear, and as we shall show later, is the mineralogical cause of the principal chemical problems that the local farmer is faced with. Before we do this however, we need to look at the overall conditions of weathering in terms of the two master variables pH and pe.

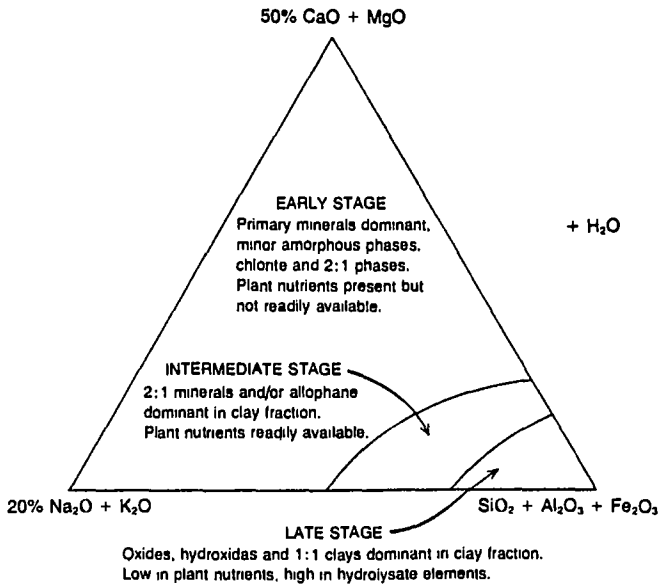

Fig. 2.6 Summary of the three gradational weathering stages in soils of southern Tanzania.

2.4.1 pH CONDITIONS

The pH of a soil is determined by the nature of the acids and bases that are present there. The acids are produced initially from an atmospheric source, the only important one in the Tanzanian context being carbonic acid. In addition, rain water percolating through vegetation and the organic upper horizon of soil can pick up acids of organic origin. In tropical climates, where organic debris breaks down more readily than in temperate and cold climates, this will not be an important factor to any great depth in the soil.

The bases in the system are the minerals that make up the inorganic portion of the soils. The principal base in soils of importance here, is kaolinite. The reaction of kaolinite with acid provides the ultimate buffer in these soils by the reaction

$$Al_2Si_2O_5(OH)_4 + 6H^+ = 2Al^{3+} + 2H_4SiO_4 + H_2O$$

kaolinite

which consumes hydrogen ions. In most soils, this buffer does not allow the pH to decrease below about 4, and for this limit to be reached stronger acids than natural carbonic acid must be present. If the stronger, usually organic, acids are not present, or are only present in very low concentrations, the ambient pH is set by H^+ - HCO_3^- equilibria. At atmospheric P_{CO_2} (10-3.5 atmospheres) this generates a pH of 5.7. Because of the breakdown of organic constituents soil P_{CO_2} may be 100 times higher than this, giving a pH of about 4.5.

Table 2.6 shows pH values measured in soils from the two study areas, most of which indicate a range within the field of control by carbonic acid equilibria. The most acid ones however lie outside this range. These low pH values are believed to be produced by the use of acidifying fertilizers, notably ammonium sulphate.

Table 2.6 Chemical anlayses of soils (0-3 cm) in Mbeya region (J.A. Kamasho, Uyole Agricultural Centre).

Location	Soil pH in water 1:1	Exchangable Acidity meq/100 g	C.E.C. meq/100 g	Base Saturation %
Tukuyu area				
Kapugi	4.1	25.8	30.0	4.0
Mitalula	4.8	33.0	41.0	18.3
Masoko	5.3	20.8	29.0	24.5
Chivanjee Estate	5.1	26.6	26.0	16.9
Mwela	4.8	30.0	39.0	20.4
Mbozi area				
Ilindi	5.3	27.6	19.0	46.3
Mbozi Mission	5.2	23.8	47.0	44.4
Ihanda	5.1	35.0	26.0	38.0
Chiwanda	5.4	20.8	30.6	42.6
Idiwili	3.5-4.5			

2.4.2 REDOX CONDITIONS

Atmospheric oxygen reacts with various soil constituents to set ambient redox conditions in a weathering system. The demands of reactions leading to the oxidization of organic matter to produce CO_2 and H_2O, are the most important. This lowers the P_{O2} from values found in the atmosphere itself to values in the vicinity of the organic fence shown in figure 2.7.

The intersection of the organic fence with the 1:1 clay fence (Fig. 2.7) represents a first approximation of the pH-pe conditions expected in the most acid of the Tanzanian soils.

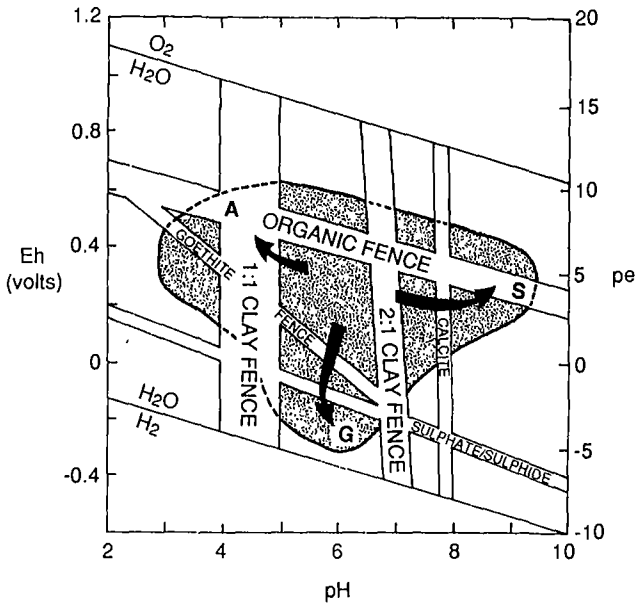

Fig. 2.7 pe-pH scheme showing geochemical fences pertinent to weathering processes and soil formation. The stippled area covers the environmental range in normal soils. The arrows indicate the three principle trends towards extreme conditions A: acidification trend, S: salinization trend, G: gleying trend.

2.5 THE PRINCIPAL AGRICULTURAL PROBLEMS RELATED TO SOIL CHEMISTRY

2.5.1 THE MAJOR CHEMICAL PROBLEMS

The general range of pH-pe conditions in a soil is shown as the stipled region in figure 2.7. Problems inevitably arise when conditions stray towards the environmental limits of this range, illustrated by the three arrows leading to (A), (S) and (G). The caption to figure 2.7 explains the symbolism and the (A) or acidification trend, is the most acute in the most agriculturally productive parts of Tanzania.

If we take environmental conditions for the oxisols, ultisols and most of the inceptisols of the Mbeya and Morogoro regions we see (figure 2.8) that acid conditions are concomitant with low fertility, aluminum and possibly manganese toxicity, and phosphorus fixation. All of these problems in fact, are a consequence of the weathering system having been simplified towards assemblages dominated by quartz-kaolinite-goethite. Assemblages of these minerals buffer the system at a low pH, they do not contain notable amounts of nutritional elements, nor do they have a high enough cation exchange capacity to retain such elements. Furthermore, the physico-chemical system is poised near the kaolinite-solution equilibrium giving levels of Al^{3+} in solution that are toxic to many plants. In addition, the Al^{3+} ions, as well as the iron hydroxy phase can fix large amounts of phosphorus.

The extensive leaching that has produced the quartz-kaolinite-goethite assemblages is also the cause of the low fertility already mentioned. Fertility is almost always considered in terms of the 'big three', nitrogen, phosphorus and potassium, with S becoming increasingly recognised as a fourth important nutrient element. However, minor elements are also important, and highly leached soils will always suffer from trace element deficiencies. The main one to be discovered in the Mbeya region has been Cu-deficiency (Kamasho et al., 1982). Doubtless there are others, though they will only be revealed by extensive agronomic testing over a long period of time.

2.5.2 OTHER CHEMICAL PROBLEMS

The other two pathological trends shown on figure 2.7 are also represented in our study areas. The high water table in the low lands bordering the north end of Lake Nyasa, produces gleyed soils which are best for rice production since to produce other crops they would have to be drained. Also, the semi-arid conditions north of the Rungwe massif result in evaporation exceeding precipitation for most of the year so that the net motion of the soil water is upwards where it can deposit salts in the upper parts of the solum and at the surface. The results are most obvious in the Rukwa trough, where sodium carbonate efflorescences can be seen at the surface.

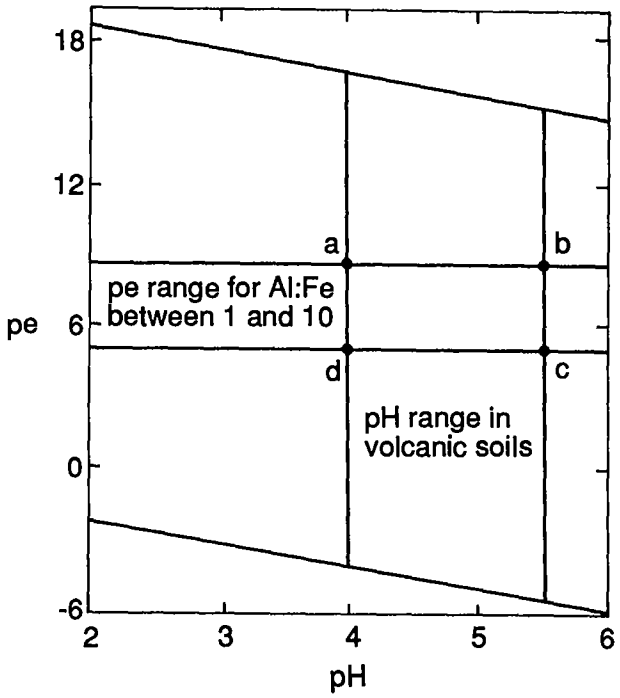

Fig. 2.8 Environmental conditions (box abcd) estimated for oxisols, ultisols and most inceptisols of the study area

2.6 PHYSICAL PROBLEMS

Two physical problems are encountered in our study areas, namely soil erosion and water loss.

The slopes that are formed in and around the volcanic massif in Mbeya district, and on the Uluguru block in Morogoro district, are prone to gullying and sheet erosion. Gullying is especially common in the ashy deposits of Ngozi crater and on the eastern side of the Rungwe volcano.

Two techniques have been introduced to counter this problem, the commonest being to construct contour ridges on the slope. It also has the advantage of being relatively easy to maintain. Terracing, a more permanent solution, is less common, though it can be found in the Uluguru mountains as well as near Tukuyu. Unfortunately, the usual practice is to ignore the problem and to take no precautions. Consequently topsoil constantly winds up in the river and stream valleys.

The problems of water conservation generally increase as the distance away from elevated landforms such as the Uluguru Mountains and Mount Rungwe increases. On the high ground the climate is humid and rainfall generally adequate, whereas on the plain the climate grades into a semi-arid type. However even in regions where rainfall is generally adequate, water conservation can be a problem because of the seasonality of rainfall, or because many of the soils are on materials and/or slopes that drain rapidly.

CHAPTER 3

GEOLOGICAL EXPLORATION

3.1 METHODOLOGY

The first step in an agrogeology programme is to identify specific problems a farmer is faced with, and that admit of a geological solution. In most cases these problems will relate to soil and to water. In the Mbeya and Morogoro regions, as shown in chapter 2, the following chemical and physical problems are found:

1. Chemical problems:
   - (a) High acidity,
   - (b) Low fertility,
   - (c) Elemental toxicities (Al and Mn in particular),
   - (d) Phosphate fixation,
   - (e) Micronutrient deficiencies (e.g. Cu and Zn).

2. Physical problems:
   - (a) Sheet and gully erosion,
   - (b) Water stress.

The second step is for the geologist to look for materials and techniques that would enable the farmer to overcome, or at least ameliorate, these problems. In fact, solutions to all these problems were at hand or have been found locally, as will be shown in this chapter. However, the main geological thrust has been to localize phosphorus resources, and, where possible, easily mineable phosphates close to P-deficient agricultural centres. Apart from phosphate exploration, we also investigated for liming materials, trace element resources and all purpose soil amendments such as volcanic glass and scoria.

The initial phase of the geological programme was to select target areas for mineral exploration. Intensive literature surveys and studies of aerial photographs, airborne magnetic and radiometric data were carried out prior to conducting the actual field surveys.

Seventeen areas were selected for semi-detailed ground survey, several other areas were to be traversed on a reconnaissance scale to assess their potential.

The survey of the target areas were carried out by geologists and geophysicists from the Ministry of Minerals and Energy (Madini), the State Mining Corporation (Stamico), Tanzania, and the University of Guelph, Canada. A list of participating scientists and technicians is provided in chapter 1.3.

The geological-geochemical surveys involved semi-detailed mapping, trenching and pitting, lithogeochemical surveys and soil and stream sediment sampling. The geophysical ground surveys were conducted using gamma ray spectrometers (URTEC UG 135, and McPhar, Spectra 44D).

Large numbers of samples had to be analysed for their P_2O_5 content. As part of an Inter-African technology transfer, Tanzanian technicians were trained by personnel from the Zambia Industrial and Mining Corporation (ZIMCO) to set up a phosphate field laboratory. With these appropriate field techniques the laboratory could handle up to 100 samples per day. The analytical techniques are summarized in appendices I and II. In addition, samples were analysed at the University of Guelph by XRD, XRF, INAA, SEM and chemical methods.

Of importance on a wider scale are the detailed studies of carbonatite complexes. Here we have started to develop new phosphate exploration guides and models which might be applied in phosphate exploration in other tropical and subtropical areas.

The bulk of this chapter is an itemised catalogue of specific exploration targets leading to an assessment of their potential as sources of agricultural raw materials, but first, a brief synopsis of the regional geology is presented.

3.2 REGIONAL GEOLOGY

The regional geology of Tanzania is characterized by a central Archean craton, which is surrounded by Proterozoic fold belts. While the Proterozoic development is marked by the formation of orogenic belts, the Phanerozoic is characterized by intermittent tensional events, including rifting. The periods of rifting affected the area outside the rigid craton: Mesozoic rifting in the south of the country and Cenozoic rifting confined to narrow zones East and West of the craton.

The two project areas both lie in zones affected by rifting. The Mbeya region lies along the southwestern edge of the Archean craton, the Morogoro area lies to the SE of the craton.

The Precambrian geology of the Mbeya region is characterized by a NW-SE striking, early Proterozoic fold belt, the 2000-1800 Ma Ubendian belt. The Ubendian is made up of quartzo-feldspathic gneisses, pelitic and amphibolitic rocks, and was intruded by syenite-gabbro complexes at around 730 m.a. This intrusion age seems largely to coincide with the first thermotectonic episode of the Pan-African (Cahen and Snelling 1984). The Proterozoic rocks are also intruded by several carbonatite complexes of late Proterozoic and Mesozoic age (van Straaten 1986).

This area also marks the coming together of the eastern and western arms of the East African rift system, with the most prominent faults in the region being the Rukwa, Nyasa and Mbeya-Usangu faults. At the intersection the Rungwe volcanic zone occurs with activity dating from mid Cretaceous times (carbonatites) to late Tertiary to Recent. Picritic basalts to phonolites occur in the later period, as both flows and pyroclastics.

Finally, Neogene lacustrine and fluviatile sediments are associated with the rift valley, (conglomerates, sandstones, clays and cherts, commonly with volcanogenic additions).

The Precambrian geology of the Morogoro region is characterized by polycyclic deformation and metamorphism. The Uluguru Mountains south of Morogoro form an extensive block of granulite facies rocks surrounded by Proterozoic amphibolite-facies gneisses and Phanerozoic sediments. Flat lying Karroo sediments, Permian-Jurassic in age, cover large parts of the southern Morogoro region (Kreuser 1984). The area was affected by rifting and associated carbonatite magmatism.

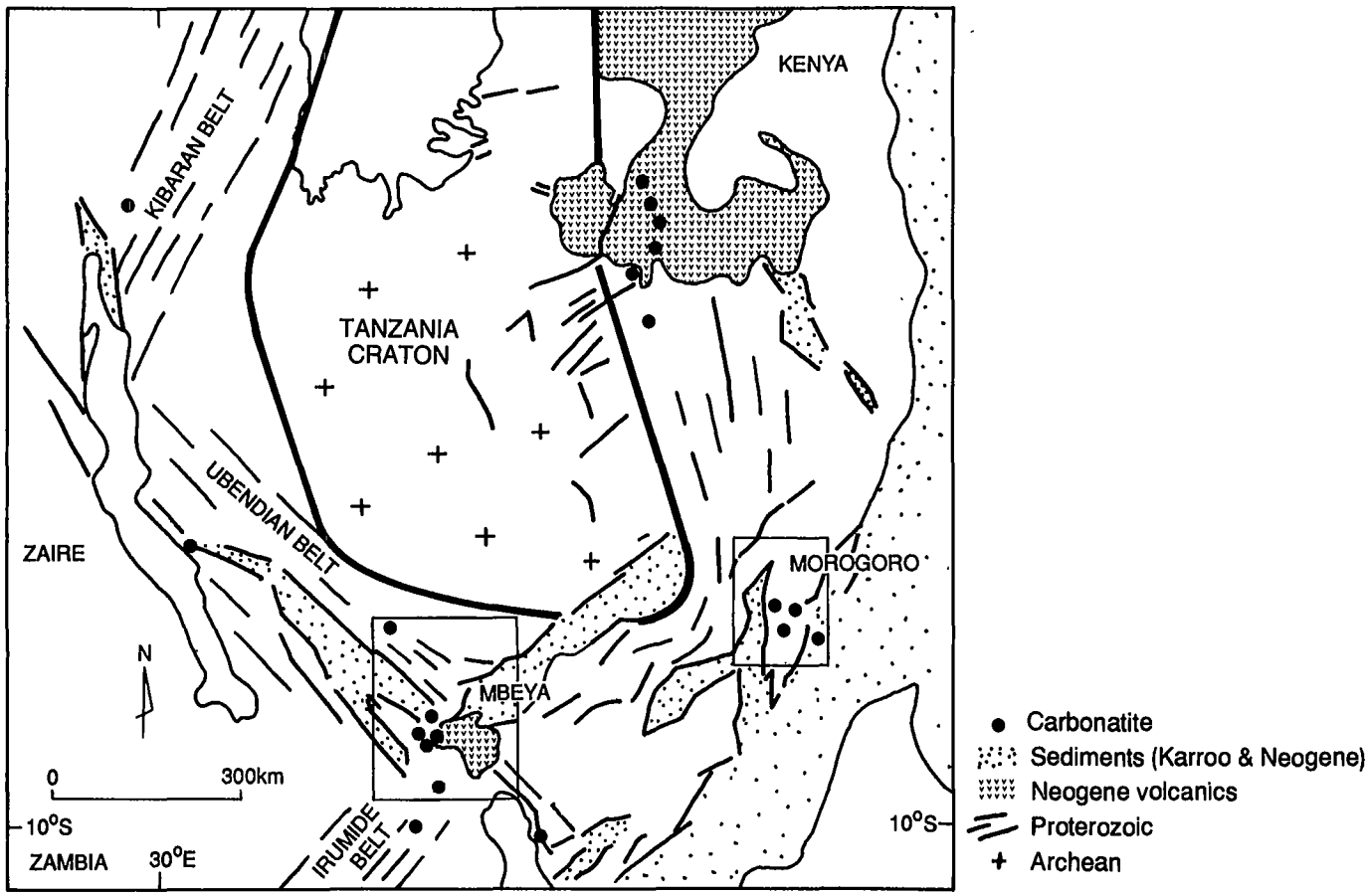

Fig. 3.1 Regional geological setting

3.3 PHOSPHATE PROSPECTS

3.3.1 PANDA HILL

Location and Access: The Panda Hill carbonatite, previously also called the Mbeya carbonatite, is situated close to road and railway approximately 25 km WSW of Mbeya, the capital of Mbeya region (Fig. 3.2 The carbonatite is located at N: ^{90}063 E: ^{5}264 on the Universal Transverse Mercator Grid (UTM), Zone 36.

It can be reached from Mbeya (about 36 km by road) via the Mbeya cement factory site at Songwe, at about 7 km from the main Tanzania-Zambia highway. The distance to the next railhead of the TAZARA railway is 4 km.

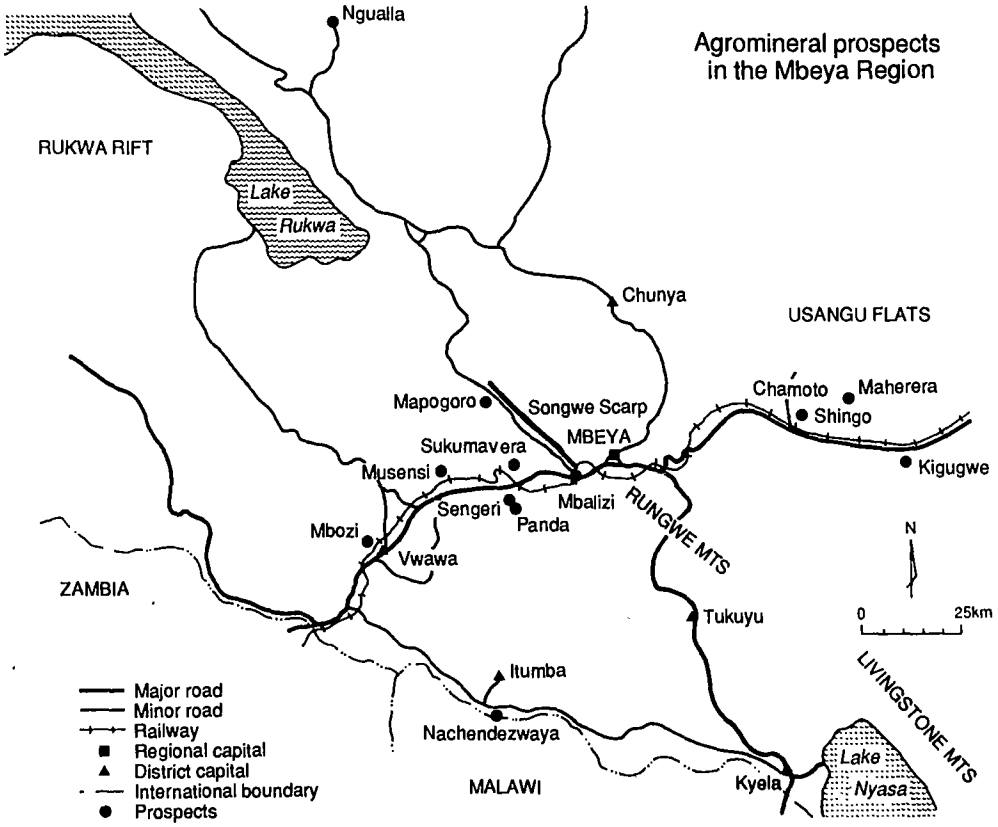

Fig. 3.2 Agromineral prospects in the Mbeya region.

Previous Work: Crystallized limestone was discovered at Panda Hill in 1950 by A.M.M. Spurr of the Tanganyika Geological Survey. In 1952 the 'crystallized limestone' was recognized as pyrochlore bearing carbonatite. Follow up work by Fawley and T.C. James (1955) resulted in detailed geological mapping and drilling of approximately 1400m. Preliminary reserve figures for this niobium bearing carbonatite indicated 9.5 million tonnes at 0.31% Nb_2O_5.

In the framework of exploration for niobium the Mbeya Exploration Company (MBEXCO) drilled another 6000 m between 1955 and 1963. MBEXCO also erected and operated a pilot flotation plant at the foot of Panda Hill. In 1961 MBEXCO estimated reserves 50 million tonnes grading 0.30% Nb_2O_5.

The borehole data of MBEXCO were re-evaluated 1972/73 by a Canadian company consulting for CIDA. They proposed selective mining of the pyrochlore rich portions of two zones with indicated reserves of approximately 10 million tonnes at 0.64% Nb_2O_5.

In 1978/79 the Yugoslav mining association RUDIS in cooperation with the State Mining Corporation (STAMICO) studied the primary phosphate potential of Panda Hill. They drilled 13 boreholes (totalling 1306 m) and calculated the reserves: 480 millions tonnes at 0.33% Nb_2O_5 and 3.5% P_2O_5.

Detailed geological accounts are compiled by Fawley & James (1955) and Fick & van der Heyde (1959). Petrographic and chemical details are described by Basu and Mayila (1986).

General Geological Setting: The Panda Hill carbonatite intruded and fenitized gneisses and granulites of the early Proterozoic NW-SE striking Ubendian fold belt. It intruded into a structurally weak position of the crust, which was repeatedly activated by block faulting and rifting. The carbonatite intrusion took place at the southwestern rift fault of the Rukwa rift. The NW-SE striking rift fault is post-Karroo and pre mid-Cretaceous in age. The carbonatite intruded into the intersection of this major fault with a N-S striking fault.

The carbonatite intrusion is dated by Snelling (1965) as mid-Cretaceous (113± 6 Ma.).

The whole of SW Tanzania was peneplained in two or three separate events in Mesozoic and Tertiary times. The plateau of Panda hill forms part of the dissected peneplain of the Mbozi plateau, a laterite surface of probable pre-Miocene age (Spurr 1955). Lateritic weathering caused the development of deep residual soils.

In Neogene times the whole area was covered by pumice and volcanic ash derived from the Rungwe volcanics.

The Geology of Panda Hill: The Panda Hill carbonatite is roughly circular in shape with a diameter of approximately 1.5 km (Fig. 3.3). It is surrounded and partly overlain by fenitized country rock, mainly fenitized gneisses. T.C. James carried out detailed mapping and, based on the measurement of flow banding, he reconstructed a steeply dipping plug like carbonatite. According to James (1954) the inner ring is largely made up of sovite surrounded by magnesiocarbonatite and, at the outer periphery, dikes of varying composition.

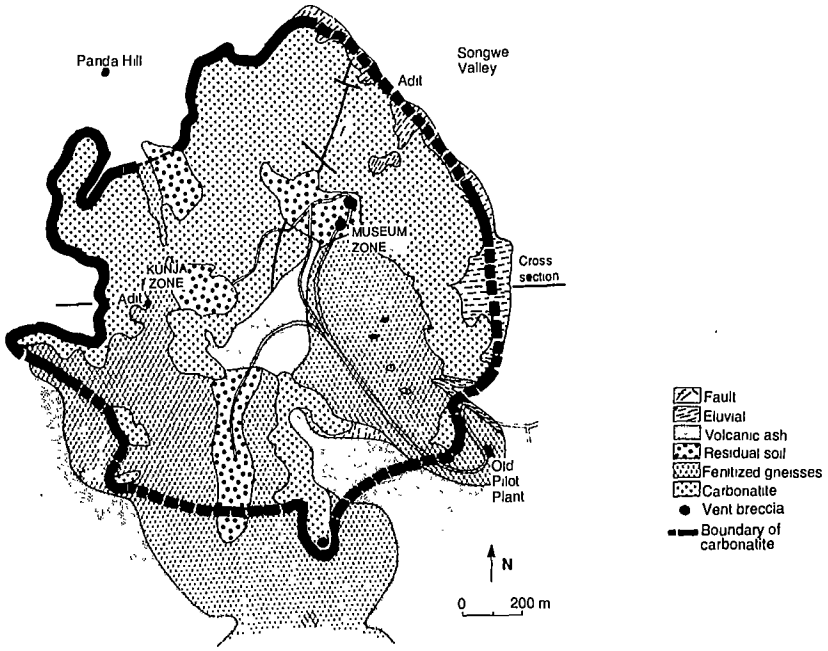

Fig. 3.3 Generalized map of the Panda Hill carbonatite.

Fawley & James (1955) interpreted the whole carbonatite as a steep central plug which is part of a much larger volcanic complex, most of which has been eroded away. Fick & van der Heyde (1959) viewed the structure of the carbonatite complex differently. Their survey suggests that the exposed carbonatite is part of a high level intrusion with parts of the roof still exposed (Fig. 3.4). The top of the carbonatite is capped by fenitized gneisses. Borehole evidence from the central part of the carbonatite largely supports the view of Fick & van der Heyde.

Explosion vents made up of fenitized basement rock in a ferrocarbonatite matrix are exposed in the central zone and at the southern margin of the carbonatite complex.

The general intrusion sequence is, from old to young:

- sovite,
- magnesiocarbonatite,
- ferrocarbonatite.

This sequence of the major carbonatite intrusions is followed by various dike intrusions. The chemistry from the various rock types is given in Table 3.1.

The two minerals of economic potential at Panda Hill are: pyrochlore and apatite. Studying the borehole data of MBEXCO and RUDIS, it can be concluded that highest concentrations of pyrochlore in primary rock occur in the fenites which form the shallow roof cap and in the carbonatite zone directly underlying this cap zone.

Apatite mineralization is partially related to that of pyrochlore, Highest apatite concentrations are found at the contact between the sovite and the fenitized roof. The current research has shown that large amounts of apatite actually occur in the fenitized roof portion. This indicates that the fenitizing fluids were not only rich in Nb and P but also in halogens, particularly in F.

Highest values of Nb_2O_5 and P_2O_5 occur in residual and transported soils overlying zones of primary pyrochlore and apatite enrichments in the fenite/sovite contact zone of the roof portion.

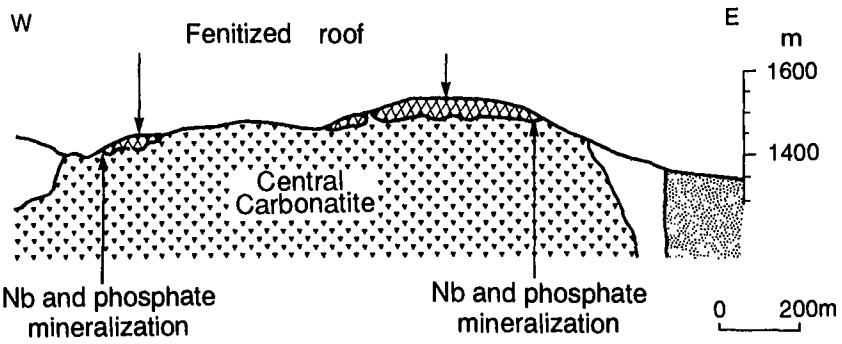

Fig. 3.4 East - west cross section of the Panda Hill carbonatite.

Work Carried Out: We started with detailed studies of all published and unpublished reports and available borehole data from MBEXCO (1957) and RUDIS (1980). Field work commenced with a lithogeochemical survey of the various rock types to identify the most potential source rock.

After the initial finding of phosphate rich residual and transported soils in the Kunja-Mtoni-Mstari zone and the Museum zone south, we carried out semi-detailed soil and rock surveys along a 50 x 100 m grid. A complementary radiometric survey was carried out along the same grid.

Detailed surveys were carried out in the old exploration adit IV and along a section of the old quarry road at the Museum zone south.

Results: Two separate zones with sizeable phosphatic residual soils have been delineated on Panda Hill. The two zones overly carbonatite-fenite contact zones.

The mineralized area of the Kunja-Mtoni-Mstari zone covers more than 25,000 m^2 surface area. Previous borehole data indicate a thickness of the residual soil in this zone of more than 10 m. The average grade of the limonitic soft material is 8-15% P_2O_5. In addition it contains some pyrochlore (Nb_2O_5 content of soil up to 0.6%).

The second zone (the Museum zone) is smaller, preliminary estimates reach 10,000 m^2 surface area. Also this zone overlies the carbonatite/fenite contact zone. The mineralization occurs actually in the deeply weathered fenite zone. Two separate sections of the deeply weathered, soft fenite material revealed apatite accumulations with P_2O_5 content being in average 12 and 14.5% P_2O_5. Pyrochlore, a potential co-product, is also concentrated in these zones (highest value 1.4% Nb_2O_5, average over 20 m = 0.4 - 0.5% Nb_2O_5).

We carried out simple beneficiation tests using material from the Kunja zone involving mainly washing and magnetic separation. With three times washing (decanting of the limonitic fines) we could concentrate a sample from adit IV from 11% to 19% P_2O_5. Additional magnetic separation reached a concentrate of 36% P_2O_5 (i.e. ~ 85% apatite) (Table 3.1).

The unprocessed and three times washed material was supplied to the agronomic teams and pot and field trials using these materials resulted in encouraging yield response (see 1985 experiments of Uyole, chapter agronomic results).

Assessment: Based on the studies conducted so far it is evident that this target has the greatest potential as phosphate resource in Mbeya district. Its proximity to P-deficient farmland, its closeness to road and rail, its sufficient grade and tonnage, its ease of beneficiation and, above all, its positive agronomic response on P deficient soils, makes it the prime target for follow up work.

Table 3.1 Chemical analyses of rocks from the Panda Hill carbonatite

	Kunja Zone								Museum Zone					
	Apatite rock	Residual adit IV		328	conc.	3X Washed	25X Washed	Magnetic separation	36.0	38.0	48.5	51.5	56.0	Com posite
							%							
SiO_2	11.69	35.70	28.24	26.48	11.93	17.23	12.77	.33	15.01	21.24	41.55	26.85	48.64	46.23
Al_2O_3	0.57	3.64	6.02	2.59	0.67	3.82	2.64	0.73	6.11	4.43	1.44	0.60	1.85	5.33
Fe_2O_3	20.50	24.81	23.50	33.18	4.61	17.60	7.36	1.63	25.25	12.81	10.00	8.56	6.04	10.85
MgO	2.06	0.91	1.16	0.78	1.36	35	1.45	0.30	1.88	2.05	1.69	2.14	1.71	1.93
CaO	38.78	15.98	20.12	17.13	30.94	33.15	37.23	56.03	26.15	32.62	26.41	35.44	27.10	18.59
Na_2O	0.21	0.21	0.31	0.20	0.16	0.28	0.46	0.31	0.25	0.49	0.31	0.23	0.51	0.37
K_2O	0.08	0.21	1.49	0.73	0.06	1.53	1.22	0.19	0.32	0.39	0.45	0.47	0.55	0.44
TiO_2	0.87	1.20	2.62	1.99	1.80	2.65	2.02	0.51	1.80	0.51	0.60	0.32	0.62	2.18
MnO	0.09	0.26	0.43	0.55	0.40	0.18	0.16	0.04	0.75	0.0	70.03	0.37	0.30	0.20
P_2O_5	22.98	11.54	10.39	12.11	15.70	18.88	21.98	36.13	14.66	21.37	14.50	22.06	10.25	9.33
LOI	2.16	5.55	5.71	4.27	2.37	3.33	2.72	0.73	7.83	4.01	3.01	2.96	2.43	4.56
							ppm							
Rb	17	21	ND	16	6	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sr	2980	2220	2250	4280	1630	1330	11.90	480	3310	2890	1060	4200	4920	3170
Y	29	44	ND	61	23	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zr	1470	1160	ND	425	1360	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nb	4640	1720	2410	1390	2310	1840	1590	1670	1010	8100	670	10150	660	295
Ce	1960	7600	ND	3790	2950	ND	ND	ND	ND	ND	ND	ND	ND	ND
Nd	990	3730	ND	1540	1050	ND	ND	ND	ND	ND	ND	ND	ND	ND
La	850	5200	ND	2190	1320	ND	ND	ND	ND	ND	ND	ND	ND	ND

XRF analyses, McMaster University

Table 3.1 Panda Hill (cont'd)

	Sovites		
	VS483A	VS412	296B
		%	
SiO_2	4.70	6.98	29.6
Al_2O_3	0.07	0.09	7.01
Fe_2O_3	6.72	1.93	11.50
MgO	2.91	4.72	3.52
CaO	45.51	46.14	19.84
Na_2O	0.10	0.22	0.40
K_2O	0.29	0.07	5.13
TiO_2	0.17	0.03	2.40
MnO	0.71	0.43	0.26
P_2O_5	4.79	6.85	2.92
LOI	34.02	32.54	11.34
		ppm	
Rb	6	11	96
Sr	2060	8100	2040
Y	29	35	29
Zr	690	1480	918
Nb	629	6174	674
Ba	1540	343	1190
Ce	1430	781	528
Nd	769	302	231
La	848	402	161

XRF analyses, McMaster University

Gully: NE - side Panda Hill

	soil profile				
	47	48	49	50	51
	Top				Bottom
			%		
SiO_2	48.19	48.12	48.09	48.81	45.03
Al_2O_3	15.11	15.18	15.16	17.05	12.91
Fe_2O_3	12.41	12.10	11.35	11.55	13.98
MgO	1.33	1.16	2.05	1.27	1.60
CaO	4.11	4.10	5.21	4.35	4.88
Na_2O	1.98	2.10	1.97	1.69	1.50
K_2O	4.19	4.25	4.43	3.83	4.65
TiO_2	1.32	1.34	1.26	1.23	1.25
MnO	0.65	0.69	0.60	0.67	0.67
P_2O_5	1.29	1.72	1.74	1.25	2.01
LOI	9.42	9.24	8.14	8.31	11.51

XRF analyses, McMaster University

3.3.2 NGUALLA CARBONATITE

Location and Access: The Ngualla carbonatite complex lies in an isolated area of Northern Chunya District, Mbeya Region, at N: $^{91}488$ and E: $^{4}816$ on UTM zone 36. A prison and a village lie at the foot of the carbonatite and can be reached by a secondary road and a motorable track from Mbeya via Mkwanjuni and Kininga. The total distance from Mbeya is 212 km.

Previous Work: In 1949/50 geologists from Union Corporation discovered a ring-like structure in the Ngualla area which was identified in 1954 as carbonatite complex. The area was intensively studied between 1957 and 1961 by the Western Rift Exploration Company on its niobium and base metal potential. Later, after the initial finding of a few diamonds the area was re-visited and intensively studied by Williamson & Diamonds (1966-69). An airborne geophysical survey was carried out by Geosurvey Ltd. in 1979 and revealed strong magnetic and radiometric anomalies over the Ngualla complex.

General Geological Setting: The Ngualla carbonatite occurs in an area which is widely underlain by rocks of the NW-SE striking Ubendian fold belt. The high metamorphosed rocks and granites, approx. 2000 - 1800 Ma in age, were invaded by volcanics of mainly rhyolitic-rhyodacitic composition. The age of these volcanics has not been established as yet. However, they are certainly Proterozoic, postdating the 2000-1800 Ma Ubendian orogenic event and predating the intrusion of the 1040 Ma Ngualla carbonatite.

The Ngualla carbonatite is not accompanied by any major alkaline silicate intrusions. It is a plug-like intrusion made up of various carbonate phases and is roughly circular in shape with a diameter of approximately 3 km (Fig. 3.5).

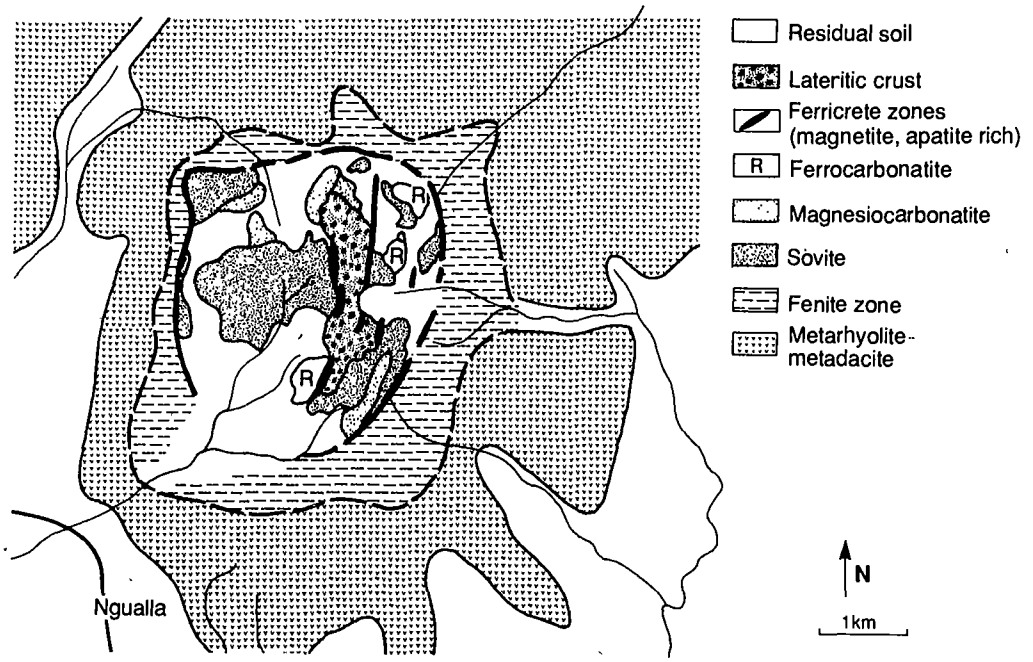

Fig. 3.5 Generalized geological map of the Ngualla carbonatite, modified after Williamson Diamonds (1970).

The Ngualla carbonatite complex is surrounded by a 1 km wide fenite zone. In this zone, the felsitic country rock is largely shattered (brecciated), veined and altered to a pinkish, blocky, feldspar rock. An extensive intrusive breccia forms the contact of the carbonatite to the fenitized country rock at the western margin.

The carbonatite complex is made up of three major rock types. They are, in descending order of volume:

sovite,
magnesiocarbonatite,
ferrocarbonatite.

Sovite, is the most common carbonatite in the Ngualla complex, forming the centre and large portions of the outer parts of the complex. The central sovite consists of mainly white massive calcite carbonatite. Major parts

of the sovite are characterized by steep dipping foliations, whereby the accessory minerals magnetite, mica and apatite are aligned along the foliation planes. At places the sovite occurs in coarse veins and as aggregates with dendritic textures, apatite crystals forming the long dendritic laths. In the more marginal portions of the carbonatite complex, the sovite is less massive. Here it is largely invaded by later carbonatite phases, in particular by magnesiocarbonatites.

The magnesiocarbonatite is the second most common carbonatite type. This brownish weathering dolomitic carbonatite intruded pervasively all parts of the carbonatite except the central part. It occurs mainly in veins and can make up more than 50% of the rock.

The sideritic ferrocarbonatite is the third major rock type and occurs mainly in the northwestern and southeastern portion of the complex. The ferro carbonatites occur as large pods in the carbonatite complex. The dull reddish to purplish carbonatite is massive without any foliation. Large xenoliths of magnesiocarbonatite and earlier carbonatite phases are common in this late stage carbonatite.

The relative age of intrusion of the three most voluminous carbonatite phases, established on the basis of crosscutting relationships, is:

1. sovite, followed by
2. magnesiocarbonatite, followed by
3. ferrocarbonatite.

Dikes and veins of various compositions intruded into the carbonatite at various stages. Up to 20 cm wide mafic dikes consisting of calcite, biotite, pyroxene and/or amphibole crosscut the sovite. They are transected by later magnesiocarbonatite. They occur mainly in the northern and eastern sector of the complex.

Most other dikes intruded during late phases of the carbonatite intrusion. The main types are:

1. magnetite-apatite veins,
2. barite veins,
3. quartz-calcite veins,
4. fluorite veins.

All four types are interesting from the economic point of view. The magnetite-apatite veins are up to 20 m wide and can be followed for several hundred meters. The P_2O_5 content is between 15 and 35% P_2O_5. The barite veins in the eastern sector of the carbonatite are not only rich in Ba but also in REE (up to 5% REE).

The quartz-calcite veins and stringers were investigated by the Western Rift Exploration Company on their base metal content as the veins are partially mineralized with chalcopyrite and galena. Fluorite occurs in small veins postdating the ferrocarbonatite.

Large parts of the Ngualla carbonatite complex are covered by thick residual and transported soils. At places an indurated laterite cap is developed. A resistant ferricrete covers large portions of the magnetite-apatite vein systems.

Field Work: Geological field work was conducted on a reconnaissance scale. A lithogeochemical survey was carried out to identify the mineral potential of the various carbonatite phases. Additionally, stream sediments were sampled and soils collected over selected areas. Several pits were dug in soils suspected of being rich in phosphates. The survey was supplemented by routine radiometric measurements using the URTEC UG 135 differential Gamma Ray Spectrometer.

Selected rock samples were collected for scientific studies in collaboration with Prof. K. Bell from the Dept. of Geology, Carleton University, Ottawa.

Results: A clear trend of the element distribution in the sequential order of carbonatite emplacement is established (Fig. 3.6). The lithology controls the potential mineralization of the Ngualla carbonatite in respect to phosphates. The survey shows a bimodal distribution with high P_2O_5 contents in the early, mainly sovitic phase and in the late phase of residual enrichment in the magnetite-apatite veins. Barium and strontium show inverse correlation with barium clearly enriched (and strontium depleted) in the late phases of the carbonatite intrusion. Similarly, the Rare Earths Elements (REE) are accumulated in the late phase of the intrusion (Table 3.2).

In regard to phosphates two types of mineralization were discovered. The primary magnetite-apatite mineralization occurs in 15-20 m wide, several hundred meter long veins. Zones exist within the extensive N-S striking vein system that contain 15-35% P_2O_5. Also discovered were thick blankets of residual and transported soils. Particularly rich ar the soils derived from the early apatite sovite and the late magnetite-apatite veins. Several pits revealed soils with 12-20% P_2O_5 to depth of 5 m and more.

In the course of the phosphate exploration we also discovered considerable Rare Earth mineralization

associated with barite veins. The total REE content in residual soils reached 5%.

Preliminary data from isotope studies at Carleton University, Ottawa, indicate a radiometric age of 1000 Ma (mid Proterozoic) with initial $^{87}Sr/^{86}Sr$ values of 0.7023.

Assessment: Preliminary studies indicate the existence of two types of phosphate mineralization in the Ngualla carbonatite. Primary and secondary phosphate mineralizations are widespread, and although it is too early to give figures on tonnage and grade it seems that several hundred thousand tonnes of phosphate for each of the two types can be expected. Consequently, high priority is given for this target.

Follow up work should focus not only on the evaluation of reserves but also on its economic feasibility since the Ngualla carbonatite occurs in a remote area.

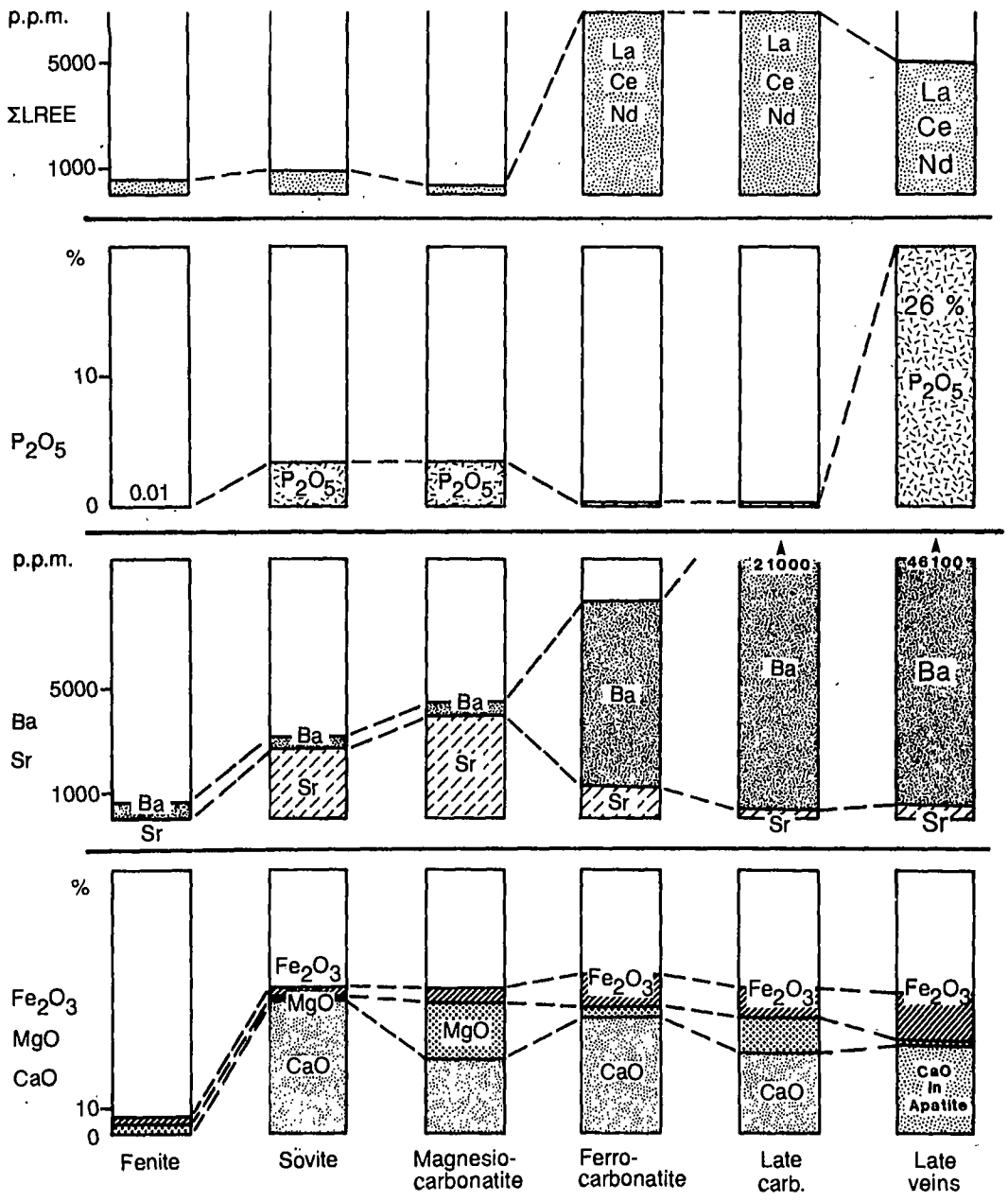

Fig. 3.6 Selected element distribution from the main phases of the Ngualla carbonatite intrusion.

Table 3.2 Chemical analyses of rocks from the Ngualla carbonatite

	Fenite	Central Sovite		Magnesio "Alnoite" Carb.			Ferro-Carb		Apatite-Magnetite Veins	
		VSNg-75	VSNg-64	VSNg-58	VSNg-59	VSNg	VSNg-83	VSNg-84	VSNg-67	VSNg-65
					%					
SiO_2	61.63	3.45	6.36	9.86	21.20	0.92	5.57	4.26	0.71	2.04
Al_2O_3	15.43	0.17	0.36	1.21	3.62	0.13	0.20	0.16	2.87	0.20
Fe_2O_3	6.23	2.89	5.34	18.80	11.92	3.99	12.13	10.14	36.69	6.78
MgO	2.01	3.34	4.76	13.08	8.03	21.00	1.94	2.19	1.06	1.42
CaO	0.37	46.56	49.24	21.94	25.16	28.01	45.17	46.11	31.49	51.04
Na_2O	1.60	0.52	0.75	0.52	1.40	0.34	0.32	0.45	0.40	0.39
K_2O	10.62	0.25	0.20	0.09	2.74	0.07	0.11	0.11	0.07	0.11
TiO_2	0.57	0.10	0.29	5.23	4.43	0.01	0.00	0.02	4.97	0.00
MnO	0.16	0.17	0.20	0.30	0.16	0.19	0.32	0.30	0.39	0.41
P205	0.01	6.791	2.76	0.19	2.86	3.81	0.14	0.15	19.99	4.90
LOI	1.37	35.76	19.74	18.78	18.39	41.53	34.10	36.11	1.35	2.69
					ppm					
Rb	212	9.3	6.0	40	112	9.3	2.7	3.3	4.8	24
Sr	99	4120	2510	1160	2390	4010	1120	1000	900	1430
Y	22	19	27	18	56	12	6.7	7.6	27	61
Zr	113	192	380	184	420	171	38	37	500	240
Nb	77	28	93	108	83	132	7.3	8.1	190	430
Ba	534	360	620	510	1250	550	7200	2100	46100	1510
Ce	387	240	245	135	280	46	3400	1490	450	570
Nd	73	175	250	74	105	42	1350	790	410	470
La	65	240	163	85	160	54	2370	710	280	290

XRF analyses, McMaster University

	Fenite A	Fenite B	VS 379	VS 370	VSNg 74	VSNg 60	VS 380	VS 85-1026-4	VS 384A	VSNg 82	VSNg 68
						%					
SiO_2	62.26	66.08	0.19	1.76	3.61	69.03	0.73	0.51	0.22	19.10	0.29
Al_2O_3	13.99	13.43	0.03	0.07	0.02	0.62	0.04	0.08	0.03	1.53	0.11
Fe_2O_3	7.85	4.66	0.64	1.13	2.93	3.96	3.76	3.97	10.9	17.8	73.25
MgO	2.82	0.42	5.16	1.06	4.71	2.38	4.11	16.79	15.4	0.55	0.49
CaO	3.58	0.02	50.57	52.48	45.58	11.87	47.56	32.97	30.96	30.22	13.21
Na_2O	5.23	0.59	0.03	0.05	0.41	0.84	0.09	0.05	0.05	0.55	0.19
K_2O	3.36	11.49	0.01	0.01	0.16	0.19	0.06	0.01	0.03	0.06	0.07
TiO_2	0.49	0.19	0.00	0.01	0.16	0.00	0.02	0.03	0.02	0.00	2.71
MnO	0.11	0.04	0.25	0.19	0.25	0.22	0.24	0.49	0.62	0.4	50.17
P_2O_5	0.30	0.00	0.17	3.08	6.95	4.11	4.70	2.33	0.12	25.61	9.42
LOI	0.01	3.05	42.91	40.16	35.22	6.78	38.67	42.77	41.47	4.05	0.10
						ppm					
Rb	146	235	10	9	8.8	14	8	6	4.2	1	
Sr	820	117	5980	2520	4950	1220	4000	3000	656	890	770
Y	42	60	25	24	19	103	26	20	16	58	21
Zr	240	480	1200	782	219	350	1180	710	225	94	90
Nb	25	91	18	145	740	140	218	300	51	205	1200
Ba	1650	610	468	675	390	155	509	906	2150	63800	530
Ce	98	42	324	439	220	550	375	254	3940	2500	800
Nd	56	48	135	171	148	465	179	110	1670	1180	650
La	39	21	131	199	170	280	121	88	1590	1470	440

XRF analyses, McMaster University

Table 3.2 (cont'd) Ngualla

	WD pit top 80 cm	WD pit 5m	Top gossan	329	330	331	332
				%			
SiO_2	8.17	5.78	3.35	0.60	1.19	0.92	0.96
Al_2O_3	14.16	9.57	0.66	2.21	0.40	0.13	1.97
Fe_2O_3	62.46	66.77	43.86	9.66	5.43	39.40	16.17
MgO	0.17	0.20	0.20	1.31	1.76	0.94	1.26
CaO	0.64	0.60	42.85	44.80	47.80	31.03	42.13
Na_2O	0.06	0.28	0.11	0.15	0.20	0.24	0.26
K_2O	0.67	0.48	0.36	0.06	0.06	0.09	0.07
TiO_2	5.56	4.07	0.01	2.30	0.12	1.37	1.45
MnO	2.08	3.36	1.37	0.38	0.18	0.35	0.19
P_2O_5	0.20	0.20	0.22	34.25	42.09	24.06	32.82
LOI	5.84	8.67	7.00	4.26	1.16	1.47	2.70
			ppm				
Rb	5	5	ND	ND	ND	ND	ND
Sr	512	358	ND	ND	ND	ND	ND
Y	25	18	ND	ND	ND	ND	ND
Zr	375	597	ND	ND	ND	ND	ND
Nb	775	1070	ND	ND	ND	ND	ND
Ba	25000	16600	ND	ND	ND	ND	ND
Ce	18100	21500	ND	ND	ND	ND	ND
Nd	9620	10800	ND	ND	ND	ND	ND
La	1270	12670	ND	ND	ND	ND	ND

XRF analyses, McMaster University

Table 3.2 (cont'd) Ngualla

	VS 375	VS 378	VS 382	VS 385	VS 387
			%		
SiO_2	40.51	11.44	11.32	14.48	16.46
Al_2O_3	14.37	3.70	2.28	10.18	11.69
Fe_2O_3	23.65	34.67	29.67	59.60	47.04
MgO	0.22	0.36	4.10	0.36	0.19
CaO	1.62	26.07	29.60	0.33	1.06
Na_2O	0.22	0.10	0.51	0.42	0.24
K_2O	3.99	0.19	0.18	0.68	0.37
TiO_2	2.41	2.57	3.80	4.45	5.47
MnO	0.85	1.48	0.69	2.82	2.01
P_2O_5	2.85	12.62	14.04	0.47	8.10
LOI	9.30	6.80	6.80	6.22	7.37
			ppm		
Rb	ND	ND	ND	6	31
Sr	ND	ND	ND	380	2590
Y	ND	ND	ND	33	340
Zr	ND	ND	ND	360	501
Nb	ND	ND	ND	1100	398
Ba	ND	ND	ND	20800	227
Ce	ND	ND	ND	20100	519
Nd	ND	ND	ND	9700	220
La	ND	ND	ND	13700	226

XRF analyses, McMaster University

3.3.3 MBALIZI

Location and Access: The Mbalizi carbonatite is intersected by the main Tanzania-Zambia highway, some 10 km west of Mbeya. It lies approx. 500 m East of Mbalizi township and 200 m East of the junction between the Tanzania-Zambia highway and the TAZARA railway (Fig. 3.2). The coordinates are N: $^{90}124$, E: $^{5}405$ in the UTM zone 36. The best outcrops are along the road cut of the Tanzania-Zambia highway and in the steep valley just North of it.

Previous Work: The Mbalizi carbonatite lies on Quarter Degree Sheet 244. The area was mapped in 1957/58 by P.E. Brown but no carbonatite was reported. The map indicates the area to be covered by basalts of the Rungwe volcanics. The carbonatite was discovered in 1972 by a group of Soviet geologists who also carried out radiometric dating (122±8 Ma., 118±9 Ma./K:Ar) (Pentel'kov & Voronovskiy 1979).

General Geological Setting: The Mbalizi and Songwe Scarp carbonatites occur along the Eastern escarpment of the Rukwa Rift. They occur in a general area of repeated structural instability, a zone of shearing and faulting with mainly NW-SE trends.

There is evidence that the area was affected by strong shearing already in Proterozoic times (Brown 1962). The gneisses and muscovite-garnet schist of probable Ubendian (~ 2000 m.y.) age are affected by granulation and shearing, in particular in the area of the Mbeya range. The shearing and mylonitization of the Ubendian is thought to be of Kibaran (Ukingan) age (Brown 1962). Daly (1986) suggests that the Ubendian of West Tanzania was deformed during the Irumide (Kibaride) orogeny by a large scale continental transform fault, striking N.W. - S.E.

An extensive N.W.-S.E. striking basinal depression developed prior to and during the sedimentation of the Karroo sequences (late Carboniferous-Triassic). It is worth stressing that as part of the post-Karoo rifting a strong N.W.-S.E. striking fault zone developed prior to the mid-Cretaceous intrusion of the carbonatites. The Songwe Scarp carbonatite intruded into this pre-existing fault zone.

The whole area was peneplained post mid-Cretaceous and underwent lateritic weathering.

Lake beds were deposited at the rift floor. Subsequent rift faulting including the development of the impressive Songwe rift escarpment are thought to have taken place post-Miocene (Brown 1964). Rift faulting continued probably up to recent times.

Geology of the Mbalizi Carbonatite: The Mbalizi carbonatite lies in the striking continuation of the Songwe Scarp carbonatite (Fig. 3.7) and it is probable that both have a common origin. It is suggested that the Mbalizi carbonatite is a centre of the carbonatite intrusion from which the extensive dike system of the Songwe Scarp carbonatite is a late stage high level intrusion. The Mbalizi carbonatite would thus be part of the parent sovite body predicted by P.E. Brown (1964).

The Mbalizi carbonatite is largely covered by Neogene volcanics and volcaniclastics. It is exposed only in deeply incised river sections. The extent of the coarse grained Mbalizi carbonatite could not be established due to this volcanic cover, but it is at least 1.1 x 0.4 km in extent.

The main part of the exposed Mbalizi carbonatite is coarse grained sovite. Detailed studies suggest a complicated multiphase intrusive episode. The initial phase is characterized by large scale fenitization. Gneissic country rocks were strongly feldspathized. The central pyroxenite was altered at its contact into phlogopite-apatite rocks. Coarse-grained apatite- phlogopite-feldspar rocks occur at the western side of the exposed carbonatite and are considered fenitized bedrocks.

The centre of the exposed carbonatite is largely sovitic, parts of which are characterized by dendritic crystal growth (Treimann 1986). The latter are rich in apatite, P_2O_5 reaching 9%.

A late carbonatite phase is characterized by the intrusion of fine grained greyish- bluish carbonatite dikes. These dikes resemble in appearance and geochemical signature the Songwe Scarp carbonatites. This geological evidence suggests that the Songwe Scarp carbonatite is younger than the sovitic part of the Mbalizi carbonatite and is the late phase high level extension of this carbonatite intrusion.

The Mbalizi carbonatite was affected by long lasting weathering processes. Karstholes are exposed in the river section and a 0.5 m thick limonitic weathering crust with P_2O_5 enrichment (up to 30% P_2O_5) is developed at places.

Exploration Work: The area around the Mbalizi carbonatite was mapped in detail on a scale of 1:2500. Furthermore, detailed lithogeochemical and soil surveys were conducted outlining the potential phosphate rich zones.

Results: Three phosphate rich zones could be delineated in the Mbalizi carbonatite:

- parts of the sovitic carbonatite are hard, coarse grained calcite-apatite rocks with P_2O_5 contents around 6-8% (Table 3.3),
- soft, apatite-phlogopite (-feldspar) rocks at the western and northwestern margin of the carbonatite, containing 7 to 20% P_2O_5,
- enrichment of phosphates in irregular, up to 0.5 m thick limonitic weathering crust (P_2O_5 content up to 30%).

Assessment: The area around the Mbalizi carbonatite is ideally suited in regard to communication. Road and railway cross the carbonatite and phosphate bearing rocks. However, only a few thousand tonnes of phosphate rich material are considered easily mincable resources.

The apatite rich sovite with approximately 6-8% P_2O_5 was supplied for agricultural testing in 1985. However, as it is a carbonate rich material the apatite solubility is very low. It is regarded now as a liming material with low phosphate content.

A better material for agronomic application is probably the apatite-phlogopite (-feldspar) rock from the fenitic zone. This material (Mbalizi F) is carbonate free, soft, relatively easily mineable and contains apart from apatite the K-bearing minerals phlogopite and K-feldspar.

From the preliminary survey it was concluded, however, that only small tonnages (few thousand tonnes) exist, too small for conventional mining. These soft ores could be suitable for small scale mining, to be used in the immediate surrounding of Mbalizi village.

Further investigations of this occurrence will depend on the outcome of pot trials conducted presently at the Uyole Agricultural Centre and at the Sokoine University of Agriculture.

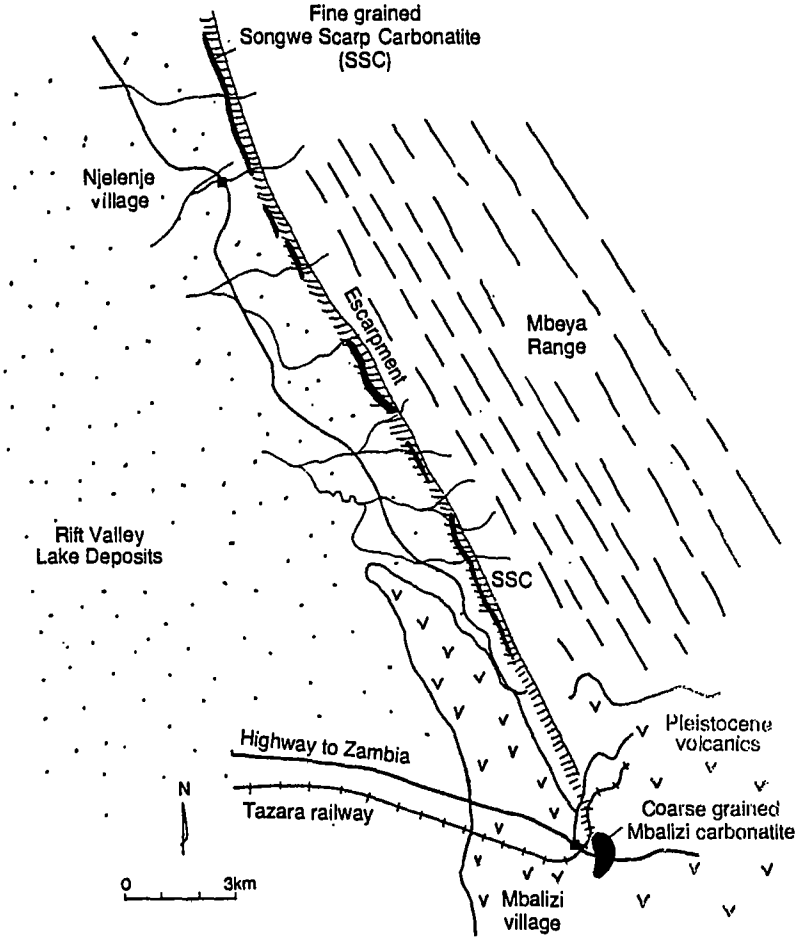

Fig. 3.7 Geological setting of the Mbalizi and Songwe Scarp carbonatite.

Table 3.3 Chemical analyses of rocks from the Mbalizi carbonatite

	Mbal. F	VS 289B	VS 282	Mbal. PVS	VS 84 - 125 a	b	c	d	VS 295	EP 377	PM 224	VS 287
							%					
SiO_2	29.60	26.42	1.54	2.44	1.80	2.72	6.80	3.10	1.76	4.31	2.14	2.39
Al_2O_3	8.66	5.54	0.09	0.39	0.48	0.57	1.30	0.32	0.13	0.33	0.28	0.41
Fe_2O_3	20.41	11.74	3.22	0.72	2.15	2.99	3.93	1.44	5.42	2.27	0.83	3.74
MgO	4.51	8.73	1.38	1.26	2.52	0.54	0.67	2.38	0.33	0.19	0.67	1.72
CaO	12.99	23.18	50.06	47.59	53.36	51.84	48.67	51.76	51.33	50.23	51.03	50.13
Na_2O	0.22	0.7	0.0	0.01	0.29	0.34	0.25	0.40	0.08	0.10	0.00	0.10
K_2O	2.49	4.88	0.06	0.17	0.35	0.12	0.17	0.21	0.31	0.39	0.31	0.62
TiO_2	4.87	1.64	0.0	0.01	0.02	0.11	0.23	0.04	0.18	0.09	0.00	0.24
MnO	0.19	0.23	0.19	0.22	0.16	0.06	0.04	0.03	0.37	0.35	0.23	0.21
P_2O_5	7.17	5.25	8.6	8.35	8.30	8.71	2.86	0.87	0.18	4.56	1.42	5.08
LOI	8.89	11.69	34.75	38.75	30.56	31.99	35.07	39.43	39.91	37.17	42.99	35.35
							ppm					
Rb	127	99	21	33	ND	ND	ND	ND	ND	ND	ND	20
Sr	870	2560	6180	7230	ND	ND	ND	N	ND	ND	ND	6420
Y	125	43	132	68	ND	ND	ND	ND	ND	ND	ND	35
Zr	368	872	880	453	ND	ND	ND	ND	ND	ND	ND	1000
Nb	390	301	980	211	ND	ND	ND	ND	ND	ND	ND	591
Ba	1760	260	400	440	ND	ND	ND	ND	ND	ND	ND	648
Ce	2810	701	677	400	ND	ND	ND	ND	ND	ND	ND	558
Nd	1070	346	251	180	ND	ND	ND	ND	ND	ND	ND	226
La	1040	244	282	240	ND	ND	ND	ND	ND	ND	ND	246

XRF analyses, McMaster University

3.3.4 SONGWE SCARP

Location and Access: The Songwe Scarp carbonatite (SSC) lies 17-35 km NW of Mbeya (Fig. 3.2). It is a dike which strikes over approximately 20 km in a NW-SE striking direction. It reaches from 2 km NW of Utengule Mission (N: ^{90}187 E: ^{5}350 on the UTM grid, zone 36) to close the Itega village at N: ^{90}337 E: ^{5}222. Access to the carbonatite dike is good. The dike is exposed in many stream sections at the densely populated foot of the Songwe Scarp. An all weather road leads at the base of the escarpment from Mbalizi via Mshewe to Njelenje and Itega.

Previous Work: Two international mining companies, Anglo-American Corporation and New Consolidated Gold Fields Ltd. prospected parts of the Songwe Scarp carbonatite in 1956/57 mainly for uranium (Special Exclusive Prospecting Licence 824, 825). Detailed mapping was carried out over anomalous zones of the carbonatite, mainly at the 'Mineral Slope' some 2 km NW of Njelenje village. P.E. Brown mapped large parts of the carbonatite dike in 1957. He studied in detail the feldspathized zones and the intrusive bodies (Brown 1962, 1964). Radiometric age determinations of the feldspathization event (100±10 Ma) were conducted by Miller & Brown (1963).

General Geology: The Songwe Scarp carbonatite intruded into a rift fault zone at the foot of the Mbeya Range which is made up of the Proterozoic Ubendian belt. Parts of the rock sequence of the NW-SE striking Ubendian were repeatedly affected by cataclastic deformation, by mylonitisation and phyllonitisation. The NW striking shear zones have been interpreted by McConnell (1972), Brown (1962) and Daly (1986) as weak structural zones which were reactivated during the Irumide (Kibaran) deformation. Ueda et al. (1975) dated strongly sheared rocks of the Mbeya range with 430 Ma, 600 Ma and 610 Ma respectively, ages which represent the early Pan-African thermotectonic reactivation episode.

The floor of the Rukwa rift is covered with Permo-Triassic Karroo, Cretaceous and Neogene sediments. One major event of faulting occurred during a post-Karroo rift event, before mid-Cretaceous. The other event of rift faulting is of post Miocene, mainly Pleistocene age. It is associated with the outpour of the alkaline Rungwe volcanics.

Geology of the Songwe Scarp Carbonatite: The Songwe Scarp carbonatite (SSC) lies in the continuation along strike of the Mbalizi carbonatite (Fig. 3.7), with which it seems to have a common origin. The age of the SSC is 100±10 Ma (Miller and Brown 1963), the age of the Mbalizi carbonatite is 122±28 and 118±9 Ma (Pentel'kov and Voronovsky 1979). Both carbonatites have a different texture and composition. The Mbalizi carbonatite is a coarse-grained sovite, the SSC is a fine-grained ferrocarbonatite (Brown 1964). It is thought that the linear SSC is a part of a dike system which spread from the Mbalizi carbonatite body. Typically, the Songwe Scarp carbonatite is grey-bluish in colour, homogeneous, hard, and breaks with a conchoidal to splintering fracture. It weathers to a yellow and ochreous limonitic mass.

The dike with its average thickness of 50 m intruded the post-Karroo/pre-Cretaceous rift fault over a length of approximately 20 km. The intrusion of the dike had three principal phases. In the first phase the country rock was affected by K-rich fluids resulting in widespread feldspathization. The second phase is the actual injection of the carbonatite dike along the old fault zone. The intrusion is followed by a phase of brecciation manifested by the red 'siliceous breccia' which largely veined and silicified the carbonatite.

Intensive weathering has led to thick accumulations of residual soil over the SSC and feldspathized zones.

Exploration Work: A baseline with 20 km and 700 m long crosslines at 400 m intervals were cut and surveyed geologically, lithogeochemically and geophysically. Additionally, soil samples were collected at selected areas. More than 300 samples were essayed for P_2O_5, several samples were analysed on their major and minor elements. The trace element analyses included the elements Rb, Sr, Y, Zr, Nb, Ba, Ce, Nd, La (Table 3.4).

Results: The survey resulted in the delineation of several portions of the SSC which are relatively rich in primary apatite. Additionally the areas with high radiometric response near the village of Njelenje yielded also higher amounts of Heavy REE and Y. The highest phosphate contents were found in limonitic residual soils overlying the carbonatite. P_2O_5 content reached up to 18-20%, K_2O reached 6%. As pointed out in the agronomic part of this report, this residuum seems to be an agronomically effective resource material.

Assessment: The area around Njelenje is well situated in regard to transportation. Mining is, however, potentially difficult due to the fact that not all ochreous masses along this zone - though similarly looking - are

phosphatic (needs geochemical grade control) and that the zones are relatively thin and at places not easy to mine. The advantage is that the area is close to farming communities and could possibly be worked and utilized on a local scale. The distance to farming areas is 1 - 4 km.

The overall assessment is that the deposit yields a potential only for small scale mining and local application.

Table 3.4 Chemical analyses of rocks from the Songwe Scarp Carbonatite

	PM 150	VS 392	EP 97	PM 140B	VS 351C	PM 65	VS350	VS352	PM172 43	(17) Njelenje	Utengule VS126a	Utengule VS126b
						%						
SiO_2	56.60	30.10	44.98	24.06	18.28	15.77	13.39	56.65	15.34	24.82	23.20	16.77
Al_2O_3	3.06	9.28	1.49	1.29	4.25	2.02	2.58	10.16	4.03	5.97	10.24	6.18
Fe_2O_3	3.84	9.55	4.00	6.33	10.18	9.94	4.84	17.50	10.68	14.52	11.66	10.13
MgO	6.29	4.48	9.04	11.98	9.38	7.70	10.04	0.76	10.167	0.16	1.90	6.67
CaO	11.87	17.24	15.78	21.02	20.86	26..75	29.31	2.84	22.72	25.46	22.56	23.63
Na_2O	0.10	0.07	0.14	0.25	0.00	0.15	0.10	0.28	0.11	0.76	0.04	1.05
K_2O	1.37	7.29	1.59	2.09	5.06	1.88	2.71	2.88	4.75	5.49	6.66	6.07
TiO_2	0.67	2.21	0.37	0.70	1.62	1.43	1.10	2.88	1.27	1.59	2.09	0.82
MnO	0.09	0.16	0.11	0.14	0.20	0.24	0.22	0.14	0.21	0.36	0.13	0.27
P_2O_5	0.09	2.45	0.21	0.10	0.19	7.35	9.89	0.00	0.20	17.75	2.17	3.12
LOI	16.01	17.18	22.30	32.03	29.88	26.77	25.82	5.89	30.54	3.11	19.34	25.29
						ppm						
Rb	19	99	ND	ND	ND	20	23	22	37	74	ND	ND
Sr	1300	590	ND	ND	ND	2470	3010	1130	1715	4610	ND	ND
Y	26	120	ND	ND	ND	350	420	570	18	1243	ND	ND
Zr	324	580	ND	ND	ND	138	195	250	379	989	ND	ND
Nb	181	270	ND	ND	ND	162	155	240	255	395	ND	ND
Ba	58200	1790	ND	ND	ND	3970	430	80400	1150	505	ND	ND
Ce	228	ND	ND	ND	ND	630	440	ND	557	1200	ND	ND
Nd	104	ND	ND	ND	ND	480	120	ND	240	435	ND	ND
La	87	ND	ND	ND	ND	310	270	ND	189	129	ND	ND
Ni										104		
Co										33		
Cr										143		

XRF analyses, McMaster University

3.3.5 SENGERI HILL

Location and Access: Sengeri Hill lies some 7 km NW of Panda Hill, approximately 30 km W of Mbeya, at N: ^{90}098 E: ^{5}210 on UTM, zone 36 (Fig. 3.2). Cross sections of the carbonatite dikes are exposed along the old Tanzania-Zambia highway. The TAZARA railway passes the foot of Sengeri Hill, some 200 m East of the outcropping carbonatite.

Previous Work: Only little work has been done on the Sengeri Hill carbonatite in comparison to the neighbouring Panda Hill. It was mapped in 1952 by Spurr and briefly studied by Fick and van der Heyde (1959) and RUDIS (1980). A strong airborne radiometric anomaly was recorded over Sengeri Hill by Geosurvey (1979).

Geology of Sengeri Hill: The Sengeri Hill consists of two major carbonatite dikes, each 50 - 100 m wide and up to 2 km long. The dikes cut the NW-SE striking gneisses of the Ubendian fold belt at an angle of 50°. The dikes consist mainly of coarse grained dolomitic carbonatite. A breccia with rounded and angular fenitized basement fragments in a ferro-carbonatite matric occurs at the southeastern margin of the dike. Thin late stage fluorite veins cut both the carbonatite and the fenites.

Field Work: The semi-detailed work at Sengeri Hill included geological mapping at a scale 1:1000, a lithogeochemical and soil survey and subsequent pitting (Fig. 3.8). A total of 163 rock and soil samples were collected including soil samples from six pits in residual soils.

Results: Except three rock samples with high phosphate content (up to 22% P_2O_5) all rock samples analysed lower than 6% P_2O_5. The soils analysed lower than 4% P_2O_5. The soil samples and the pit samples yielded only low to very low phosphates. Commonly the samples analysed below 1% P_2O_5 (Table 3.5).

Assessment: The phosphate content of most rocks and residual soils was found to be too low to warrant any follow up work. Consequently the work at this prospect was discontinued.

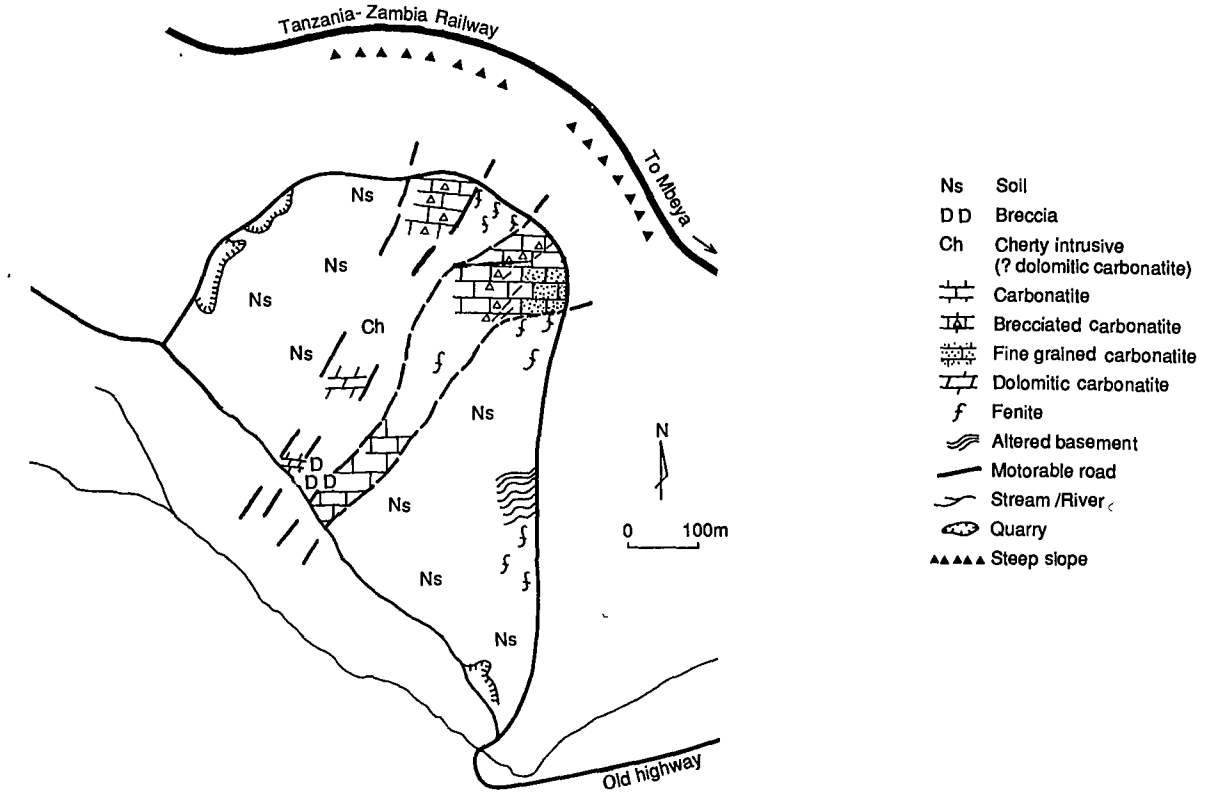

Fig. 3.8 Geology of part of the Sengeri Hill carbonatite.

Table 3.5 Chemical analyses of rocks from the Sengeri Hill carbonatite

	EP504	EP500	EP505	VS417	VS419A	EP501	VS 419B	VS 8511-10
					%			
SiO_2	0.34	2.39	1.61	3.47	3.41	13.22	10.85	18.92
Al_2O_3	0.05	0.65	0.41	0.44	0.22	0.47	1.2	5.1
Fe_2O_3	5.34	8.85	6.74	9.20	4.05	4.99	9.31	7.64
MgO	13.56	17.62	16.80	15.11	10.40	14.54	12.03	11.39
CaO	36.30	31.77	28.94	28.66	37.07	26.68	26.22	22.00
Na_2O	0.09	0.06	0.08	0.60	0.35	0.04	0.1	0.12
K_2O	0.06	0.26	0.30	0.23	0.13	0.04	1.24	4.36
TiO_2	0.00	0.07	0.02	0.03	0.04	0.39	0.48	0.76
MnO	0.80	0.97	1.00	1.07	0.71	0.48	0.49	0.42
P_2O_5	8.78	0.24	3.30	0.08	22.06	4.18	4.14	0.25
LOI	34.64	37.10	40.80	41.10	21.54	34.98	33.94	29.04
				ppm				
Rb	ND	5	9	10	3.0	6	17	87
Sr	ND	1760	3480	3250	5030	1560	6250	5800
Y	ND	30	50	14	320	33	26	33
Zr	ND	1190	1480	145	270	499	1350	1080
Nb	ND	74	96	105	42	276	227	648
Ba	ND	74600	1355	650	1560	9700	2690	2050
Ce	ND	4260	730	470	750	883	893	895
Nd	ND	2310	314	475	840	388	446	311
La	ND	200	435	9100	1360	488	443	603

XRF analyses, McMaster University

	34	38	33	32	37	35	39	36	40
					%				
SiO_2	40.17	36.27	22.02	18.13	11.39	8.74	4.97	0.41	1.91
Al_2O_3	12.20	12.46	8.41	5.46	3.08	0.04	1.05	0.11	0.12
Fe_2O_3	12.81	6.77	8.02	9.38	9.89	8.47	8.50	8.26	5.55
MgO	5.65	6.50	12.17	13.51	2.71	17.76	17.82	19.45	19.65
CaO	6.80	11.84	14.55	18.89	37.30	24.89	27.17	27.81	27.91
Na_2O	0.52	0.05	0.04	0.05	0.04	0.04	0.04	0.04	0.00
K_2O	9.20	7.95	7.53	3.66	2.57	0.02	0.70	0.05	0.04
TiO_2	1.24	0.29	0.08	0.28	0.19	0.00	0.14	0.00	0.06
MnO	0.24	0.42	0.57	0.60	0.52	0.78	0.83	1.02	0.66
P_2O_5	0.31	0.22	0.01	1.00	0.00	0.00	0.00	0.00	10.91
LOI	10.86	17.23	26.57	29.03	32.29	39.21	38.76	42.82	33.61

XRF analyses, McMaster University

3.3.6 MUSENSI

Location and Access: Munsensi Hill forms a prominent hill some 42 km in direct line West of Mbeya. (UTM zone 36, N: ^{90}138, E: ^{5}058) (Fig. 3.2). The area can be reached on motorable tracks from the main Mbeya-Tunduma highway during the dry seasons. During the rainy seasons one has to follow secondary roads and tracks via Mlowo and Mantenga.

Exploration History: The area was studied in detail by New Consolidated Gold Fields Ltd. in 1956/57 (SEPL 138). The company prospected for niobium and precious and base metals. They carried out a geological survey, a radiometric survey, trenching and finally drilling of 3 boreholes, totalling approximately 433m.

General Geological Setting: Musensi Hill is made up of volcanic rocks. The volcanics intruded into NW-SE striking rock sequences of the Ubendian fold belt, which in this area is mainly made up of quartzofeldspathic garnet gneisses and pyroxenites. Shear zones occur parallel to the structural grain of the Ubendian. The Musensi volcanics are probably associated with rift valley tectonics and igneous events. They occur approximately 10 km West of the western escarpment of the Rukwa rift valley and approximately 21 km WNW of the Panda Hill carbonatite.

Geology of the Musensi Complex: Musensi Hill is mainly made up of weathered volcanic rocks. Plugs and vents of strongly feldspathic volcanic rocks are observed, as are agglomerates and tuffs. Geologists from New Consolidated Gold Fields Ltd. recognized most of these rocks as porphyritic rhyolites. This is probably an incorrect identification. The volcanics are intruded by a red carbonatite. The present level of Musensi Hill exposes the top of the carbonatite intrusion. New Consolidated Gold Fields Ltd. delineated the carbonatite in the boreholes close to the centre of the volcanics. Our team discovered a small outcrop of red carbonatite 100 m S of one of the borehole sites.

Present Exploration Work: Project geologists conducted geological mapping at a scale of 1:5000 and collected rock and soil samples along grid lines with 100 m spacings. MADINI geophysicists carried out a detailed radiometric survey along the above mentioned grid lines. Radiometric readings were made at 25 m intervals, with data collection from 891 stations.

Results: The lithogeochemical and soil surveys over Musensi Hill revealed no anomalous zones in regard to phosphates (Table 3.6). All analyses remained under 1% P_2O_5. The red carbonatite seems to be a late stage ankeritic carbonatite, low in primary P_2O_5 content. The K_2O content of the porphyritic "feldspar rock" is relatively high with up to 14% K_2O. The geophysical work revealed strong radiometric anomalies, mainly over or close to the volcanic vents.

Assessment: No further phosphate exploration work is planned in the Musensi area, as the potential of finding sizeable phosphate accumulations is very low. The feldspathic rocks forming most of Musensi Hill could be considered as a possible K-source. However, the K-solubility of these rocks are likely to be very low as the K occurs in K-feldspaths.

Table 3.6 Chemical analyses of rocks from the Musensi complex

	320	321	322
		%	
SiO_2	40.88	61.83	61.85
Al_2O_3	13.04	18.08	17.95
Fe_2O_3	8.78	3.18	3.16
MgO	2.70	0.02	0.02
CaO	11.66	0.06	0.09
Na_2O	0.28	0.43	0.47
K_2O	7.12	14.60	14.05
TiO_2	0.74	0.48	0.49
MnO	0.45	0.14	0.09
P_2O_5	0.67	0.12	0.23
LOI	13.68	1.06	1.60
		ppm	
Rb	285	ND	ND
Sr	2310	ND	ND
Y	12	ND	ND
Zr	276	ND	ND
Nb	127	ND	ND
Ba	3050	ND	ND
Ce	1790	ND	ND
Nd	580	ND	ND
La	1160	ND	ND

XRF analyses, McMaster University

3.3.7 NACHENDEZWAYA

Location and Access: The Nachendezwaya carbonatite is situated in the Mbeya region, 10 km south of Itumba, the capital of Ileje district (Fig. 3.2). On the Universal Transverse Mercator Grid, Zone 36, the carbonatite is situated at N: ^{89}506 and E: ^{5}220. The deposit can be reached by following the all weather Mpemba-Itumba road to Isongole, then on a 1 km motorable track from Ilulu to the site.

Previous Work: D. Garlick, from New Consolidated Gold Fields Ltd. discovered the carbonatite in 1958. It was investigated again by R.G. Horne (1959), and mapped by A. MacFarlane in 1974 during regional mapping of QDS 258 (Itumba). Detailed investigations to determine the primary phosphate potential was done by RUDIS in 1978/79.

General Geological Setting: The alkaline complex of Nachendezwaya occurs within the NW-SE trending gneisses of the Ubendian System. It occurs close to the NW-SE shear zone system into which the Mbozi syenite-gabbro complex intruded and the synenite complex of Ilomba in Malawi which lies approximately 3 km from Nachendezwaya in a SW direction.

Geology of Nachendezwaya Complex: The Nachendezwaya complex is an elongate alkaline intrusive body with a carbonatite forming the central part. The axis of elongation of the complex is parallel to the regional strike (NW-SE) of the Ubendian gneisses. The foliation of the carbonatite strikes NW-SE with a steep dip towards the NE. The total length of the carbonatite is 400 metres, the thickness varies from 90 m (for the first 150 m length on the NW side) to 25 m.

The carbonatite is an apatite bearing sovite (Table 3.7). Accessory minerals are biotite, plagioclase and Fe-minerals. The Nb_2O_5 content is very low with O.03%.

Field Work and Results: Residual soils overlying the apatite bearing carbonatite were the prime targets of our survey in this area. Subsequently we carried out a soil survey along a 150m X 20m grid, with the base line running parallel to the long axis of the carbonatite i.e. 145°. Soil and rock sampling was done along the established grid covering an area of 0.225 km^2. After samples had been analysed and results plotted, pits were located in areas with high P_2O_5 content. A radiometric survey using URTEC UG 135 differential Gamma Ray Spectrometer was also conducted along the same grid.

Soil P_2O_5 analyses show that relatively high P_2O_5 values (above 8%) occur in soils overlying the carbonatite and at contact zones between the carbonatite and the foyaite. Pits located in areas with high P_2O_5 content showed that P_2O_5 content decreases with increasing depth.

The radiometric survey revealed high total counts over the whole carbonatite.

Only the residual soils were considered a realistic target for possible small scale phosphate mining. Consequently estimates of P_2O_5 reserves were based only on the soil sample analyses. The 5% P_2O_5 isoline was taken as the lower limit grade. To estimate the tonnage of the phosphatic soil we eliminated the area occupied by the carbonatite rock and took the average thickness of the soil cover to be 0.5m. The calculated tonnage is 43,485 t at >5% P_2O_5, too little to be of economic interest.

Liming Material: The carbonatite of Nachendezwaya forms a large resource of liming material. RUDIS (1980) estimated the carbonate resource to be approximately 5.1 million tonnes.

Conclusion: The Nachendezwaya carbonatite is not a feasible resource for small scale phosphate mining because of the low grade and small volumes of the residual soils. However, the primary rock should be viewed as potential resource as liming material.

Table 3.7 Chemical analyses of rocks from the Nachendezwaya carbonatite

	I	II	III
		%	
SiO2	0.45	0.23	2.93
Al_2O_3	0.03	0.02	0.12
Fe_2O_3	1.66	2.06	4.36
MgO	4.83	7.10	3.10
CaO	49.71	46.57	46.72
Na_2O	0.04	0.05	0.07
K_2O	0.01	0.01	0.01
TiO_2	0.02	0.01	0.10
MnO	0.25	0.34	0.27
P_2O_5	2.85	0.07	12.10
LOI	40.15	43.54	30.01
		ppm	
Rb	1	1	1
Sr	4230	4205	1050
Y	10	10	6
Zr	163	161	308
Nb	7	7	19
Ba	377	348	299
Ce	287	240	200
Nd	85	81	77
La	290	195	78

XRF analyses, McMaster University

3.3.8 ZIZI

Location and Access: The Zizi "apatite-carbonate deposit" lies remotely in the northern part of the Selous Game Reserve in Morogoro District (Fig. 3.9). In direct line it is approximately 110 km S of Morogoro. The position of the centre of this elongated lens is, on the Universal Transverse Mercator Grid, UTM Zone 37, at N: $^{91}312$ E: $^{3}375$.

Access is very difficult. A secondary road leads from Morogoro to Kisaki (120 km) where a rough motorable track runs along the TAZARA railway to Lumango Station. An old track, largely overgrown, leads from Lumango to the Ruaha River. From this point the deposit is more than 20 km distant in a westerly direction, and can only be reached by foot.

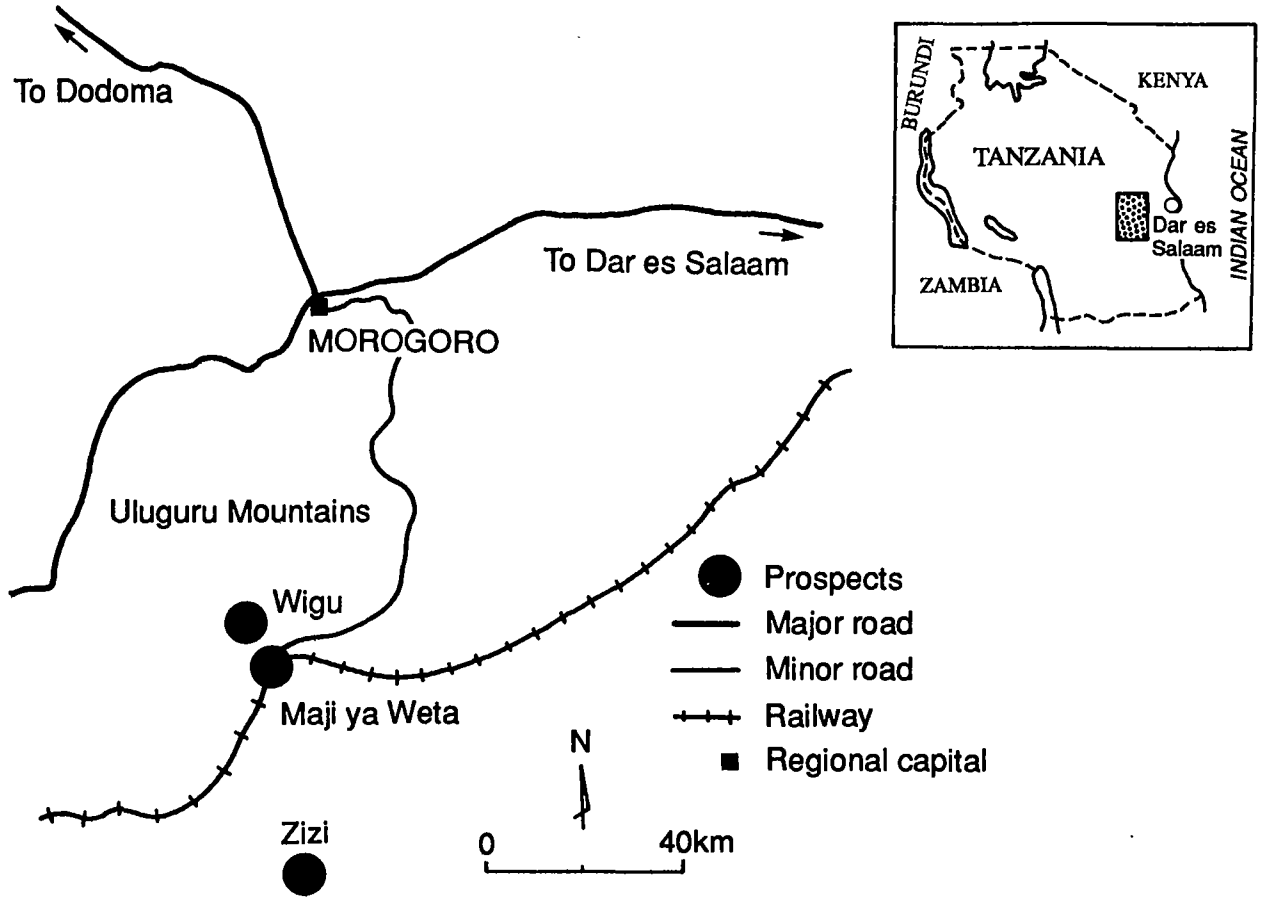

Fig. 3.9 Phosphate prospects in the Morogoro region.

Previous Work: The Zizi "apatite limestone" was discovered in 1931 by Stockley. He revisited the occurrence in 1945 and made a first reserve estimation: 2 million tons to a depth of 100 feet, average grade 6.9% P_2O_5. Stockley interpreted these apatite bearing rocks as metamorphosed phosphatic sediments. Geologists from the State Mining Corporation (STAMICO) and the Yugoslav company RUDIS studied the mineralization again in 1979 and interpreted the "apatite limestone" as being a carbonatite, probably of the same age as Wigu Hill and Maji ya Weta. RUDIS reported 1 million tonnes of this phosphate bearing "carbonatite" to a depth of 20 m. The average grade was estimated with 4.4% P_2O_5.

Geology of Zizi: Zizi lies South of the Uluguru Mountains which are made up of mainly high grade metamorphic rocks of the Usagaran. The apatite-carbonate rocks occur in the form of a 30 x 1100 m lens conformable with a metamorphic rock suite of Proterozoic age. The country rock close to the apatite-carbonate rocks include biotite and biotite-garnet gneisses, biotite-apatite schists, and biotite-apatite-calcite rocks. Pegmatites crosscut the metamorphic sequence. Stockley describes pegmatites also crosscutting the apatite-carbonate rocks. The phosphatic rocks show a clear foliation, striking at 110°.

The apatite-carbonate rocks are coarse grained and light greyish in colour. Accessory minerals in the calcite matrix are micas, apatite and, in places, feldspar. The apatite crystals are 3-5 mm in size and bluish-greenish in colour.

A nepheline bearing biotite foyaite (RUDIS 1980) occurs at the southwestern margin of the phosphatic lens between the biotite gneisses and the apatite- carbonate rock. It is largely because of this undersaturated, alkaline rock that RUDIS (1980) interpreted the Zizi rocks as carbonatite.

Field Work and Results: The Zizi apatite-carbonate rock was visited in October '87 by two project geologists and a technician. Twenty-five rock and soil samples were collected at 10 m interval across the body and analysed for their P_2O_5 content in the field laboratory. A few analyses of selected rocks were conducted in Canada (Table 3.8). The analytical results of the rock samples vary considerably, the highest phosphate content being 11.3% P_2O_5 in an apatite-carbonate rock. A biotite/phologopite- apatite rock close to the apatite-carbonates contains 8.66% K_2O.

The soils overlying the apatite-carbonate sequence show also a considerable variation in P_2O_5 contents, the highest results being 7% and the lowest 0.5% P_2O_5 respectively. The trace element distribution shows high Sr values. The Rare Earth values are very low, which is atypical for carbonatites.

Assessment: The Zizi apatite-carbonate rock suite occurs in a remote area. Access is very difficult. The area lies in a game reserve and therefore labour is not available. Furthermore, it would be very difficult to obtain permission to work a deposit in this protected area. The practical problems of access and labour clearly limit the potential of this occurrence.

However, in order to get more resource data and to understand the nature of this unique occurrence some limited follow up, not exceeding two weeks, is recommended.

Table 3.8 Chemical analyses of rocks from Zizi

	323	324	325
		%	
SiO_2	1.95	0.43	37.22
Al_2O_3	0.18	0.09	12.65
Fe_2O_3	1.89	2.86	12.50
MgO	2.63	13.13	20.37
CaO	49.17	37.20	3.06
Na_2O	0.14	0.07	0.07
K_2O	0.13	0.03	8.66
TiO_2	0.00	0.00	0.99
MnO	0.35	0.36	0.15
P_2O_5	3.50	11.33	2.41
LOI	40.06	34.47	1.91
		ppm	
Rb	10	10	390
Sr	7140	2860	235
Y	74	9	44
Zr	293	128	26
Nb	3	4	146
Ba	280	172	660
Ce	199	159	162
Nd	63	68	78
La	180	110	132

XRF analyses, McMaster University

3.3.9 WIGU HILL

Location and Access: Wigu Hill is a prominent double peak hill at the southern end of the Uluguru Mountains, at N: ^{91}813 E: ^{3}408 on the Universal Transverse Mercator Grid, Zone 37 (Fig. 3.9). Wigu Hill rises approx. 600m above the level of the plains near Kisaki. The foot of the mountain can be reached by a secondary road from Morogoro to Kisaki Gomero (~ 120 km), and by motorable track from Kisaki Gomero to Nyarutanga village (~ 4km). The mountain slopes are steep, the top of the mountains and many river sections are covered by dense vegetation.

Previous Work: Wigu Hill was identified as carbonatite by T.C. James in 1955 and subsequently studied for its Rare Earth potential by New Consolidated Gold Fields in 1956 and 1957.

General Geological Setting: The Uluguru mountains are made up of highly metamorphosed rocks of early Proterozoic (Usagaran) age. The Wigu carbonatite intruded into Ubendian pyroxene granulites and pegmatites. It intruded into a structurally weak position, the intersection of a major E-W striking fault with a set of NE-SW striking faults. The age of these faults are considered early Karroo.

Geology of the Wigu Hill Carbonatite Complex: The Wigu Hill carbonatite is not a single carbonatite body or plug but rather consists of a large number of carbonatite dikes which invaded and partially altered the enclosing basement rock. The strike of these dikes is not consistent. At places the dikes form a kind of stockwork.

Several breccia dikes were observed at the southwestern part of Wigu Hill. The breccia contain basement fragments in a carbonate matrix. Most of the carbonatite dikes are made up of a fine grained greyish carbonatite, resembling very much the ferro-carbonatite of the Songwe Scarp carbonatite (Mbeya region). Economically interesting are the Rare Earth rich bastnaesite-monazite dikes in the centre (the top) of this complex. The REO content reaches 16.3% total REO (New Consolidated Gold Fields, 1957).

Field Work and Results: In 1987 two reconnaissance surveys were carried out at Wigu Hill, the first in June and the second in October 1987. A total of 23 representative rock and soil samples were collected and analysed for their P_2O_5 content. In regard to phosphates the results were disappointing, none of the samples reaching values higher than 4.5% P_2O_5, most of them below 1.0% P_2O_5. Two analyses of the Rare Earth rich dike at the top of Wigu Hill indicated 12.06% and 9.34% LREO (Table 3.9).

Assessment: Based on the results of the phosphate survey no further agromineral exploration is recommended. The prospect bears, however, a good potential for REE mineralisation.

Table 3.9 Chemical analyses of rocks from the Wigu Hill carbonatite

	283	284	326	327
			%	
SiO_2	7.40	70.97	84.93	30.11
Al_2O_3	0.42	1.70	0.90	0.94
Fe_2O_3	8.61	3.06	4.41	2.50
MgO	15.75	1.20	0.42	2.75
CaO	28.67	11.19	1.79	38.62
Na_2O	0.19	0.11	0.15	0.06
K_2O	0.08	1.58	0.00	0.03
TiO_2	0.00	0.03	0.04	0.04
MnO	1.49	0.06	0.91	0.27
P_2O_5	0.28	0.12	1.53	1.65
LOI	37.09	9.98	4.89	23.01
			ppm	
Rb	3.7	25	2	2
Sr	3060	426	1330	3260
Y	39	24	7	10
Zr	350	145	72	182
Nb	152	23	5	4
Ba	13700	620	104000	69000
Ce	7760	150	37400	47500
Nd	2090	46	9890	12500
La	5470	76	30800	40800

XRF analyses, McMaster University

3.3.10 MAJI YA WETA

Location and Access: The Maji ya Weta hills form a hill group in the southern part of the Uluguru mountains of Morogoro District (Fig. 3.9). The hills rise approximately 300 m above the surrounding plains. They are located 5 km SW of Kisaki railway station, at N: ^{91}689 E: ^{3}435 on UTM zone 37. The hills can be reached from a secondary road which parallels the Tanzania-Zambia railway line.

Previous Work: Bornhardt (1900) discovered the hot springs at the foot of Maji ya Weta, but it was only in 1953 that T.C. James studied the Maji ya Weta carbonatite dikes during comprehensive carbonatite investigations.

General Geological Setting: Maji ya Weta carbonatite dikes intrude banded pyroxene granulites and pegmatites of Proterozoic age. They occur at a structurally weak position, close to a site where a change of direction (NE-SW to E-W) of a major block fault occurs. The age of block faults in this area is uncertain, Sampson and Spence (1964) regard them as early Karroo, Kreuser (1984) suggests a syn-Karroo to Middle Jurassic age.

It might be of significance that the volcanic vents, dikes and plugs (some possibly carbonatitic) located approximately 30-50 km SE of Maji ya Weta, at the Rufiji River, have a general strike direction of 135± 10° (Kreuser, 1984), a general strike which is also prevalent at Maji ya Weta. The carbonate - rich volcanics of Rufiji are interpreted by Kreuser (1984) as being intruded into an extensional stress field of possible lower Jurassic age.

Hot springs occur close to the foot of Maji ya Weta hills at a fault controlled, structurally weak position.

Geology of the Maji ya Weta Carbonatite Complex: Like the adjacent Wigu Hill carbonatite, Maji ya Weta is not a single carbonatite body or plug. It is made up of a great number of narrow carbonatite dikes, rarely exceeding 0.5 m in width. The dikes across the gneisses and pegmatites are aligned in a general direction of 140°.

A coarse breccia (basement fragments in carbonatite matrix) is exposed at the western part of Maji ya Weta hills (at N: ^{91}694, E: ^{3}426). The breccia is probably a volcanic breccia indicative of an explosive phase during the carbonatite igneous episode. The breccia is cut by fine grained carbonatite dikes.

Field Work and Results: In four geological traverses (two in June and two in October 1987) some 26 soil and rock samples were collected. They were subsequently analysed in the project phosphate field laboratory. The analytical data of these samples are generally low (below 3% P_2O_5) the highest P_2O_5 values (4.7% P_2O_5) come from a thin fine grained greyish-bluish dike rock.

Assessment: Analytical data from rocks and soils representing the Maji ya Weta carbonatite dikes and residual soils are too low to justify any detailed follow up work for phosphates. However, the dike system should be checked for its REE potential.

3.3.11 MBOZI SYENITE-GABBRO COMPLEX

Location and Access: The Mbozi syenite-gabbro complex is situated approximately 5 km SW of Vwawa, the capital of Mbozi District, Mbeya Region (Fig. 3.2). The centre of the complex lies approximately at N: $^{89}900$ E: $^{4}815$ on the Universal Transverse Mercator grid, UTM zone 36. The Mbozi complex is crossed by the Tanzania-Zambia highway. It is easily accessible from the highway by various secondary roads and motorable tracks.

Previous Work: The complex was geologically surveyed by A.M.M. Spurr in 1950-51. Detailed work on the complex was done by P.W.G. Brock in 1961-63. His Ph.D. thesis is based on this detailed investigation. A. MacFarlane re-visited the area in 1963 as part of regional mapping of Quarter Degree Sheet 257,Tunduma.

Geology of the Complex: The Mbozi syenite-gabbro complex intrudes the NW-SE striking Ubendian fold belt which is made up mainly of gneisses and amphibolites here. Furthermore, the area is characterized by widespread shearing and mylonitisation. It seems probable that these northwest shear zones largely controlled the emplacement of the gabbroic and alkaline rock suites. The age of the complex is late Proterozoic, K:Ar determinations yielded an age of 755±25 Ma (Cahen & Snelling 1966).

The Mbozi complex is a NW to SE striking elongate body (30 x 12 km) of basic and alkaline syenite intrusive rocks with a ring structure in the central zone. The centre of the complex is a layered gabbro which was deformed and faulted prior to the intrusion and metasomatism of the later alkaline rocks. The central ring structure is an oval shaped faulted belt (approx. 3.5 x 5.5 km in size) made up of nepheline bearing medium to coarse grained rocks. Their composition varies from gabbro through intermediate types of syenite, nepheline-syenite, to melteigite and ijolite. Towards the margins of the whole complex and on either side of the ring structure the basic rocks are progressively metasomatised and altered by later alkaline material. The marginal parts of the complex are predominantly intrusive although at the contact with the country rocks there is evidence of metasomatic alteration. Nepheline bearing gneisses outcrop mainly in the SE and are conformable with and grade into the country rock.

Field Work and Results: Field work was geared towards finding potentially apatite rich zones in this alkaline syenite complex by analogy to a similar occurrence in Zambia, and the possible finding of an apatite bearing carbonatite as in Burundi (Tack et al., 1984).

However, lithogeochemical and soil surveys and geological work on targets related to airborne magnetic and radiometric anomalous zones near the complex revaled no apatite-rich zones. Soil and rock samples contained only very little P_2O_5 (soils: 0.2 - 2.5% P_2O_5, rocks: 0.1 - 0.8% P_2O_5).

Conclusion: Lithogeochemical and soil surveys and additional geological and radiometric surveys revealed no apatite mineralization and the prospect was dropped.

3.3.12 CHAMOTO

Location and Access: The Chamoto phosphate and zeolite occurrence lies in the Usangu (Buhoro) flats north of the Chimala-Elton mountain range (Fig. 3.2). The occurrence lies approximately 2 1/2 km N of the village of Igurusi, which is a local trade centre at the intersection of the Tanzania-Zambia highway leading to Mbeya and TAZARA and the N-S running road to Utengule (N: ^{90}270 E: ^{5}932, on UM zone 36). The phosphate occurrence lies between a small but prominent flat lying mesa, Chamoto hill, and the Luwanji river. The zeolite occurrence lies at the northern banks of Luwanji river, south of Chamoto Hill. Access to the occurrences is good, as they lie only a few hundred metres W of the Utengule-Igurusi road.

Previous Work: Slightly radioactive nodules of 'chert' were discovered by W.R. Williams in the early 1960's. Subsequent field and laboratory work of Guest (1954) and McKie (1958) concentrated on a few isolated patches of radioactive phosphate fragments in a serious of pyroclastic rocks. Also the detailed mapping and radiometric survey of Harris (1958) could not delineate a continuous bed of phosphate.

General Geological Setting: The Chamoto lacustrine basin lies in the downfaulted rift floor 3-10 km North of the E-W striking rift scarp fault. The sediments of Chamoto are part of a larger lake deposit of probably Pleistocene age. These lacustrine deposits with an approximate extent of 25 x 6 km stretch along the southern end of the Usangu (Buhoro) rift valley floor. The thickness of the exposed sequence is approximately 20-30 m. The deposits are mainly waterlain tuffs, clastic sedimentary intercalations, and at places cherts and phosphorites.

The lake beds are capped at places by coarse volcaniclastic and lavas, and by recently deposited colluvium and alluvium.

Geology of Chamoto: The lithological sequence exposed in the Chamoto area can be divided into two principal units: the lake bed sequence and the overlying coarse volcaniclastic succession. The lake beds are made up of zeolitic tuffs (with chabazite as the main zeolite mineral) and intercalating claystones. The tuff sequence is overlain by pale green bedded cherts and magadi-type reticulated nodules, which presumably formed from sodium silicate precursors in alkaline environments (Eugster 1966). The volcaniclastic series overlying the lake beds is made up of a series of coarse pyroclastic breccia, agglomerates and lapilli-tuffs, probably originating from nearby explosive volcanic activity.

The phosphorites are whitish to cream in colour and commonly stained with Mn-oxides. The shape of the phosphorites varies from coarsely layered to irregular and concretionary. Nodular phosphorites exhibit structures resembling desiccation cracks.

The phosphoritic materials occur in two different positions of the Chamoto sequence:

1. as 10-60 cm cherty phosphorite layers and irregular shaped phosphorite concretions at the interface between the lower lake bed sequence and the upper coarse pyroclastic series.

2. as irregular shaped fragments within the lower part of the coarse volcaniclastic sequence.

Present Exploration Work and Results: The area around Chamoto was surveyed in detail by a project geologist during parts of the 1985 and 1986 field seasons. The survey included geochemical soil sampling and radiometric profiling along 10 grid lines, 50 m apart. Additionally, 10 trenches and 5 pits were dug and sampled. Altogether more than 150 rock and soil samples were analysed for P_2O_5 and more than 500 radiometric stations measured. The survey of this area shows the existance of a continuous 0.1 - 0.6 m thick phosphorite bed analysing 16-36% P_2O_5 (Table 3.10). The bed is steeply dipping and can be followed for approximately 350 m. The reserve figures to a depth of 10 m is in the range of 2000-3000 tonnes only.

Assessment: The phosphorite bed at Chamoto is of no economic value due to the low reserve base.

Table 3.10 Chemical analyses of phosphatic rocks from Chamoto and Maherera

	Chamoto								Maherera	
	18	19	20A	20B	21A	21B	22A	22B	23	24
						%				
SiO_2	20.00	16.55	8.99	43.56	18.78	20.76	33.72	25.29	11.71	24.53
Al_2O_3	4.65	4.30	2.38	4.29	5.46	5.84	9.32	6.95	3.68	7.31
Fe_2O_3	0.72	01.59	0.62	0.53	1.18	1.35	1.72	1.57	0.65	1.39
MgO	0.05	0.13	0.14	0.17	0.35	0.28	0.27	0.16	0.16	0.37
CaO	40.35	42.20	48.98	27.87	39.40	36.11	27.17	33.10	46.43	37.12
Na_2O	0.25	0.21	0.29	0.38	0.43	0.40	0.53	0.35	0.26	0.88
K_2O	3.65	2.82	0.34	3.05	3.56	3.91	6.15	4.80	0.38	1.59
TiO_2	0.09	0.06	0.06	0.06	0.11	0.12	0.20	0.15	0.07	0.17
MnO	0.00	0.02	0.01	0.00	0.19	1.45	0.34	1.89	0.06	0.06
P_2O_5	28.65	30.63	35.58	18.28	17.25	4.10	17.95	22.45	33.34	23.80
LOI	1.58	2.48	2.59	1.79	13.29	25.68	2.62	3.29	3.26	2.78
					ppm					
Rb	ND	ND	ND	103	104	105	ND	ND	ND	55
Sr	ND	ND	ND	140	296	448	ND	ND	ND	623
Y	ND	ND	ND	36	63	60	ND	ND	ND	218
Zr	ND	ND	ND	190	197	168	ND	ND	ND	292
Nb	ND	ND	ND	82	65	86	ND	ND	ND	74
Ba	ND	ND	ND	15	496	1780	ND	ND	ND	460
Ce	ND	ND	ND	31	37	53	ND	ND	ND	265
Nd	ND	ND	ND	3	30	24	ND	ND	ND	85
La	ND	ND	ND	3	90	45	ND	ND	ND	220
Ni				<1	<1	<1				15
Co				<1	<1	<1				<1
Cr				<1	<1	<1				<1
V				10	18	42				23
Zn				35	44	58				31
Cu				3	3	3				4
Pb				10	12	14				12

XRF analyses, McMaster University

	Chamoto				
	VOLCANICS		ZEOLITIC TUFFS		
	18	19	185	186	188
			%		
SiO_2	56.88	53.25	52.10	51.80	53.97
Al_2O_3	21.56	20.26	18.61	18.24	20.18
Fe_2O_3	3.55	3.28	3.64	3.54	3.58
MgO	1.23	0.07	1.09	1.09	1.26
CaO	1.09	1.33	2.21	2.31	1.66
Na_2O	1.44	2.52	2.82	2.84	2.05
K_2O	5.42	6.49	5.50	6.05	4.77
TiO_2	0.42	0.39	0.49	0.48	0.33
MnO	0.01	0.07	0.16	0.11	0.06
P_2O_5	0.22	0.16	0.22	0.20	0.07
LOI	8.18	12.18	13.18	13.34	12.06

XRF analyses, McMaster University

3.3.13 MAHERARA

Location and Access: The phosphate occurrence of Maherera lies in the Usangu Flats north of the Chimala-Elton mountain range and the Chimala scarp fault (Fig. 3.2). The phosphate bed is found in a river section of Maherera river some 6 km NE of the village of Itamboleo, ~ 70 km East of Mbeya, at N: $^{90}292$ E: $^{6}062$ on the Universal Transverse Mercantor Grid, zone 36. Access from Itamboleo to the area is difficult and possible only by using local logging roads and animal tracks. Itamboleo itself lies at the main Tanzania-Zambia highway and the TAZARA railway.

Geology of Maherera: The general geology of this area is described in the chapters on Chamoto and Shingo. The sedimentary sequence exposed at Maherera is part of the lacustrine succession of the 'Buhoro' paleo-lake and is characterized by flat lying layers of fluvio-terrestrial conglomerates, coarse cross-bedded tuffaceous sands and well laminated tuffaceous silt and mudstones. Interlayered with one of the mudstone beds is a 10-20 cm thick whitish calcareous phosphorite bed which analysed 16-33% P_2O_5. This bed is at places concretionary and thins out towards the north after approximately 900 m. A small bone fragment of an undeterminable animal was found in this thin layer.

Geological Field Work and Results: This Maherera phosphate bed was discovered in 1985 by project geologists during a geological and geophysical (radiometric) survey of the lacustrine sediments of the 'Buhoro' paleo-lake. The grade of this very thin phosphatic bed is between 20 and 33% P_2O_5 (Table 3.10). The ensuing detailed studies of the lake bed succession revealed no other exposed phosphatic layers in this area.

Assessment: The phosphate bed of Maherera is too thin and of too small extent to be of economic value.

3.3.14 SONGWE (SUKUMAVERA) BAT GUANO CAVES

Location and Access: The Songwe or Sukumavera bat guano caves lie approximately 40km W of Mbeya in the Rukwa rift at N: ^{90}173 E: ^{5}226, UTM.

Previous Work: Bat excrements from the Sukumavera or Songwe guano caves have been exploited since 1934. Guano production for local agricultural use reached a total of 3223 tonnes for the period 1934 - 1957 (Harris 1981). Semi-detailed geological investigations have been carried out by Teale and Oates (1935) and Spurr (1954).

General Geological Setting: The Songwe caves occur close to the Songwe River in extensive 20-40 m thick horizontal travertine formations which cover the Creataceous red sandstones in the Rukwa rift valley floor. The travertines are precipitates of Pleistocene hot spring activities. The area exhibits karst topographies, the caves were formed by chemical weathering. The solution cavities reach at places 10 - 15m in height. The direction of the caves follow a pattern closely related to the joint system.

Present Exploration Work and Results: The caves were reinvestigated not only to assess the tonnage of the loose guano covering the cave floors and the tonnage of material from the leaching zone underlying the loose guano, but also to check for accumulations of possiple phosphate precipitates in solution channels and horizontal joint fillings below the caves.

The survey involved mapping of the caves and geochemical sampling inside and outside the caves. In total 182 samples were analyzed from this area on their P_2O_5 content. The results indicate very low reserves (few hundred tonnes only) of good grade material (26-37% P_2O_5).

Assessment: The prospect was dropped due to low reserves of easily accessible guano depositions.

3.4 ZEOLITE PROSPECTS

3.4.1 SHINGO

Location and Access: Shingo Hill is a gentle hill in the Usangu Flats north of the Chimala-Elton mountain range (Fig. 3.2). The coordinates of Shingo Hill on the Universal Transverse Mercator Grid, zone 36 are N: ^{90}978 E: ^{5}948. Access to Shingo is good as several motorable tracks cross this agriculturally cultivated area. The hill lies 3 1/2 km NNE of of Igurusi village, which is a local trading centre lying at the intersection of the E-W running Tanzania-Zambia railway (TAZARA) and highway and the N-S access road to the Usangu farms.

Previous Work: Shingo Hill was mapped as phonolite during regional mapping of map sheet 245(Harpum 1953) . No zeolites have been reported from the whole area as yet.

General Geological Setting: Shingo lies in the down faulted rift floor of the NE-SW striking Usangu rift. The area is characterized by high Proterozoic mountain ranges in the south and, down faulted by approximately 800 m, the rift floor which is covered by a shallow blanket of terrestrial and lacustrine sediments. A number of volcanic plugs and domes occur aligned in E-W direction parallel to the southern fault scarp. These volcanics of probably Plio-Pleistocene age (Harkin 1960) partially overly tuffs and lacustrine sediments. The sediments were deposited in lake environments which were at times alkaline.

Geology of the Shingo Hill Chabazite Occurrence: At Shingo Hill an approximately 20 m thick sequence of flat lying tuffs and agglomerates is exposed. They are capped by a few metre thick phonolite flow.The sequence is made up of coarsely layered pebbly agglomerates at the bottom of the hill, followed by volcaniclastics which at the top grade into fine-grained whitish zeolitized tuff-beds. The zeolitic (chabazite) tuff-bed is approximately 2 - 2.5 m thick. It is harder and more compact than the underlying tuff and agglomerate horizons. Visible glass shards up to 3 cm in diameter occur in the tuff bed. The extent of the exposed zeolite bed is approximately 150 x 100 m, however extensions of this or other chabazite tuff beds are found 500 m South of Shingo.

Field Work and Results: The chabazite occurrence of Shingo Hill was discovered by project geologists in 1985. Following preliminary field studies the samples were investigated at the University of Guelph on their mineralogical and chemical properties (Table 3.12). Detailed identification studies by XRD and SEM and chemical analyses at Guelph identified Ca-chabazite as the main mineral of this zeolitized tuff. Glass shards and minerals like analcime and feldspars make up less than 30% of the zeolitic tuff.

The area was geologically surveyed in 1986 and a topographical survey of Shingo Hill carried out by plane table methods followed in the same year.The estimated reserves of the outcropping zeolite bed is in the order of 80-100,000 tonnes. Large extensions of this or other chabazite tuffs have been identified but no reserve estimates can be given from the existing field data.

Assessment: The chabazite tuff from Shingo Hill awaits still further agronomic testing, in particular its capability of NH_4^+ uptake, conservation and slow release. The amounts of easily mineable reserves are small, but could be worked on a local scale should agronomic testing provide its usefulness.

3.4.2 CHAMOTO

This deposit lies south of the Chamoto phosphate prospect (section 3.3.12., p. 45).

The zeolitic lapilli-tuffs at Lukwanji river are made up of pumice fragments, chabazite and feldspars. The chabazite content of the Chamoto tuffs is considerably lower than that of the Shingo zeolitic tuffs (chapters 3.4). More agronomic testing is needed to assess the value of these zeolitic tuffs.

3.4.3 MAPOGORO

Location and Access: The Mapogoro zeolite occurrence lies in the Rukwa rift valley close to the escarpment of the Mbeya range (N: ^{90}303 E: ^{3}204, UTM zone 36) (Fig. 3.2). Mapogoro is situated 25-30 km from the main Tanzania-Zambia highway close to the Mbalizi-Mkwajuni all-weather road.

Previous Work: The rift valley sediments of the Rukwa trough were mapped and studied by Spurr (1952), who distinguished Neogene "Older Lake Beds" and "Younger Lake Beds". No zeolites have been reported.

General Geological Setting: The geology of this area is characterized by pronounced rift fault escarpments with Proterozoic rocks occupying the rift shoulder of the Mbeya Range and Karroo and younger sediments covering the down faulted rift floor. The lake beds in which the phillipsite beds occur overlie Karroo and Cretaceous sediments. They belong to the 'Older Lake Beds' which include agglomerates, sands, conglomerates, tuffs and volcanic silts.

Present Exploration Work and Results: The zeolite deposit of Mapogoro was discovered in 1985 by project geologists. Initial testing by XRD and SEM at the University of Guelph identified the zeolite mineral as phillipsite. Associated with the phillipsite are feldspars and, in places, chabazite. The area around Mapogoro was geologically surveyed and sampled in 1986. Two and, in places, three phillipsite layers could be traced along strike for 4 km. The thickness of each of these layers vary from 0.6 to 2.0 m.

The reserves, calculated on the basis of two layers each 1.0 m in thickness, 5 m easily mineable width and 4000 m length are approximately 84000 tonnes. These are resources which could be mined easily by open cast methods. The total geological reserves are at least one order of magnitude larger.

Assessment: Experimental work with Mapogoro phillipsite indicate a good potential in regard to its use in the apatite-zeolite system and as NH_4^+ conservation medium. The usefulness of this material depends on the outcome of more agronomic testing.

Table 3.11 Chemical analyses of zeolitic tuffs rocks from Shingo and Mapogoro .

	Shingo		Mapogoro	
	MM 559	95	88	187
		%		
SiO_2	54.89	55.43	56.00	59.0
Al_2O_3	18.72	17.52	15.61	16.1
Fe_2O_3	2.54	2.53	3.72	3.58
MgO	1.00	0.80	0.60	1.21
CaO	2.44	4.97	0.46	0.82
Na_2O	3.58	0.39	2.50	4.49
K_2O	3.78	4.22	8.02	6.48
TiO_2	0.39	0.33	0.34	0.53
MnO	0.41	0.13	0.34	0.74
P_2O_5	0.08	0.17	0.02	0.05
LOI	12.16	13.50	12.38	6.93

XRF analyses, McMaster University

3.5 OTHER PROSPECTS

3.5.1 KIGUGWE

Location and Access: The well known Kigugwe copper occurrence lies South of the village of Kimani in the lower ranges of the Uwanji mountains some 95 km E of Mbeya The coordinates of one of the copper occurrences is N: ^{90}173 E: ^{6}298 on UTM, Zone 36.

Access to the area is good. An all-weather motorable track branches from the main Tanzania-Zambia highway at Kimani and passes the occurrences at close distance.

Previous Work: The copper mineralization of Kigugwe has been investigated in the past by several geologists. The latest studies were carried out by Geomin (1972), which drilled ten holes with a total depth of 3838 m into the cupriferous shale beds. The geologists concluded that this stratiform copper mineralization is of no economic value due to its low grade and insufficient thickness. However, all previous investigations assessed the occurrence on the basis of mining the copper for export. No thought was given as yet to the use of this material for internal agricultural use in copper deficient soils.

General Geological Setting: The Kigugwe stratiform copper mineralization is associated with the Proterozoic Buanji Series, which is part of the Bukoban Supergroup. The Buanji series is largely made up of purple and red shales and sandstones (red beds) and subordinate dolomitic limestones. The sedimentary Buanji sequence is capped by andesitic lavas.

Geology of the Kigugwe Copper Prospect: The Kigugwe copper mineralization occurs in the red bed sequence. Copper is concentrated in three stratiform green shale beds within a succession of predominantly red non-cupriferous shales. Copper minerals are malachite (and subordinate azurite), and chalcozite/bornite. Malachite is predominant and occurs as coatings on S-planes in the greenish cupriferous shales. Chalcozite and bornite are less common, they occur as irregular nodules.

The copper-bearing beds are only 20-50 cm thick but can be followed along strike for up to 12 kilometres.

Recent Investigations and Results: The recent investigations were made to assess the potential of the Kigugwe copper shales to supplement the currently imported copper fertilizers for the copper deficient soils of the Mbeya region. The geological investigations were confined to brief geological traverses and sampling of the cupriferous shales. The chemical analysis of a representative sample of the cupriferous shale is shown in the following table (Table 3.13).

Assessment: The initial agronomic testing in pot trials show encouraging results. It is obvious, however, that more agronomic tests are necessary to assess the usefulness of this material. The geological base for small scale mining of this material is very good as it is an extensive occurrence which can be extracted by uncomplicated mining techniques.

Table 3.13 Kigugwe cupriferous shale.

	%		ppm	
SiO_2	61.69	Cu	16,200	(1.62%)
Al_2O_3	21.20	Pb	9.4	
Fe_2O_3	4.23	Zn	160	
MgO	1.69	Co	19	
CaO	0.25			
Na_2O	1.71			
K_2O	3.11			
TiO_2	0.86			
MnO	0.08			
P_2O_5	0.16			
LOI	5.02			

XRF analyses, McMaster University

3.5.2 PYROCLASTIC AND OTHER VOLCANIC MATERIALS

The reserves of pyroclastic materials in the Mbeya region are immense. Ash, scoria and pumice are associated principally with the Rungwe, Ngozi and Kiejo volcanic centres. These materials have great potential in the conservation of soil water using the rock mulching technique of the Canary Islands (Fernandez-Caldas and Tejedor-Salguero 1988), and it is conceivable, from some of our pot trials described later in section 4.4, that they may have use as a general purpose fertilizer.

CHAPTER 4

PRELIMINARY TESTING OF GEOLOGICAL MATERIALS

4.1 PHOSPHATIC MATERIALS

Phosphate from the Minjingu deposit, which is already being worked by the Minjingu Phosphate Corporation, was chosen as a test material from the start of the project. Its main drawback is the fact that the mine is in northern Tanzania and to minimize the high cost of transport a source, or sources, closer to the field areas is more desirable. However, it is a proven resource and an important component in the agricultural economy of the country.

The phosphate at Minjingu appears to be primarily derived from a plentiful supply of bird and fish bones, and it seems likely that Minjingu Hill, which rises from a fossil lake bed was once the roosting place for a species of cormorant that fished in the lake. The bone-rich beds are interbedded with illite-kaolinite clay beds. Table 4.1 displays analyses of materials from the Minjingu deposit.

Table 4.2 lists phosphatic rocks identified by the geologists in their search for sources closer to Mbeya and Morogoro. They are ranked in order of P_2O_5 content and tonnage and it is clear that the best prospects are Panda Hill, Ngualla and Mbalizi-Songwe Scarp. Of the three, Panda Hill is preferred in that it is on a major transport route whereas Ngualla is well removed from one.

It is worth emphasizing that the phosphate deposits in question are very small in comparison with the large N. American and N. African deposits, but they are large enough to be of importance to the local economy.

Table 4.1 Minjingu phosphate analyses (see page 56)

Table 4.2 Main Phosphate resources in the Mbeya Region.

1. Panda Hill	>500,000 t at 8 - 20% P_2O_5
2. Ngualla	>500,000 t at 10 - 15% P_2O_5
3. Mbalizi-Songwe Scarp	>200,000 t at 10 - 18% P_2O_5
4. Chamoto	Few thousand tonnes

4.2 PROCLASTIC MATERIALS

Ashes, tuffs and scoria are among the commonest of all geological materials in the Mbeya region. They have obvious potential as rock mulches using the Canary Island technology described by Fernandez-Caldas and Tejedor-Salguero (1988). There is also the possibility that they can be used as general purpose fertilizers since there is a clear relationship between soil fertility in Tanzania and the occurrence of volcanic materials. The CIDA financed Tanzania-Canada wheat project for example relies entirely on the inherent fertility of the soils it is farming, and they are derived directly from the ash of the Hanang volcanic plume. If indeed, pyroclastics could serve as general purpose fertilizers the economic benefit would be immense simply because the reserve is for all practical purposes inexhaustible.

Consequently, we have tested and ranked pyroclastic materials by means of a simple test. The rocks (the chemistry of which is listed in table 4.3) were reacted with distilled water at 25°C and atmospheric pressure. No attempt was made to achieve thermodynamic equilibrium, the objective was simply to determine which nutrients were released, in what relative amounts. The results are summarized in Table 4.4.

Table 4.3 Chemical analyses of Pyroclastics (see page 57)

Table. 4.1 Major elements in rocks from the Minjingu phosphate deposit.

MAJOR ELEMENT COMPOSITION WITH LOSS ON IGNITION
MINJINGU PHOSPHATE

Sample	SiO_2	$Al2O_3$	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI
						%					
Bone Bed VS-143	0.10	0.08	0.30	1.12	51.18	0.98	0.33	0.01	0.02	37.36	8.52
#5 Top Bed	3.72	1.16	0.40	1.74	48.22	1.21	0.63	0.05	0.02	35.18	7.67
#7 Hard Phosphate	6.42	3.73	1.01	0.05	45.16	0.69	1.34	0.17	0.02	35.11	5.66
#9 2nd Phosphate Bed	11.75	2.76	1.16	2.42	40.22	1.54	1.46	0.14	0.04	29.48	9.03
Feed VS-147	11.38	2.77	1.12	2.59	40.50	1.35	1.28	0.13	0.04	29.69	9.15
Processed MPR	9.67	2.15	0.94	3.14	42.78	0.77	1.32	0.13	0.03	31.37	7.70
Tailings VS-147	40.08	7.96	4.01	5.01	16.80	1.95	3.85	0.51	0.06	8.30	11.47
Processed Phosphate Rock	10.51	1.20	0.55	1.54	47.74	0.32	0.58	0.01	0.02	28.83	8.68

XFR analyses, McMaster University

TOTAL CO_2, SULFUR, LOSS ON IGNITION

Sample	Total CO_2 (%)	Sulfur (%)	LOI (1040°C) (%)
Soft phosphate	4.69	<0.01	8.47
#7 Hard Phosphate	2.64	<0.01	6.33
Bentonite	0.18	0.01	8.33
Bone Bed	1.37	-	8.52
#5 Top Bed	1.13	-	7.67
#7 Hard Phosphate	0.72	-	5.66
#9 2nd Phos. Bed	1.53	-	9.03
Feed VS-145	1.34	-	9.15
Processed MPR	1.26	-	7.70
Tailings VS-147	2.51	-	11.47

XFR analyses, McMaster University

Table. 4.3 Major element content of volcanic rocks.

XRF ANALYSES OF MAJOR ELEMENTS INCLUDING LOSS ON IGNITION 1040°C

Sample	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	LOI	SUM
						%						
Mbaka VS-102	61.23	20.14	3.39	1.03	0.30	4.22	6.41	0.75	0.23	0.09	2.19	100
Izumbwe VS-3	41.08	7.90	12.34	20.37	11434	1.32	0.76	1.06	0.21	0.93	2.60	100
Malema VS-96	42.39	10.26	11.81	18.44	10.85	1.85	0.77	1.37	0.19	1.05	1.02	100
Mpoli VS-30	41.43	9.86	12.07	15.78	13.21	2.51	1.83	1.14	0.22	1.40	0.57	100
Mambi VS-28	61.67	17.79	3.37	0.30	0.35	1.63	5.35	0.47	0.15	0.07	8.84	100
Irango VS-58	59.56	18.56	3.24	0.16	0.81	4.00	5.57	0.69	0.22	0.10	7.08	100
Irango VS-59	46.90	24.31	6.74	0.17	0.34	1.73	2.31	1.00	0.43	0.15	15.91	100
Irango VS-60	43.27	23.47	5.90	0.20	0.37	1.50	2.72	0.72	0.30	0.11	21.44	100
Kibwe VS-77	47.65	18.10	11.97	4.41	8.97	2.17	2.20	1.97	0.20	1.09	1.26	100
Kiwira VS-77	44.57	15.24	13.86	7.58	10.35	2.02	1.55	1.83	0.24	0.75	2.01	100
Matamba VS-92	57.69	21.18	4.36	0.61	2.18	4.61	5.60	0.67	0.19	0.21	2.69	100
Uyole VS-93	58.55	19.26	6.07	1.26	3.46	3.95	4.06	1.10	0.20	0.47	1.61	100
Kikondo VS-94	68.67	16.83	2.82	0.17	0.06	4.14	5.72	0.50	0.21	0.05	0.83	100
Massoko VS-95	38.28	16.51	15.83	8.68	8.70	0.62	0.19	2.27	0.12	1.16	7.55	100
Ulenje VS-136	57.93	19.64	5.21	0.30	0.71	2.52	7.14	0.92	0.41	0.10	5.11	100
Kongolo 1	58.30	21.09	5.69	0.20	0.28	2.96	6.02	0.40	0.10	0.04	4.93	100
Kongolo 2	58.21	22.20	3.65	0.11	0.14	2.70	6.03	0.43	0.76	0.05	5.71	100
Kongolo 3	59.53	22.28	3.23	0.14	0.36	3.10	6.02	0.40	0.73	0.02	4.67	100

XRF analyses, McMaster University

Table 4.4 Solution experiments on Tanzanian materials

WATER SOLUTION EXTRACTS - Experiment #1
[P-free H_2O - pH 5.8, 25°C, Polypropylene leaching tube]
Note: Analyses expressed in ppm

SAMPLE: SARABWE-VOLCANIC SCORIA, VS-75

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.2	0.0	0.0
K	3.4	1.8	0.9
Ca	2.4	0.8	0.4
Mg	0.6	0.01	0.1
N	1.0	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Zn	0.08	0.0	0.0
Fe	0.0	0.1	0.0

SAMPLE: MPOLI CONE-VOLCANIC SCORIA, VS-30

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.8	0.7	0.5
K	5.1	4.5	3.0
Ca	0.0	0.7	0.0
Mg	0.0	0.01	0.0
N	0.0	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Zn	0.01	0.0	0.0
Fe	0.18	0.1	0.1

SAMPLE: CHALUHANGI-VOLCANIC SCORIA, VS-88

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.6	0.0	0.4
K	10.4	6.4	4.4
Ca	5.5	2.4	0.6
Mg	0.8	0.3	0.05
N	1.0	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.02	0.0	0.0
Zn	0.03	0.0	0.0
Fe	0.6	0.4	0.4

SAMPLE: MAMBI-TUFF, VS-28

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	1.7	1.7	1.5
K	86.0	94.9	21.7
Ca	21.9	5.5	1.0
Mg	1.8	0.2	0.0
N	2.5	0.0	0.0
Mn	0.01	0.0	0.0
Cu	0.03	0.0	0.0
Zn	0.06	0.1	0.0
Fe	1.4	2.1	1.4

SAMPLE: IFWOHA WEST-VOLCANIC SCORIA, VS-70

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.9	0.0	0.0
K	4.1	2.1	1.2
Ca	0.3	0.0	0.0
Mg	0.04	0.0	0.0
N	0.5	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Zn	0.02	0.0	0.0
Fe	0.08	0.0	0.1

SAMPLE : MALEMA MBAMBO-VOLCANIC SCORIA, VS-96

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.9	0.0	0.0
K	1.2	0.5	0.3
Ca	0.9	0.1	0.01
Mg	0.4	0.2	0.02
N	0.5	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Zn	0.02	0.0	0.1

SAMPLE: BLANK - H_2O

	Extract 1 (24 hrs)	Extract 2 (48 hrs)	Extract 3 (96 hrs)
P	0.10	0.0	0.0
K	0.0	0.7	0.2
Ca	0.0	1.3	0.0
Mg	0.0	0.2	0.0
N	0.0	0.0	0.0
Mn	0.0	0.0	0.0
Cu	0.0	0.0	0.0
Zn	0.02	0.0	0.0
Fe	0.0	0.1	0.1

SAMPLE: CHAMOTO (BULK) -TUFF, VS-27

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	1.0	0.9
K	10.6	7.2
Ca	0.6	0.06
Mg	0.0	0.0
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.3	0.3

SAMPLE: CHAMOTO-TUFF, VS-28

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.5	0.5
K	9.3	8.8
Ca	3.5	2.8
Mg	0.1	0.07
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.1	0.1
Fe	2.7	2.1

SAMPLE: MLIMA YA NYOKA-TUFF, VS-29

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	2.1	1.9
K	2.6	2.9
Ca	0.0	0.03
Mg	0.0	0.0
N	9.5	7.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.2	0.3
Fe	0.0	5.6

SAMPLE: CHALUHANGI VOLCANIC SCORIA, VS-91

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.3	0.3
K	10.6	12.4
Ca	1.9	1.9
Mg	0.3	0.2
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.1	0.1

SAMPLE: MBAKA RIVER -TUFF, VS-72

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.3	0.0
K	4.9	1.9
Ca	0.7	0.0
Mg	0.05	0.0
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.0	0.0

SAMPLE: MBAKA KILAMBO-TUFF, VS-104

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.4	0.5
K	0.8	0.6
Ca	0.9	0.4
Mg	0.5	0.1
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	1.1	0.8

SAMPLE: IHOMBWE- TUFF, VS-79

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	3.7	2.8
K	60.4	31.9
Ca	0.6	0.2
Mg	0.0	0.0
N	0.0	0.0
Mn	0.0	0.0
Cu	0.8	0.0
Zn	0.0	0.0
Fe	0.2	0.3

SAMPLE: IHOMBWE-TUFF, VS-80

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	14.0	6.7
K	29.4	20.7
Ca	29.7	14.9
Mg	0.2	0.0
N	22.0	1.1
Mn	0.0	0.0
Cu	0.0	0.4
Zn	0.1	0.0
Fe	0.2	0.2

SAMPLE: ILONGO - TUFF, VS-134

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.7	0.7
K	10.9	8.0
Ca	0.4	0.2
Mg	0.0	0.0
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	1.4	1.9

SAMPLE: IFWOHA EAST-TUFF, VS-71

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.0	0.0
K	2.5	1.9
Ca	1.7	0.8
Mg	0.4	0.2
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.0	0.0

SAMPLE: SENGERETI-VOLCANIC SCORIA

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.0	0.0
K	0.4	0.5
Ca	5.0	2.6
Mg	1.6	0.9
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.0	0.0

SAMPLE: KIWIRA - UPPER TUFF, VS

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.3	0.2
K	7.2	5.4
Ca	0.8	0.0
Mg	0.01	0.0
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.1	0.0
Fe	1.4	0.6

SAMPLE: ILEMGO- TUFF, VS-135

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	1.8	1.4
K	2.9	2.4
Ca	0.0	0.0
Mg	0.0	0.0
N	0.0	3.5
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.2	0.2
Fe	5.0	4.6

SAMPLE: POROTO #1 SEDIMENT, VS-133

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.0	0.2
K	8.5	4.7
Ca	6.5	1.7
Mg	1.2	0.3
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.0	0.1

SAMPLE: MPANYA HILL-TUFF, VS-97

	Extract 1 (24 hrs)	Extract 2 (48 hrs)
P	0.0	0.2
K	1.7	1.6
Ca	0.6	0.2
Mg	0.2	0.03
N	0.0	0.0
Mn	0.0	0.0
Cu	0.0	0.0
Zn	0.0	0.0
Fe	0.4	0.9

WATER SOLUTION EXTRACTS - EXPERIMENT #2

Sample wt: 50 gms. Temperature: 25°C Sample Size: 1 - 2 mm
"P" Free H_2O : 50 mls

Solutions stirred with magnetic mixing bars in Erlenmeyer flasks

SAMPLE: SARABWE-VOLCANIC SCORIA, VS-75

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.4	0.1	0.1	0.0	0.1	0.0	0.0	0.2	0.2
K	0.5	0.3	0.0	0.3	0.9	0.5	0.6	1.0	0.6
Ca	0.3	0.1	0.1	1.2	2.3	1.3	1.5	2.5	1.8
Mg	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.0	0.0	0.0	0.0	0.03	0.01	0.03	0.03	0.0
Cu	0.01	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.01	0.01	0.0	0.06	0.66	0.03	0.0	0.0	0.0

SAMPLE: MPOLI CONE-VOLCANIC SCORIA

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	1.0	1.0	1.0	0.0	0.3	0.0	0.0	0.3	0.1
K	7.9	2.3	2.0	2.0	4.3	1.5	2.1	3.2	2.7
Ca	1.7	0.8	1.0	3.1	15.5	2.8	5.9	9.0	8.6
Mg	0.2	0.2	0.4	0.8	3.3	0.5	0.9	1.0	1.2
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.02	0.0	0.0	0.0	0.03	0.006	0.04	0.05	0.0
Cu	0.02	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.04	0.01	0.01	0.01	0.06	0.03	0.01	0.0	0.0

SAMPLE: CHALUHANGI-VOLCANIC SCORIA, VS - 88

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.3	0.5	0.2	0.0	1.1	0.2	0.2	2.0	0.0
K	3.1	2.6	2.1	1.8	8.0	1.0	0.9	3.8	0.8
Ca	1.7	1.7	1.9	1.6	4.4	0.5	0.4	4.1	1.3
Mg	0.1	0.1	0.1	0.2	0.3	0.1	0.1	0.2	0.2
N	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.08	0.07	0.05	0.04	0.1	0.04	0.05	0.1	0.0
Cu	0.02	0.04	0.0	0.0	0.02	0.0	0.0	0.0	0.0
Zn	0.08	0.05	0.05	0.02	0.1	0.04	0.0	0.0	0.0

SAMPLE: MAMBI-TUFF, VS-28

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.2	0.2	0.1	0.0	0.1	0.0	0.0	0.2	0.0
K	3.0	6.5	1.2	2.6	7.6	1.4	2.1	10.0	3.8
Ca	0.1	0.3	0.0	0.5	0.7	0.7	0.3	1.2	0.2
Mg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.01	0.01	0.0	0.01	0.04	0.01	0.04	0.03	0.0
Cu	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.06	0.1	0.06	0.05	0.2	0.04	0.01	0.2	0.0

SAMPLE: IFWOHA WEST-VOLCANIC SCORIA, VS-70

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.1	0.0	0.0	0.0	-	0.0	0.0	0.2	0.0
K	1.9	2.7	0.9	1.0	8.9	0.7	0.8	1.4	0.7
Ca	0.2	0.5	0.2	0.8	3.1	0.9	0.9	0.8	0.1
Mg	0.0	0.3	0.0	0.1	0.3	0.1	0.1	0.1	0.1
N	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.02	0.04	0.01	0.03	0.01	0.02	0.03	0.0	0.0
Cu	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.03	0.04	0.03	0.02	0.01	0.05	0.0	0.1	0.0

SAMPLE: MALEMA MBAMBO-VOLCANIC SCORIA

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.6	0.0
K	0.1	0.0	0.0	0.7	0.3	0.1	0.2	0.4	0.0
Ca	0.3	0.0	0.0	0.1	1.1	0.7	0.5	1.1	0.0
Mg	0.3	0.1	0.1	0.0	0.1	0.1	0.1	0.2	0.0
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.0	0.0	0.0	0.0	0.01	0.02	0.06	0.0	0.0
Cu	0.02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.01	0.00	0.02	0.03	0.07	0.01	0.0	0.2	0.0

SAMPLE: IFWOHA EAST-VOLCANIC SCORIA, VS-71

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.2	0.0
K	1.8	0.5	0.2	1.3	5.3	0.5	0.9	4.1	1.2
Ca	0.3	0.1	0.0	0.8	2.0	0.7	0.8	2.0	1.3
Mg	0.1	0.1	0.1	0.0	0.3	0.1	0.1	0.3	0.2
N	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.01	0.0	0.0	0.01	0.1	0.02	0.02	0.01	0.0
Cu	0.01	0.0	0.0	0.0	0.02	0.0	0.0	0.0	0.0
Zn	0.02	0.02	0.02	0.03	0.03	0.01	0.0	0.2	0.0

SAMPLE: SENGERETI-VOLCANIC SCORIA

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.0	0.1	0.0	0.05	0.2	0.0	0.0	0.0	0.0
K	0.1	0.0	0.0	3.0	5.6	0.1	0.4	0.7	0.6
Ca	0.6	0.1	0.1	1.7	1.0	0.7	0.8	2.8	1.7
Mg	0.4	0.1	0.0	0.3	0.0	0.1	0.1	0.3	0.2
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.0	0.0	0.0	0.04	0.06	0.02	0.01	0.0	0.0
Cu	0.02	0.0	0.0	0.02	0.01	0.0	0.0	0.0	0.0
Zn	0.02	0.02	0.02	0.09	0.08	0.0	0.0	0.2	0.0

SAMPLE: ILONGO-TUFF, VS-134

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	2.3	6.8	0.4	1.7	0.2	1.5	1.4	0.6	1.0
Ca	0.1	0.3	0.0	1.0	1.4	0.2	0.3	0.0	0.8
Mg	0.0	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0
N	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.0	0.0	0.0	0.01	0.02	0.02	0. 02	0.0	0.0
Cu	0.03	0.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Zn	0.04	0.1	0.0	0.04	0.01	0.01	0.0	0.0	0.0

SAMPLE: CHALUHANGI-VOLCANIC SCORIA, VS-91

	1 hr	2 hrs	3 hrs	66 hrs	67 hrs	68 hrs	70 hrs	91 hrs	94 hrs
P	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
K	5.3	1.9	1.2	1.1	2.4	0.8	1.2	1.3	0.7
Ca	0.2	0.0	0.0	1.1	0.9	1.0	0.6	1.0	0.0
Mg	0.0	0.0	0.1	0.2	0.0	0.1	0.1	0.0	0.0
N	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mn	0.02	0.0	0.0	0.01	0.07	0.04	0.04	0.0	0.0
Cu	0.03	0.0	0.0	0.01	0.0	0.0	0.0	0.0	0.0
Zn	0.04	0.0	0.01	0.04	0.04	0.0	0.0	0.0	0.0

WATER SOLTUION EXTRACTS - EXPERIMENT #3

SAMPLE WT: 5.0 GMS; TEMP: 25°C; SAMPLE SIZE: 1 mm;
SOLUTION: 0.7 M H_2SO_4 50 mls

SAMPLE: SARABWE- VOLCANIC SCORIA, VS-75

	1 hr	3 hrs	70 hrs
P	115.0	90.0	5.5
K	440.0	438.0	11.4
Ca	517.0	464.0	65.6
Mg	20.3	63.0	117.0
N	4.0	3.5	1.5

SAMPLE: MPOLI-VOLCANIC SCORIA, VS-30

	1 hr	3 hrs	70 hrs
P	170.0	143.0	6.3
K	649.0	473.0	2.2
Ca	441.0	447.0	697.0
Mg	27.6	37.6	815.0
N	6.0	4.0	1.5

SAMPLE: CHALUHANGI-VOLCANIC-SCORIA, VS-88

	1 hr	3 hrs	70 hrs
P	275.0	43.5	3.2
K	171.6	36.0	27.9
Ca	796.0	327.0	61.8
Mg	79.8	39.0	102.3
N	2.5	1.0	1.5

SAMPLE: MAMBI-TUFF, VS-28

	1 hr	3 hrs	70 hrs
P	32.0	9.5	1.2
K	200.8	47.0	7.0
Ca	150.3	49.2	18.5
Mg	8.4	0.7	0.3
N	1.5	0.5	1.0

SAMPLE: IFWOHA WEST- VOLCANIC SCORIA, VS-70

	1 hr	3 hrs	70 hrs
P	78.0	34.0	2.7
K	51.1	14.3	18.0
Ca	194.5	83.2	18.2
Mg	10.4	1.84	4.5
N	1.0	0.5	1.5

SAMPLE: MALEMA MBAMBO-VOLCANIC SCORIA, VS-96

	1 hr	3 hrs	70 hrs
P	170.0	70.0	7.0
K	178.4	54.2	9.2
Ca	801.0	142.8	110.3
Mg	0.4	2.3	418.0
N	1.0	0.5	2.0

SAMPLE: IFWOHA EAST-VOLCANIC SCORIA, VS-71

	1 hr	3 hrs	70 hrs
P	145.0	28.0	3.0
K	31.1	11.8	44.9
Ca	352.0	39.9	43.3
Mg	0.8	0.6	6.8
N	2.0	0.5	1.0

SAMPLE: SENGERETI VOLCANIC SCORIA

	1 hr	3 hrs	70 hrs
P	195.0	75.0	5.7
K	51.3	23.8	4.8
Ca	467.0	166.2	37.0
Mg	3.0	32.8	338.0
N	1.0	0.5	1.0

SAMPLE: ILONGO -TUFF, VS-134

	1 hr	3 hrs	70 hrs
P	25.5	9.5	1.70
K	116.5	22.6	10.0
Ca	134.1	32.2	9.7
Mg	26.0	0.5	0.1
N	1.5	0.5	1.0

SAMPLE: CHALUHANGI-VOLCANIC SCORIA, VS-91

	1 hr	3 hrs	70 hrs
P	13.5	7.0	1.2
K	256.1	50.0	41.1
Ca	75.7	15.6	5.3
Mg	0.9	0.2	0.3
N	3.0	1.0	1.0

SAMPLE: BLANK H_2SO_4 - 0.7 Molar

	1 hr	3 hrs	70 hrs
P	0.3	1.0	0.5
K	26.1	3.3	2.3
Ca	17.2	5.5	2.5
Mg	0.4	0.2	1.2
N	0.0	0.0	0.5

4.3 ZEOLITES

The principal remaining materials investigated have been zeolites. Their nature and provenance are shown in table 4.5, and figure 4.1 shows their morphology by scanning electron microscopy.

The principal use for the zeolites that we have investigated so far has been as a means of inducing apatite breakdown (see Lai and Eberl 1986). The various forms of apatite release Ca^{+2} and P-bearing anions into solution. The generally low solubility of these phases, however, has been a drawback to the use of apatite as a direct source of nutrient P in agriculture. Apatite has for the most part been used as a raw material for the production of the more soluble phases used in conventional fertilizers. This necessitates industrial processing by such techniques as acidulation or heat treatment, processes that inevitably increase the cost of the finished product. An alternative is to introduce a cation exchanger which will take up Ca^{+2}, inducing further breakdown of apatite to produce a high enough concentration of P-bearing anions in solution to sustain a crop. Zeolite is a convenient cation exchanger to use in the present case since the geologists have discovered zeolites close to Mbeya. Preliminary solubility experiments show that zeolites do in fact increase the availability of P from apatite. They are as good or better at this than any other cation exchanger tested (table 4.6). A more complete account of this work has been published in Applied Clay Science (Chesworth et al. 1987).

Table 4.5 Zeolite occurrences in the Mbeya Region

Chabazite	Shingo, Chamoto, minor in Mapogoro
Phillipsite	Mapogoro
Analcime	Chamoto

Table 4.6 Preliminary solubility experiments, 25°C and 100 kPa, reaction period was 24 h

	pH	P aq. (moles/litre)	Ca^{2+} (moles/litre)
Apatite 1 + H_2O	5.7	3.6×10^{-4}	2.7×10^{-4}
Zeolite A + H_2O	9.7	n.d.	n.d.
Clinoptilolite + H_2O	6.7	tr.	2.5×10^{-4}
Vermiculite + H_2O	7.5	tr.	1.9×10^{-4}
Palygorskite + H_2O	6.6	tr.	8.5×10^{-4}
Apatite 1 + Zeolite A + H_2O	8.4	6.2×10^{-4}	4.7×10^{-4}
Apatite 1 + Clinoptilolite + H_2O	7.7	1.5×10^{-4}	1.1×10^{-4}
Apatite 1 + Vermiculite + H_2O	7.1	2.5×10^{-4}	2.5×10^{-4}
Apatite 1 + Palygorskite + H_2O	7.0	2.3×10^{-4}	2.9×10^{-4}

n.d. = not detected; tr = trace.

Plotted on a pH log ($H_2PO_4^-$ or HPO_4^{2-}) diagram the solubility of apatite in the presence of a cation exchanger is seen to approach that of much more soluble phosphatic minerals such as brushite and monetite.

Continued reaction in the systems containing cation exchangers takes the pH to much higher values especially in the case of zeolite A where a pH of greater than 9 was reached. These values are similar to those achieved in zeolite or alkali carbonate bearing soils. In a few runs of longer duration (up to 140 h) values of P in solution have been monitored up to 10^{-3} moles/litre. No attempt has been made at this stage to determine what reactions account for this, since the pH's are much higher than the values for normal farm soils, and would not be obtained in the latter because of the buffering effect of organic matter and clay phases. We suspect that these higher pH's, up to 10 in the case of zeolite A runs, are caused by the breakdown of the ion exchanging phase, since the pH values approach those expected for the equilibrium dissolution of the minerals concerned.

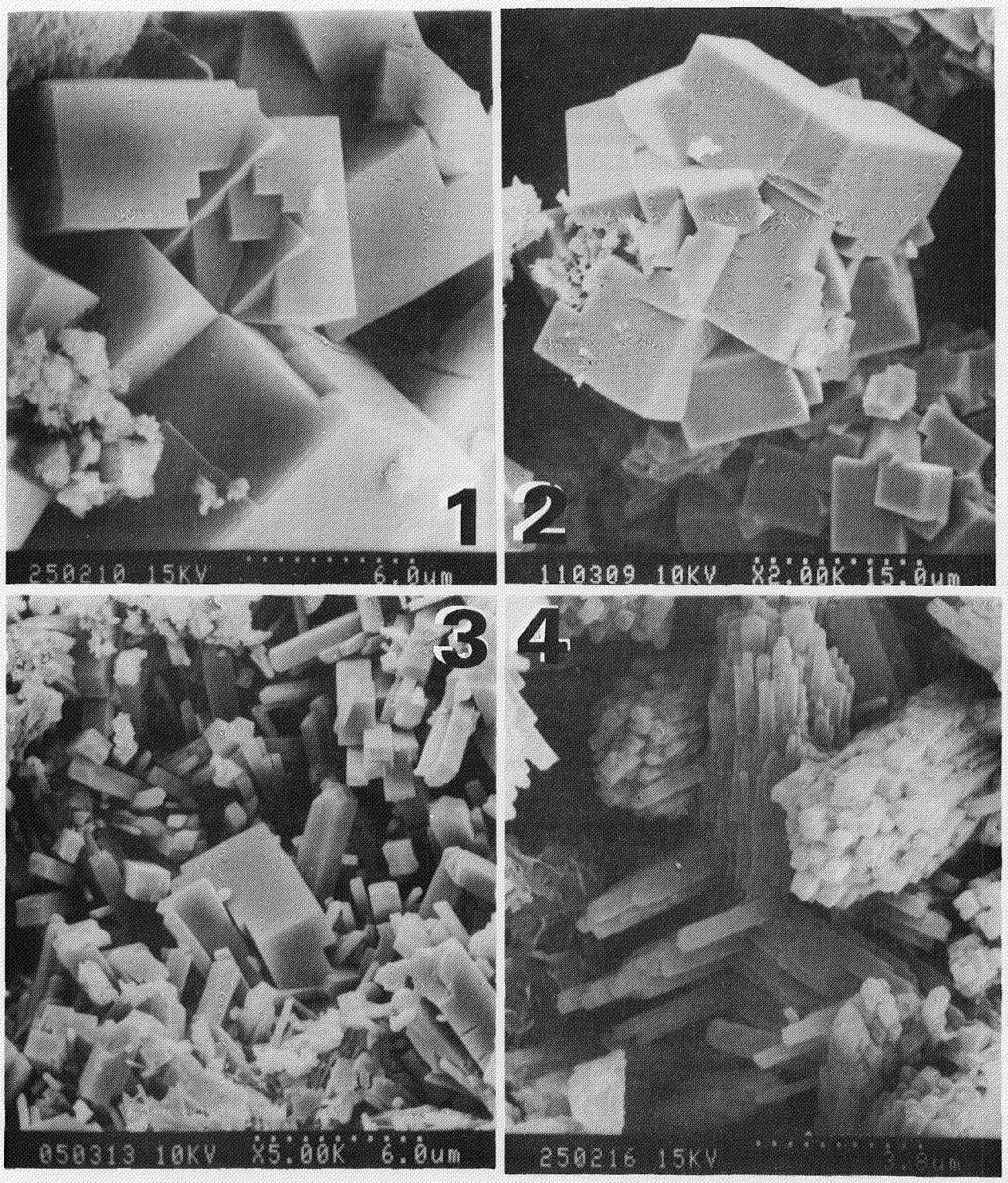

Fig. 4.1 Zeolites from Shingo and Mapogoro

1,2 chabazite, Shingo
3,4 phillipsite, Mapogoro

4.4 POT TRIALS AT GUELPH

A series of preliminary pot trials were performed at Guelph in the greenhouse maintained by W.A. Mitchell of the Department of Land Resource Science. The results are given in table 4.7.

Turface was used in place of soil since soil equivalent to Tanzanian examples was not available at Guelph. By comparison with the problem soils of Morogoro and Mbeya, turface generates a pH close to neutrality and so cannot be used as a direct model for the aforesaid acid soils. It does, however, like the Tanzanian soils, have a low cation exchange capacity.

However the results show clearly that Minjingu rock phosphate (MRP) with an ammonia doped zeolite gives excellent results compared with an NPK fertilizer. Surprisingly, the Chaluhangi Scoria also gives good results if N is added to the system. It appears to release enough P to satisfy the plant's needs, since adding P produces no further response.

A further interesting point is that manure with zeolite added to conserve N, gave easily the best results.

Table 4.7 Corn yields in pot trials using Tanzanian materials as nutrient sources.

Sample + Treatment	Total Plant Wt. (gms)	Root Wt. (gms)	Root Comments
Chaluhangi not crushed +N	50.3	4.1	good root development towards sides and bottom of pots
Chaluhangi crushed +N	48.6	4.9	good root
Chaluhangi crushed +N 200 + 500 g Turface	54.7	5.9	development towards sides and bottom of pots
Sarabwe not crushed + N 200 g + 500 g Turface	29.1	3.9	good root development - towards sides & bottom of pots
Sarabwe not crushed +N 200 g + 500 g Turface	27.1	2.7	roots penetrating volcanic scoria
Sarabwe crushed +N	25.6	2.8	same as above
Sarabwe crushed +N 200 g + 500 g Turface	23.8	3.2	
Chaluhangi crushed +NP	48.9	4.0	same as above
Chaluhangi crushed +NP 200 g + 500 g Turface	41.1	4.1	
Minjingu Rock Phosphate (MRP)	1.5	0.7	weak root
Minjingu Rock Phosphate (MRP) 200 g + 500 g Turface	3.0	0.7	development - poor penetration due to compaction
MRP + (NH_4-Erionite) 200 g + 500 g	3.9	0.7	good initial root development, then

Turface			died off leaving fragments in pot, soil compacted- clayey
MRP + (NH_4^+-Clinoptilolite) 200 g + 200 g + 350 g Turface	77.5	3.5	strong, thick roots at base of stem, weak root development towards bottom of pot
Mbaka Valley Ash	2.8	0.3	weak root
Mbaka Valley Ash 200 g + 500 g Turface	3.0	0.5	development
NPK + Turface	23.3	3.3	good root
NPK + Turface 700 g	19.0	1.2	development throughout pot
Blank & Turface	2.1	0.2	weak root
Blank & Turface 700 g	1.6	1.1	development - thin and sparce, but long
Mpoli crushed +N	33.7	3.9	good root
Mpoli crushed +N 200 g + 500 g Turface	38.2	5.0	development throughout pot
VS1:1 clinoptilolite-Manure	90.2	5.2	best root development,
VS1:1 clinoptilolite-Manure 400 g + 400 g Turface	104.1	7.6	clinoptilolite not disintegrated
Manure + Zeolite (clino)	64.6	5.1	similar root
Manure + Zeolite (clino) 200 g + 550 g Turface			development to VS1:1 but more fine roots

Note: 100 mls of appropriate nutrient solution was added each day of the experiment. Amount of nutrient solution per pot was calculated on the basis of standard field applications of kg/ha.

CHAPTER 5

POT AND FIELD TRIALS IN TANZANIA

1. PROPERTIES OF THE SOILS

The sites chosen for the study differed widely in agro-ecological characteristics. Such diversity is necessary in order to generate data representative of a wide range of existing conditions. The properties of the soils used in the study are given in Table 5.1. The soils belong to four soil orders according to the Soil Taxonomy System, namely Ultisols, Oxisols, Inceptisols and Entisols. The important properties in relation to phosphate rock (PR) studies are pH, available P, total P and exchangeable Ca. The ranges for these are as follows: pH: 4.6 - 6.6; available P: 1.8 - 21.6 ppm and exchangeable Ca: 0.9 - 5.8 m.e.100 g^{-1}. Most of the P levels are low, the problem being particularly severe in Ihanda and Chivanjee soils. Mafiga 2 soil had an available P level close to the critical value of 25 ppm reported by Singh et al. (1977). Soils with low P levels (<25 ppm) are expected to respond to P application.

Four of the soils namely Chivanjee, Magadu 2, Mzumbe and Ilindi are strongly acidic and contain exchangeable aluminum. These properties together with low Ca may limit productivity of these soils. The rest of the soils are moderately acid and problems related to acidity are not expected to limit their productivity.

Data on the type of clay minerals and micronutrient contents are given in Table 5.2. The dominant clay mineral in most of the soils is kaolinite and/or halloysite. Illite also exists in some soils but to a much less degree.

Of the few soils where the micronutrient data are available, low amounts of Cu were observed in Ilindi, Ihanda and Uyole. Generally a large proportion (60%) of the soils from Mbeya district are known to be deficient in Cu (Kamasho et al. 1982). Available Zn (extracted with diethylene-triamine-penta-acetate-DTPA) contents of soils from Morogoro were close to the value of 0.85 ppm suggested by Nzabhayanga and Mnkeni (1985) to be the critical level for deficiency for these soils.

It is thus evident from the above data that the commonest problem limiting productivity, apart from N, is phosphorus deficiency, followed by acidity, and Cu and Zn deficiencies. Problems of soil erosion and for Morogoro and Mbozi districts moisture stress are also considered important.

Table 5.1. Properties of the soils used in the different studies.

Location	Soil Order	pH H_2O	O.C. (%)	Bray1-P (ppm)	Exchangeable Cations Ca	Mg	K	Na	Al	C.E.C.	Clay content (%)
					m.e. $100g^{-1}$						
Morogoro											
*Magadu 1	Ultisol	6.2	1.5	10.6	5.8	5.2	1.5	0.36	-	19.8	23
*Magadu 2	Ultisol	4.6	1.2	5.6	1.6	1.3	0.7	0.04	1.4	9.1	19
*Magadu 3	Ultisol										
Mzumbe	Oxisol	5.2	n.d.	6.3	1.3	1.0	0.6	3.30	1.1	4.8	n.d.
Mafiga 1	Ultisol	6.6	n.d.	6.1	4.5	2.1	0.3	0.07	0	7.1	n.d.
Mafiga 2	Entisol	6.2	n.d.	21.6	3.3	2.6	0.5	0.31	0	6.9	n.d.
Mbeya											
Chivanjee	Oxisol	4.8	n.d.	1.8	0.9	0.8	n.d.	n..d.	1.5	29.0	58
Ilindi	Inceptisol	5.3	2.2	5.6	0.9	2.1	0.42	0.16	0.5	28.0	35
Ihanda	Ultisol	5.6	1.7	3.5	2.4	2.5	0.84	0.24	0	19.0	55
Magamba	Inceptisol	5.7	1.5	4.2	2.3	2.3	0.72	0.19	0	17.0	27
Mitalula	Oxisol	5.8	1.4	9.1	2.2	2.4	0.72	0.19	0	18.5	26
Uyole	Inceptisol	6.2	1.9	14	n.d.	n.d.	0.7	n.d.	n.d.	20.0	14

n.d. = not determined *Magadu 1 = pasture experiment; Magadu 2 = maize and bean experiment; Magadu 3 = second maize experiment.

Table 5.2. Mineralogy and micronutrient contents of the soils used in the different experiments.

Location	Dominant Clay Mineral	Micronutrient Content Cu (ppm) Total	Cu (ppm) Avail	Zn (ppm) Total	Zn (ppm) Avail	Total Mn %	Total Fe %
Morogoro							
Magadu 1	Kaolinite , *some illite	---	---	---	---		
Magadu 2	Kaolinite , +some illite	---	---	---	0.7[3]		
Magadu 3	---- ----	---	---	---	---		
Mzumbe	*Kaolinite + Al and Fe oxyhydroxides	---	---	---	0.9[3]		
Mafiga 1	*Kaolinite + Al and Fe oxyhydroxides	---	---	---	0.8[3]		
Mafiga 2	*Kaolinite and hydrous micas	---	---	---	---		
Mbeya							
Chivanjee (Majengo)		36.1[1]	1.4	----	8.9[4]	---	---
Ilindi	Kaolinite	2.4	0.9[4]	78	5.0[4]	0.11	6.7
Ihanda	Kaolinite	4.8	1.7[4]	83	6.7[4]	0.31	10.1
Mbimba(Magamba)	*Kaolinite/halloysite	15.0[1]	1.0[4]	---	10.0[4]	----	---
Mitalula	---	---	1.3[4]	-----	11.0	---	---
Uyole	*Halloysite + Al & Fe-oxyhydroxides	8.1[1]	0.5[2]	---	4.0	---	----

*From Moberg (1981)

1. Mbonika and Uriyo (1984) 2. J.A. Kamasho (1980) (M.Sc. Thesis, University of Dar-es-Salaam) 3. Nzabhayanga and Mnkeni (1985) 4. Kamasho J.A. (Unpublished data)

5.2 PROPERTIES OF THE PHOSPHATE ROCKS

Table 5.3 gives the properties of the phosphate rocks evaluated. Panda concentrate was obtained from Panda PR by washing twice with water. Minjingu PR is a sedimentary phosphate whereas the rest are igneous ones. The total P_2O_5 content varied from 8.3 to 34.0% while the ammonium citrate (pH 7) soluble P_2O_5 varied from 0.11 for Mbalizi PR to 2.86 for Minjingu PR. Minjingu PR is of high grade (20-24% P_2O_5) and the amount of P_2O_5 soluble in neutral ammonium citrate is comparable to values reported by Leon et al. (1986) for very reactive PRs (North Carolina) suggesting that it may behave similarly. Mbalizi and Njelenje PRs have much lower solubilities in neutral ammonium citrate, a characteristic of igneous PRs.

The CaO content varied from 25.5 to 47.6%. For two PRs, the neutralizing values were also determined and found to be 79.5% for Mbalizi and 2.5% for Njelenje. This suggests that Mbalizi PR could be an effective liming material.

Table 5.3. Chemical properties of phosphate rocks

Phosphate rock	P_2O_5 Total	P_2O_5 NAC	CaO	MgO	Na_2O	K_2O	MnO	SiO_2	Al_2O_3	Fe_2O_3	N.V.
							%				
Minjingu	34.0	2.86	46.4	3.4	0.84	1.4	0.04	10.4	2.3	1.0	6.5
Njelenje	17.8	0.23	25.5	0.16	0.76	5.5	0.36	24.8	6.0	14.5	2.5
Mbalizi*	8.3	0.11	47.6	1.26	0.10	0.17	0.22	2.4	0.4	0.7	79.3
Panda	10.4	n.d.	20.1	1.2	0.3	1.5	0.4	28.2	6.0	23.5	n.d.
Panda Conc.	18.9	n.d.	33.2	1.4	0.3	1.5	0.2	17.2	3.8	17.6	n.d.

n.d.-not determined

*Mbalizi PR also refered to as Mbalizi carbonatite

NAC - refers to neutral ammonium citrate soluble P_2O_5

N.V. - neutralising value

5.3 POT EXPERIMENTS

Three phosphate rocks, namely Minjingu phosphate rock (MPR), Njelenje phosphate rock (NJPR) and Mbalizi phosphate rock (MBPR) have been evaluated for their effectiveness in supplying P to maize under glasshouse and field conditions on soils differing widely in properties crucial for PR effectiveness. Phosphates from Panda Hill were not used in these experiments since their discovery took place only towards the end of the second year of the project. In addition to maize, pasture was also used as a test crop in a field experiment in Morogoro.

The effect of triple superphosphate (TSP) and MPR applied to four soils on maize dry matter yield and P and Ca uptake are given in Table 5.4. Triple superphosphate gave significant dry matter increases in three soils, namely Magadu, Mzumbe and Mafiga 1, which had low levels of Bray No. 1 extractable P. Mafiga 2 soil which had 21.6 ppm of Bray No. 1 extractable P did not respond to TSP application. Minjingu PR gave responses comparable to those from TSP in Magadu and Mzumbe soils, which were strongly acidic and low in available P. However, no significant response was observed with MPR in Mafiga 1 soil, which had low available P level but a pH of 6.2, a high enough value to limit severely the solubility of apatite, and hence the availability of P to plants. The P uptake data followed the same trend as that for dry matter yield in all the soils.

The effectiveness of MPR relative to TSP is clearly reflected in Table 5.5 which compares the agronomic effectiveness of the two P sources at equal rates. In Magadu soil MPR was better than TSP in increasing dry matter yield, whereas TSP was superior in the other three soils. As far as P supply to plants is concerned, as revealed by the relative efficiency in P uptake, TSP was superior to MPR in all four soils. However, MPR was again superior to TSP in supplying Ca as indicated by the relative efficiency in Ca uptake (Table 5.5). This suggests that the superiority of MPR in Magadu soil is not entirely due to P supply but may also be due to improved Ca nutrition as well.

The results of a glasshouse study with TSP, NJPR and MBPR on P concentration, P uptake and dry matter yield in five soils from Mbeya region are given in Table 5.6. All the soils showed a response to TSP application confirming the low P status revealed by the analysis of the soils (Table 5.1). Application of NJPR at the rate of 300 kg P ha^{-1} also increased dry matter yield, the effect being comparable to that from TSP in two soils (Chivanjee and Ilindi) but somewhat lower than that of TSP in the other soils (Ihanda, Mitalula, Magamba,and Mbimba). Mbalizi PR did not increase dry matter yield in all the soils. It should be noted that the rate of PRs was three times that of TSP.

The P concentration and uptake data indicates that even Mbalizi PR increased these parameters slightly except in Magamba soil where no increase was found. Njelenje PR, however, caused a much greater increase of both parameters.

The effects of the P treatments on selected properties of soils from Mbeya and Morogoro regions after harvesting the pot experiment are shown in Tables 5.7 and 5.8, respectively. The P data for the soils from Mbeya (row 2 of the table 5.7) indicate that TSP caused the greatest increase in available P, raising the P level to sufficient levels (25 ppm) in four soils out of five. The rates used appear to be insufficient for Chivanjee probably because of high P fixation. Njelenje PR was intermediate in increasing available soil P. In two cases the amounts of P were comparable to those from TSP. Mbalizi PR had negligible effect in increasing available P except in the Mitalula soil. In fact, in two soils (Ihanda and Ilindi) Mbalizi PR depressed extractable P.

In three of the four soils from Morogoro, application of TSP increased available P from 1 ppm to about 10 ppm. Minjingu PR at the same rate resulted in the same increase in available P except in Mzumbe soil where the increase was higher. When MPR was applied at 240 kg ha^{-1} higher available P levels were obtained.

In general the soil analysis results correspond well with the dry matter yield results reported above.

As for the other properties, i.e. pH and exchangeable Ca, Mbalizi PR increased pH and exchangeable Ca considerably demonstrating high liming potential. Njelenje and Minjingu PRs increased these parameters but only slightly whereas TSP had no effect on these properties.

Table 5.4. Effect of Minjingu phosphate rock (MPR) and triple superphosphate (TSP) application on maize dry matter yield (g/pot), phosphorus and calcium uptake.

	Soils											
	Magadu			Mzumbe			Mafiga 1			Mafiga 2		
Treatment	DM (g/pot)	P uptake (mg/pot)	Ca uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)	Ca uptake (mg/pot)	DM (g/pot)	P uptake (mg/pot)	Ca upake (mg/pot)	DM (g/pot)	P uptake (mg/pot)	Ca uptake (mg/pot)
Control	4.48b	4.24c	4.04b	2.44c	4.77c	1.68d	2.91b	3.61a	2.49b	8.71a	16.9a	8.70a
TSP (80kg P/ha)	8.77a	13.9ab	5.94ab	5.78b	10.3ab	4.25b	7.20a	9.71a	9.78a	9.98a	19.5a	8.70a
MPR (80kg P/ha)	8.94a	12.4b	7.64a	4.06bc	6.96bc	2.89c	3.68b	4.88a	3.97b	8.54a	16.5a	9.39a
MPR (240kg P/ha)	10.3a	16.7a	8.29a	7.69a	12.8a	5.35a	4.29b	6.64a	5.20b	10.3a	21.1a	11.2a
CV (%)	12.0	7.44	15.5	10.4	13.5	8.50	16.2	28.9	14.7	6.17	8.67	4.53

Means within each soil followed by the same letter are not significantly different at 5% probability level according to the Duncan's New Multiple Range Test.

Table 5.5. The relative agronomic effectiveness of triple superphosphate (TSP) versus Minjingu phosphate rock (MPR) and their relative efficiencies in affecting P and Ca uptake by maize.

	Experimental Soils			
Treatment	Magadu	Mzumbe	Mafiga 1	Mafiga 2
		Relative agronomic effectiveness		
TSP (80kg P/ha)	100	100	100	100
MPR (80kg P/ha)	125	48.5	23.8	-15.1
		Relative efficiency in P uptake		
TSP (80kg P/ha)	100	100	100	100
MPR (80kg P/ha)	84.5	39.6	20.8	-15.0
		Relative efficiency in Ca uptake		
TSP (80kg P/ha)	100	100	100	100
MPR (80kg P/ha)	189	47	20.3	----

Table 5.6. Effects of Njelenje and Mbalizi phosphate rocks in comparison with TSP on P concentration, P uptake and dry matter yield of maize grown in five soils from Mbeya region.

	Soils														
	Chivanjee			Ilindi			Ihanda			Mitalula			Magamba		
Treatment	DM (g/pot)	P conc (%)	P uptake (mg/ pot)	DM (g/pot)	P conc (%)	P uptake (mg/ pot)	DM (g/pot)	P conc (%)	P uptake (mg/) pot)	DM (g/pot)	P conc (%)	P uptake (mg/) pot)	DM (g/pot)	P conc (%)	P uptack (mg/ pot)
Control	12.9	0.07	9.0	13.2	0.19	25.1	13.0	0.23	29.9	17.1	0.13	22.	14.3	0.16	22.
TSP (100kg P/ha)	17.0	----	-----	15.9	---	---	21.4	---	-----	31.9	----	---	21.0	---	---
Njelenje (300kg P/ha)	16.1	0.17	27.4	14.7	0.39	57.3	17.1	0.42	71.8	23.0	0.26	59.8	17.3	0.29	50.
Mbalizi (300kg P/ha)	12.7	0.10	12.7	13.5	0.26	35.1	13.0	0.32	41.6	15.6	0.19	29.6	13.2	0.16	21.1

Table 5.7. Effects of different sources of phosphorous on selected properties of five soils from Mbeya region after P treatment and harvesting.

Soil Property	Experimental Site	Treatments			
		Control	TSP (100kg P ha^{-1})	Mbalizi PR (300kg P ha^{-1})	Njelenje PR (300kg P ha^{-1})
Soil pH (1:1 soil: H_2O ratio)	Chivanjee	4.7	4.7	7.3	4.6
	Mitalula	4.7	5.2	7.4	4.9
	Magamba	5.0	4.9	7.3	5.1
	Ihanda	5.3	5.4	7.3	5.1
	Ilindi	5.4	5.1	7.2	5.2
Bray 1 extractable P (mg kg^{-1})	Chivanjee	---	12.3	2.6	12.3
	Mitalula	9.1	27.6	17.1	29.8
	Magamba	4.2	47.4	4.8	18.4
	Ihanda	3.5	28.5	2.6	7.0
	Ilindi	5.6	24.9	2.6	13.6
Exchangeable Ca (me $100g^{-1}$)	Chivanjee	4.0	4.0	31.9	3.7
	Mitalula	2.7	3.0	39.7	6.6
	Magamba	7.6	6.4	33.3	5.8
	Ihanda	5.1	4.5	31.7	4.4
	Ilindi	4.0	3.6	30.2	3.6

Table 5.8. Effects of added triple superphosphate (TSP) and Minjingu phosphate rock (MPR) on selected soil properties after harvest.

Soil Property	Experimental Site	Treatments			
		Control	TSP (80kg P ha^{-1})	MPR (80kg P ha^{-1})	MPR (240kg P ha^{-1})
Soil pH	Magadu	4.7	4.7	4.9	4.9
	Mzumbe	5.2	5.2	5.3	5.5
	Mafiga 1	6.7	6.8	6.8	6.9
	Mafiga 2	6.2	6.1	6.2	6.3
Bray 1 extractable P (mg kg^{-1})	Magadu	5.8	10.2	10.0	25.0
	Mzumbe	6.5	10.3	11.4	17.3
	Mafiga 1	6.4	11.3	20.0	28.3
	Mafiga 2	21.7	22.7	21.9	24.7
Exchangeable Ca (me $100g^{-1}$)	Magadu	1.61	1.74	2.16	2.02
	Mzumbe	1.37	1.41	1.62	2.04
	Mafiga 1	4.53	4.53	4.80	4.70
	Mafiga 2	3.29	1.83	2.67	2.55
Exchangeable Al (me $100g^{-1}$)	Magadu	1.31	1.29	1.20	1.18
	Mzumbe	1.0	1.0	0.81	0.80
	Mafiga 1*	---	---	---	----
	Mafiga 2*	---	---	----	----

*Soil samples from Mafiga 1 and Mafiga 2 did not have detectable levels of exchangeable Al.

Table 5.10. Effects of the application of TSP and Minjingu PR (MPR) alone and in combination with Compost (CO) & Manure (MA) on dry matter yield, P uptake and Ca uptake in the pot experiment.

Treatment	Dry matter yield (g/pot)	P uptake (mg/pot)	Ca uptake (mg/pot)
Control	3.97 f	3.17 b	88.59 ef
TSP (40 kg P ha^{-1})	5.23 b	6.58 a	97.53 e
MPR (40 kg P ha^{-1})	4.47 d	4.05 ab	94.39 e
MPR (120 kg P ha^{-1})	5.95 a	6.42 a	126.53 bc
MPR (200 kg P ha^{-1})	5.97 a	6.77 a	151.68 a
CO (5 onnes ha^{-1})	3.88 gf	2.99 b	78.84 ef
CO (5 tonnes ha^{-1}) + MPR (40 kg P ha^{-1})	4.27 de	3.63 ab	94.98 e
CO (10 tonnes ha^{-1})	3.68 g	2.29 b	72.56 f
CO (10 tonnes ha^{-1}) + MPR (40 kg P ha^{-1})	4.10 ef	3.08 b	99.50 de
MA (5 tonnes ha^{-1})	4.76 c	4.02 ab	96.46 e
MA (5 tonnes ha^{-1}) + MPR (40 kg P ha^{-1})	5.44 b	6.03 a	141.23 ab
MA (10 tonnes ha^{-1})	5.37 b	5.39 a	118.26 cd
MA (10 tonnes ha^{-1}) + MPR (40 kg P ha^{-1})	5.66 b	6.32 a	142.64 a
F - Ratio	86.67 **	5.51 **	16.20 **
CV (%)	4	28	12

Means within the same column followed by the same letter are not significantly different at 0.05 according to the Duncan's New Multiple Range Test.
** Significant at 0.01 level

5.4 INCUBATION STUDIES

These studies were carried out to monitor the dissolution of the different PRs in selected soils. One study was carried out with Magadu 3 soil. In this study 20 g air dry soil samples were weighed into 100 ml centrifuge tubes and then mixed with ground PRs (80 mesh) and TSP at a rate of 36 ppm P. The PRs studied were from Minjingu, Njelenje and Mbalizi. The treated soils including controls were watered to approximately field capacity and maintained so throughout the incubation period. The samples were incubated for 0, 7, 14 30 and 45 days at a temperature of 25°C. At the end of each incubation period a complete set of treatments were withdrawn from the incubator for P extraction and analysis. Extraction was done following the Bray 1 procedure (Bray and Kurtz 1945) while P in the extracts was determined by the ascorbic acid-molybdate blue method (Murphy and Riley 1962). Available P as extracted by the Bray 1 procedure in the soil has been shown to correlate well with chemical reactivity of PRs (Chien 1979; Hammond 1979) and with plant yield and P uptake (Hammond 1979).

5.4.1 RESULTS OF SOIL INCUBATION STUDIES

The release of Bray 1 extractable P in Magadu 3 soil from different P carriers is shown in Figure 5.1. The results show that extractable P in TSP treated samples decreased sharply with time throughout the incubation period indicating a high rate of P fixation in this soil. The high rate of fixation of P from TSP could be associated with its high solubility as well as the likely high contents of P fixing minerals, e.g. Fe and Al oxides in the experimental soil. Application of Minjingu PR and Njelenje PR resulted in net P release with incubation time while virtually no P was released from the Mbalizi PR. The greater release of P from Minjingu PR indicates that it is more reactive than Njelenje PR under the specific conditions of our experiments. The difference in the reactivity of the two PRs could be related to the fact that Minjingu PR is of sedimentary origin. Sedimentary PRs tend to be microcrystalline with relatively large specific areas which makes them reactive while igneous PRs are coarsely crystalline, hard and therefore relatively insoluble (Khasawneh and Dolls 1978).

The inertness of the Mbalizi PR which is a carbonatite could be related to its high free $CaCO_3$ content. The $CaCO_3$ being more soluble than the apatite component probably neutralised the H^+ ions in the soil which would otherwise have decomposed the apatite. In addition, the dissolving $CaCO_3$ probably saturated the soil with Ca^{++} ions and had the mass action effect of decreasing the solubility of the apatite component of the PR.

5.4.2 COMBINATIONS OF MPR AND ORGANIC MATERIALS

Experiments were also conducted to assess the effects of mixing Minjingu PR with organic materials (fresh cattle dung which will hereafter be referred to as manure and compost) on the release of plant available P. A rate of 400 mg P kg^{-1} as Minjingu PR with and without compost or manure were tested in an incubation study. The rate of manure or compost was 5 tons ha^{-1}. The results are shown in Figure 5.2. It is clear that both compost and manure enhanced the release of P from MPR but manure was more effective. For instance after 15 days of incubation, the mixture of organic materials and MPR had 10 ppm more available P than MPR alone. For the combination of manure and MPR this difference increased with time of incubation probably because of a higher microbial activity supported by the fresh manure than that possible with compost. With compost the difference with MPR alone was more-or-less maintained throughout the incubation period. These results were assessed further in a pot study involving different rates of MPR with and without compost or manure. Two rates, 5 and 10 tons ha^{-1}, of compost or manure were tested with each rate of MPR. Four kg of soil were amended with each of the above treatments, potted and maize grown for 45 days. The results of the study are given in Table 5.10.

Minjingu PR at rates of 120 and 200 kg P ha^{-1} gave the highest dry matter yield followed by MPR at 40 kg P ha^{-1} in combination with manure. The yield from the latter treatments (i.e. MPR + manure) were comparable to that from TSP. The P uptake in all these treatments was comparable but Ca uptake was higher in the MPR or MPR plus manure treatments. This indicated that the better yield performance of the high rates of MPR or MPR + manure than TSP was partly due to improved Ca nutrition in the former treatments. Similar results were obtained earlier when MPR alone was tested with this soil (section 5.3).

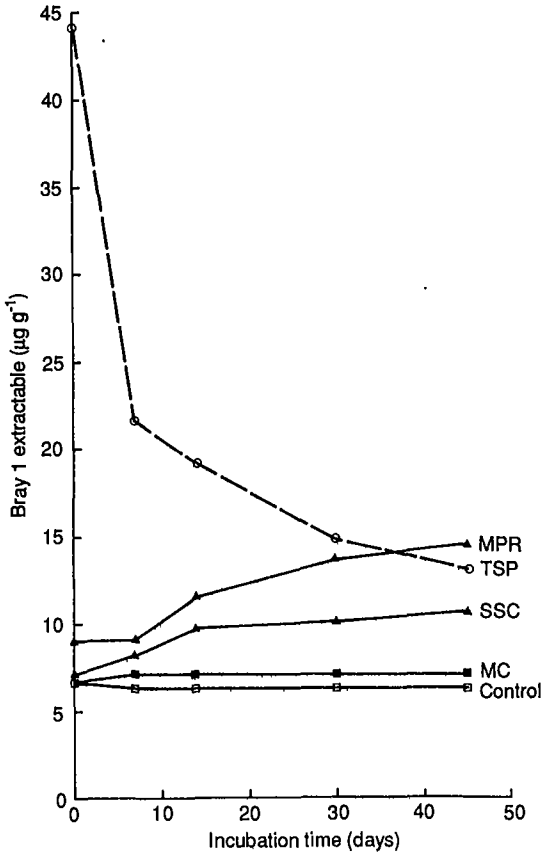

Fig. 5.1 Phosphate flux in Magadu 2 soil incubated with 400 ppm P as Monjingu phosphate rock (MPR), Songwe scrap carbonatite (SSC), Mbalizi carbonate (CM) or triplesuperphosphate (TSP).

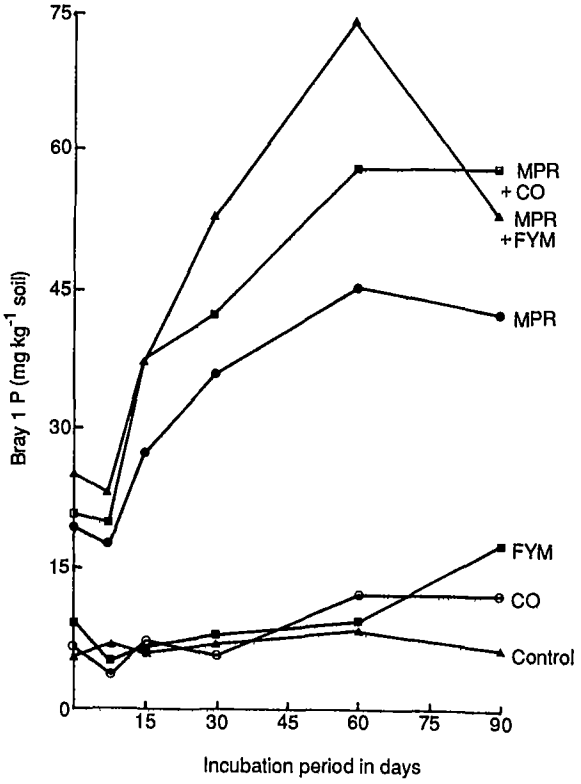

Fig. 5.2 Changes in Bray 1 P with incubation time in a Paleutuly treated with 400 mg P kg^{-1} as Minjingu Phosphate Rock (MPR) alone and in conjuction with 5 tonnes ha^{-1} of compost (CO) ar farm yard manure (FYR)

5.5 FIELD EXPERIMENTS

5.5.1 MAIZE AND BEANS EXPERIMENTS

Field experiments testing the effects of three phosphate rocks (Minjingu, Njelenje and Mbalizi) in comparison with TSP on maize and beans were conducted on an Ultisol (Magadu 2 site) in Morogoro during March 1986. Selected properties of the soil are shown in Table 5.1. Treatments for both experiments (maize and beans) consisted of a control and two rates of P application (40 and 120 kg P ha^{-1}) for each P carrier. The treatments were applied to plots measuring 3m x 4m arranged in a randomised complete block design with three replications. TSP was band applied next to the seed in the planting furrow while the PRs (80 mesh) were broadcasted to individual plots and worked in by rake.

The yields of maize and beans in relation to the treatments are given in Table 5.11 (a) and (b), respectively. The results indicate a slight increase in yield with application of P particularly with TSP, Minjingu PR and Mbalizi PR but none of these increases were statistically significant. The lack of significant responses to P application was unexpected since a pot study with the same soil had given good response with both TSP and Minjingu PR (Table 5.4). The lack of significant response is probably due to some other soil factor. Ikerra (1986) found that the subsoil (depth 26 cm of this soil contained much higher exchangeable Al than the topsoil (6.8 me 100 g^{-1} in subsoil vs. 1.4 me Al 100^{-1} g in topsoil). These exchangeable Al values correspond to Al saturation values of 80% and 21% respectively. The high level of exchangeable Al in the subsoil might have limited root development and P response.

The experiments were repeated on the same sites in March 1987 to assess residual effects but no useful results were obtained because of vermin attack and poor weather conditions. An attempt is being made at present to assess the residual effects during the current short rain season (November 1987) using cow peas (Vigna unguiculata) as test crop.

A new field experiment was established during March 1987 at another site (Magadu 3) in Morogoro to test further the effectiveness of the three PRs (Minjingu, Njelenje and Mbalizi) using maize as the test crop. The properties of the experimental soil are shown in Table 5.1. The treatments included a control and three rates of P application (40, 80 and 120 kg P ha^{-1}) for each P source. Other experimental procedures followed are as described for the previous field experiment.

The results are given in Tables 5.12 and 5.13. Response to increasing levels of TSP application was observed on total dry matter yield, grain yield and P uptake indicating that the soil needed supplemental P because of low P status (Table 5.1). It was therefore a good soil for evaluating the effectiveness of the PRs. Of the three PRs tested, only Minjingu PR increased yields and P uptake. However, unlike TSP, only the lower rate of application increased yields significantly while the higher levels depressed yields relatively. The decrease in yields occurred in spite of the fact that P concentration and uptake increased with higher rates of Minjingu PR application. The cause for the yield depression needs to be investigated. Nevertheless, it is striking to note that at 40 kg P ha^{-1} Minjingu PR performed better than TSP as reflected by the yield data (Table 5.12) and relative agronomic effectiveness values (Table 5.13). These results confirm those of the pot studies that Minjingu PR is indeed an effective P source for P deficient acid soils.

Field experiments were also set up in Mbeya region during the 1986/87 growing season to test the effectiveness of Njelenje and Panda PRs as sources of P for maize. Six sites were used in the study and the treatments tested included a control, 50 kg P ha-1 from TSP and 150 kg P ha^{-1} from Njlenje and Panda PRs. Each treatment was applied in 9 x 4 m^2 plots and the treatments were replicated at least three times. Standard agronomic practices were followed until the crop was harvested.

The results obtained are given in Table 5.14. Responses to P application were obtained in all the sites with the phosphate rocks giving better response than TSP in three out of the four sites in which the materials were applied. The better performance of the PRs compared to TSP is thought to be probably also due to their supply of other nutrients which are deficient such as Cu and in some cases Ca. The superiority of Minjingu PR over TSP in one site in Morogoro has been found to be probably due to its Ca supply (section 5.2).

Njelenje PR performed better in the Mbeya trials than in Morogoro. This is probably due to the favourable moisture conditions prevailing in Mbeya region. In Morogoro especially during the 1987 season, severe moisture stress occurred during the growing season and this may have limited solubility of the PR.

Table 5.11. Yield of maize and beans grown in a Ultisol in Morogoro treated with different phosphate rocks and TSP at two rates

(a) Maize yield

P rate (kg/ha)	P source			
	TSP	Minjingu	Njelenje	Mbalizi
	Grain yield (tons/ha)			
0	2.43	2.43	2.43	2.43
40	3.41	2.48	2.24	3.29
120	3.26	2.98	3.17	3.47

(b) Yield of beans

P rate (kg/ha)	P source			
	TSP	Minjingu	Njelenje	Mbalizi
	Yield of beans (kg/ha)			
0	792	792	792	792
40	931	1056	785	1070
120	1125	944	833	1053

Table 5.12. Effect of different sources of phosphorus applied to Magadu 3 soil on dry matter yield, grain yield, P concentration and uptake.

Treatment		Dry matter yield	Grain yield	Phosphorus	
P source	P rate ($kg\ ha^{-1}$)	($tons\ ha^{-1}$)	($tons\ ha^{-1}$)	Concentration (%)	Uptake ($kg\ P\ ha^{-1}$)
Control	-	9.4 c	2.6 cde	0.17	4.3 de
TSP	40	12.1 bc	3.4 abc	0.17	5.7 bcde
	80	14.4 ab	4.2 ab	0.18	7.5 ab
	120	16.8 a	4.4 a	0.19	8.6 a
Minjingu	40	12.3 bc	3.8 ab	0.17	5.8 bcde
PR	80	11.4 c	3.3 abc	0.18	6.3 ab
	120	11.7 bc	3.1 bcd	0.20	6.1 bcd
Njelenje	40	9.2 c	2.4 cde	0.18	4.0 e
PR	80	9.6 c	2.6 cde	0.19	5.3 bcde
	120	9.5 c	2.5 cde	0.19	4.7 cde
Mbalizi	40	10.1 c	2.2 de	0.16	3.2 f
PR	80	9.4 c	2.5 cde	0.18	4.2 de
	120	9.1 c	2.1 e	0.18	3.6 e

Table 5. 13 Relative agronomic effectiveness (RAE) values of the three phosphate rocks (PRs) for total dry matter yield, grain yield and P uptake when TSP is taken as 100%.

Treatment		RAE Parameters (%)		
P source	P rate (kg ha^{-1})	DM yield	Grain yield	Grain P uptake
			(%)	
Minjingu PR	40	107	156	107
	80	40	48	63
	120	31	32	42
Njelenje PR	40	-7	-24	-21
	80	4	6	31
	120	1	-3	7
Mbalizi PR	40	26	-41	-79
	80	0	-5	- 3
	120	4	-27	-16

Table 5.14. Effects of Ground Njelenje and Panda Phosphate Rocks on Maize Yield in Different Sites in Mbeya Region.

Source of P	Rate of P (kg ha^{-1})	Maize yield at different sites (kg/ha)						
		Mbimba	Mitalula	Ilindi	Ihanda	Uyole	Chivanjee	Mean
1 None	0	2967	1392	1891	1941	5029	952	2362
2 TSP	50	3516	1575	2628	3223	6399	1245	3097
3 Njelenje PR	150	4103	1978	-	2711	-	-	-
4 Panda PR	150	4212	2126	1401	3407	-	-	

5.5.2 PASTURE EXPERIMENT

The effects of the three phosphate rocks and TSP on the yield of Centrosema pubescens and Rhodes grass (Chloris gayana) growing in a mixed pasture experiment were also investigated in another site (Magadu 1) in Morogoro whose properties are given in Table 5.1. The treatments consisted of a control and two rates of P application (40 and 120 kg P ha^{-1}) for each P source. The treatments were arranged in a randomised complete block design with three replications in plots measuring 3m x 4m. All fertilizer materials were broadcasted and mixed with soil before pasture establishment. The establishment of the pasture was through Centrosema pubescens broadcasted seeds and Chloris gayana suckers. The pasture has till now been harvested 5 times at intervals of approximately 3 months.

The results are given in Table 5.15-17. Centrosema did not respond to P application irrespective of the source. Lack of response is partly attributed to failure to compete with the grass resulting in poor growth of the legume. This problem could be overcome in future through reduced C. gayana density and earlier establishment of Centrosema pubescence. This would enable the legume to creep into the stolons of the grass at an earlier stage of development and thus avoid the suppressing effect of the grass. Chloris gayana, on the other hand, responded to P application, the highest yield being obtained from TSP application of 40 kg P ha^{-1}. The trend is better indicated by the total yield from the five harvests taken up in May 1984. The PRs also increased yield although to a lesser extent than TSP. The effectiveness being in the order Minjingu, Njelenje, Mbalizi. This trend is best reflected by the relative agronomic effectiveness values which were 89%, 44% and 39% for Minjingu, Njelenje and Mbalizi PRs respectively. A similar trend was observed for P uptake data (Table 5.17).

It is interesting to note that the effectiveness of Mbalizi appears to increase with time. Similar observations were reported by Chien and Hammond (1978) who also found that less reactive PRs maintained more P in solution relative to more reactive rocks as more time elapsed.

The experiment also demonstrates that with Chloris gayana PRs are beneficial even at soil pH values higher than 6. Results with maize (Table 5.18) showed Minjingu PR to be ineffective at such pH values. Studies in South America have also demonstrated that pasture species were better utilizers of PRs than annual crops (Lathwell 1979).

Analysis of soil samples from the pasture experimental plots after the first harvest, gave the data shown in Table 5.8 for pH and available P. The P data indicate that all P treatments increased available P, the smallest being associated with Mbalizi carbonatite. This material, however, increased soil pH more than the others confirming the potential of this carbonatite as a liming material observed earlier with Mbeya soils (Table 5.4).

Table 5. 15 Dry matter yield of Centrosema pubescens as affected by different sources of phosphorus.

Treatment		Time of harvesting (months after planting)					
P source	P rate (kg ha^{-1})	3	6	9	12	15	Total Yield
		Dry matter yield (tons ha^{-1})					
None	0	0.24	0.21	1.23	O.37	0.26	2.31
TSP	40	0.28	0.33	1.18	0.41	0.42	2.62
	120	0.19	0.42	1.23	0.27	0.45	2.56
Minjingu PR	40	0.27	0.34	1.29	0.47	1.10	3.47
	120	0.17	0.35	1.06	0.43	0.40	2.55
Njelenje PR	40	0.21	0.29	1.01	0.35	0.40	2.26
	120	0.17	0.37	0.03	0.31	0.50	2.24
Mbalizi	40	0.19	0.29	0.83	0.38	0.47	2.16
carbonatite	120	0.18	0.33	1.12	0.34	0.44	2.41

Table 5.16 Dry matter yield of Chloris gayana as affected by different sources of phosphorus.

Treatment		Time of harvesting (months after planting)						*Relative
P source	P rate (kg ha^{-1})	3	6	9	12	15	Total	Agronomic Effectiveness(%)
		Dry matter yield (tons ha^{-1})						
None	0	3.3	2.8	6.5	5.9	10.7	29.3b	
TSP	40	3.0	4.1	7.5	7.5	13.7	35.7a	100
	120	3.9	4.0	8.1	1.6	12.5	35.0a	100
Minjingu PR	40	3.4	4.2	7.4	6.5	13.4	35.0a	89
	120	2.6	4.8	6.2	6.4	12.1	32.1ab	49
Njelenje PR	40	2.2	3.8	6.9	6.7	12.0	32.1ab	44
	120	2.2	3.8	6.9	6.8	11.5	31.3ab	35
Mbalizi PR	40	2.3	3.1	7.3	7.5	11.3	31.8ab	39
	120	2.6	3.6	5.7	7.1	9.9	29.0b	-5.0

*calculated from the total yield data.

Table 5.17 Phosphorus uptake by Chloris gayana as affected by different sources of phosphorus.

Treatment		Time of harvest (Months after planting) in P uptake						Relative Efficiency
P source	P rate (kg ha^{-1})	3	6	9	12	15	Total	in P uptake %
		P uptake (kg ha^{-1})						
None	0	3.8bc	3.1c	6.3bc	6.8	12.2e	32.3e	
TSP	40	4.2abc	5.8b	8.6ab	12.4	20.9bc	51.9b	100
	120	5.5a	7.5a	10.8a	11.0	24.9ab	59.6a	100
Minjingu PR	40	4.7ab	6.2b	9.0ab	10.6	25.4a	56.1ab	121
	120	3.6bc	8.6a	7.8b	11.3	21.1abc	52.5ab	74
Njelenje PR	40	3.5bc	5.3b	7.3bc	8.0	19.7c	43.8de	59
	120	3.1c	6.2b	7.66c	8.5	18.7cd	44.2cd	44
Mbalizi PR	40	3.3c	3.5c	3.76c	8.9	14.6de	37.1e	24
	120	3.2c	5.6b	5.3c	8.8	12.8e	35.8e	13

*calculated from the total P uptake data.

Table 5.18 Effects of P from different sources on soil pH and available P content after the first harvest of pasture at Magadu 1 site

Treatments		pH	Available P
P source	P rate (kg P ha^{-1})		(ppm)
None	0	6.1	6.7
TSP	40	5.8	26.4
	120	5.8	38.0
Minjingu PR	40	6.4	35.4
	120	6.4	72.4
Njelenje PR	40	6.3	19.3
	120	6.4	38.4
Mbalizi	40	6.4	10.9
Carbonatite	120	6.7	17.1

CHAPTER 6

ACHIEVEMENT OF OBJECTIVES

The following discussion of results examines our work in terms of the objectives given in chapter 1. A discussion of the overall objective will be left until the end, since it will be an examination of the detailed objectives that will provide a basis of judging the degree to which the overall objective has been achieved.

6.1 THE DETAILED OBJECTIVES.

1. The first objective was to specify the soil fertility problems known to exist in selected test areas of the Mbeya and Morogoro regions and to identify soils that are susceptible to improvements.

This objective was achieved. The principle soil-related problems that limit agricultural productivity in all the two areas can be outlined under two headings. First, there are the chemical problems: in both regions low pH, low fertility, Al and possibly Mn toxicities, P-deficiency and P-fixation are found. In addition Cu-deficiency is found in some soils of the Mbeya region. Second, there are two important physical problems, namely soil erosion on slopes in all two areas and water deficiencies in parts of Mbeya and all two areas.

2. The second objective was to locate and assess locally available materials needed to ameliorate the problems identified.

In the Mbeya region this objective was achieved and in fact was part of one of the most intensive surveys of its kind ever achieved in East Africa. The agricultural raw materials that were discovered and investigated for use in Mbeya and Mbozi districts are tabulated below.

Materials	Provenance	Uses
Apatite	Residual soils over carbonatite intrusives and fenites. Lacustrine deposits.	Major source of slow release phosphate in acid soils
Carbonate	Carbonatite intrusives. Limestone	Liming materials used to correct problems of acidity and associated toxicities.
Zeolites	Volcaniclastic-sedimentary beds in lacustrine deposits	Useful in conserving N, and in releasing P from apatite by coupled reaction. Raises pH.
Scoria, Pumice	Explosive vents in and around the Rungwe massif	Used as mulch to conserve soil water and provide slow release nutrients and micronutrients. Raises pH.
Malachite/ Azurite	Red bed Cu deposit between Mbeya and Iringa (Kigugwe)	Useful in correcting Cu-deficiencies in wheat areas of the Poroto mountains.

The fact that a similar success was not possible in the Morogoro region is simply accountable on the basis of the unsuitable geology of the area. Reconnaissance geological exploration did not provide any justification for more detailed work on targeted localities.

3. The third objective was to carry out a thorough chemical and mineralogical characterization of all soils and geological materials of interest.

This objective was achieved. In fact the Agrogeology project has probably provided the most comprehensive body of data yet available for the areas studied. The major element chemistry for all rocks and all soils collected has been determined. For selected samples, and to throw light on specific problems, rare earth and heavy metal analyses have also been made. In addition pH, cation exchange capacities, base saturation and nutrient status of the soils have been determined. The mineralogy of all samples has also been determined, including the nature of the clay fraction.

4. The fourth objective was to carry out weathering experiments in the laboratory in order to clarify the processes by which nutrient elements are released and/or retained in the soils under study. This objective was achieved. Laboratory work, including all analyses performed in characterizing samples of rock, weathered rock and soil, indicated that progressive hydrolysis during weathering drives the composition of the land surface in these regions towards the simplified chemistry and mineralogy of the residua system of weathering. The overall tendency replaces existing cations in the weathering materials by H^+, leading to terms of the relatively simple system SiO_2-Al_2O_3-Fe_2O_3-CO_2-H_2O. The fifth objective was to carry out glasshouse and field tests, and evaluate promising materials in order to formulate fertiliser recommendations to the local, especially the small scale farmer.

In effect this is two objectives. The first concerns testing and evaluation, the second involves the formulation of recommendations. The first of these was achieved but not to the degree that recommendations to the farmer can be made. Soon after the start of the project it was clear that three years would not be enough both to locate suitable agricultural raw materials and to test them. As it is the testing has made a solid start and has provided data on two years of pot and field trials. No agronomist, however, would feel safe in formulating recommendations after so short a trial period. At least three more years are required.

6.The sixth objective was to adapt and develop a grinder for the geological materials, appropriate for local use. This objective was not achieved.

THE OVERALL OBJECTIVE

The overall objective was to increase the capability of selected Tanzanian soils to maintain crops, by using locally available geological and organic resources to restore and improve the chemical and physical properties of the soils. The intention is to achieve this objective in ways that is least disruptive of traditional agricultural practices.

The foregoing analysis of the detailed objectives reveals that this overall objective was very substantially achieved. Locally available resources, capable of treating the soil problems that we encountered, were discovered in one of the regions. Agronomic tests were completed on these materials over a two year period.

However, full achievement of the objective cannot be claimed until local farmers are using materials that we have discovered and tested. A longer period of agronomic trials is necessary before this can happen.

CHAPTER 7

THE FUTURE OF AGROGEOLOGY IN TANZANIA

7.1 INTRODUCTION

Food security is a legitimate hope for all countries and in the main it is achieved by a careful management of soil and water resources. Problems associated with both of these are endemic in tropical regions and largely account for the food shortages that still beset Africa. Any attempt to improve the situation there must attempt to remove constraints on agriculture arising from the properties and use of these resources. Our work has dealt specifically with soil-related constraints. By choosing to work in regions where rainfall for the most part is adequate, water-related problems (other than erosion) are minimised. We do have some contribution to make in this area however, though our principal effort has clearly been in the development of materials and techniques useful in ameliorating the soil.

A second point worth making is that we have stressed the importance of finding agricultural raw materials on a local scale. Most farmers in Tanzania are relatively poor, and if they are to benefit from the addition of amendments to their soils, the amendments in question must be cheap. This means that they cannot be far distant from areas of application since the cost of transporting such bulky materials would become prohibitive. In addition, developing local resources is the best way we know of stimulating the local economy.

Finally, we have no intention of interfering with traditional agricultural practices in the regions under study. Farmers all over the world develop techniques that best suit their particular locales. They modify their techniques slowly and on the whole carefully, aiming always to maintain a sustained yield system. They are close to this in the most agriculturally productive parts of Tanzania, though the progressive acidification of their soils, as already explained, is a source of worry. What we have sought to do mainly, is to search for materials to treat the problems encountered in such soils, and although the materials may be new, the techniques of working them into the soil are no different from those employed by farmers using conventional fertilizers, composts or manures. Thus, unlike most of the 'Green Revolution' procedures, use of our materials does not involve abandonment of traditional methods of farm husbandry.

7.2 THE NEXT PHASE

In any future work the main objective remains the same: to increase the food producing capacity of selected Tanzanian soils using locally available geological materials in such a way that traditional husbandry practices are not disrupted. Specific activities written into our second phase proposal to IDRC are:

a) to evaluate, in detail, the geological resources identified in the first phase that were found to have agronomic potential, with respect to mineable tonnage and grades;

b) to develop simple physical beneficiation procedures for the Panda Hill phosphate deposit and to produce sufficient material for agronomic evaluation;

c) to continue to search for new fertilizer raw materials and their characterization;

d) to monitor possible harmful trace element buildup in the soils as a result of the application of the geological materials;

e) to develop new agromineral exploration models for general use in Eastern and Southern Africa and other areas with a similar geological settings;

f) to provide the geotechnical expertise necessary for the water conservation experiment using rock mulch;

g) to continue the agronomic evaluation of the geological fertilizer raw materials by glasshouse and field trials. Particularly important here is the assessment of residual effects in field experiments already in progress;

h) to continue assessment of soil fertility problems particularly P deficiency, Cu deficiency, soil acidity and related problems of metal toxicity and P fixation;

i) to investigate rock mulching as a means of soil water conservation particularly with perennial crops;

j) to survey existing farming practices regarding soil and fertilizer management;

k) to assess the economic feasibility of using the agronomically effective geological materials identified in the project.

Tangible results arising from this are:

a) the authorities in the Mbeya region will be provided with maps and other documentation detailing soil problems of the area investigated and locally available geological resources with agronomic potential;

b) for agronomic testing, sufficient apatite concentrates will be produced from the Panda Hill deposit, beneficiated by simple physical means;

c) a demonstration, for extension purposes, will be carried out of the successful application of geological materials and techniques in increasing food production in Mbeya region;

d) an initial assessment will be made of the costs and benefits to the local farmer of using geological amendments and techniques to improve food productivity.

Finally, we stress the following socio-economic aspects and benefits:

a) this project addresses the two major fertilizer problems facing the local, small scale farmer in Tanzania. One is the high cost of commercial produced fertilizer and the second is availability of such fertilizer.

b) approximately 140,000 tons of fertilizer is currently used per year in Tanzania. 40,000 tons of this is imported and even the remaining 100,000 tons that is produced within the country has substantial inputs of imported raw materials. The demand and needs far exceed these levels of availability.

c) transportation problems aggravate the availability of fertilizers particularly in remote areas.

d) another potential benefit of this approach is the creation of jobs in connection with the small-scale mining and processing of the geological materials.

e) thus, the project should lead to increased food production, import substitution and hence foreign exchange savings, and development of local industries.

Looking further afield, the exploration and application methodologies we are developing are directly applicable to other parts of Tanzania and to much of the neighbouring regions of East Africa. The similar geological structures encountered in Burundi, Ethiopia, Kenya, Malawi, Mozambique,Uganda and Zambia make these countries ideal for a direct transfer of the methods developed in Tanzania. In fact, with very little modification they can be applied to other parts of the Third world.

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