A FEVER TREE, MARANGUDZI



"Go to the banks of the great, grey-green,
greasy, Limpopo river, all set about with
fever trees, and find out."

The Elephant's Child
Rudyard Kipling

THE GEOLOGY OF EASTERN MARANGUDZI SOUTHERN RHODESIA

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ABSTRACT

The area studied is situated in Southern Rhodesia fifty miles east of Beitbridge in the Limpopo valley.

Field work showed that igneous intrusions, previously recognised in 1957, formed part of a more extensive igneous complex emplaced in the high grade metamorphic rocks of the basement.

The eastern position of this complex was mapped and found to contain basic intrusions, mainly of gabbro, acid intrusions of quartz syenite and granite, and undersaturated intrusions some of which contain pseudoleucite. The basic intrusions which form an irregular mass are cut by later acid and undersaturated ring dykes intruded about six centres.

Minor intrusions in the form of dykes are associated with the major intrusions. They show radial trends within the ring intrusions and form a dense swarm, striking east-west, in the basement complex to the east of the major intrusions. Doleritic and phonolitic types are most numerous but other types including lamprophyric varieties are also present.

The field relations and petrology of the various intrusions are described and conclusions regarding the form of the complex, the sequence of intrusions, and trends of differentiation are given. The structure of the complex is correlated with Karroo tectonic activity in the region and the complex as a whole is compared with other alkaline complexes in Africa and ring complexes in general.

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CHAPTER 1

GENERAL

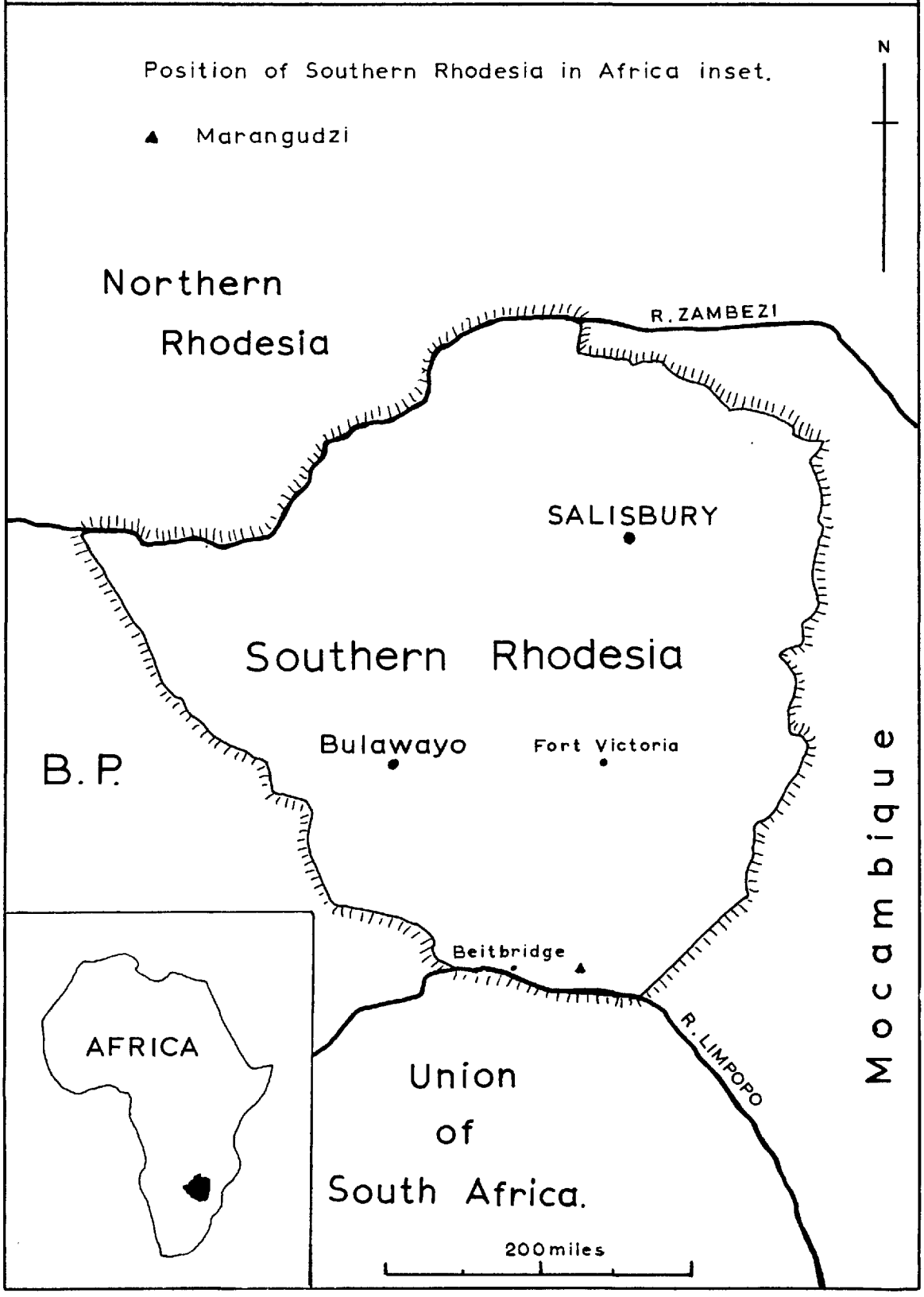
Introduction

Marangudzi is the native name for a small group of hills which forms the centre of an igneous complex. The complex is situated just north of the Limpopo river, at the southernmost part of the Federal State of Southern Rhodesia.

Mr G. Rees and the author spent several months during 1958-59 mapping the area, which was originally thought to contain a carbonatite intrusion. The complex was not, however, found to contain any carbonate rocks, the field work showing it to be a series of ring intrusions following an early gabbro intrusion. The rocks of the ring intrusions vary from granites and quartz-syenites to undersaturated syenitic types containing felspathoids. Numerous dykes are associated with the major intrusives and extend some way into the basement, as well as cutting the rocks of the complex.

The igneous rocks have been intruded into highly metamorphosed rocks, probably originally both sedimentary and igneous, although mainly of sedimentary origin. The commonest rocks exposed in the vicinity of the complex are metaquartzites, and serpentine bodies are also found. The rest of the basement remains unexposed over large areas, a few exposures of gneissose type being present.

Fig. 3 Location of Marangudzi.



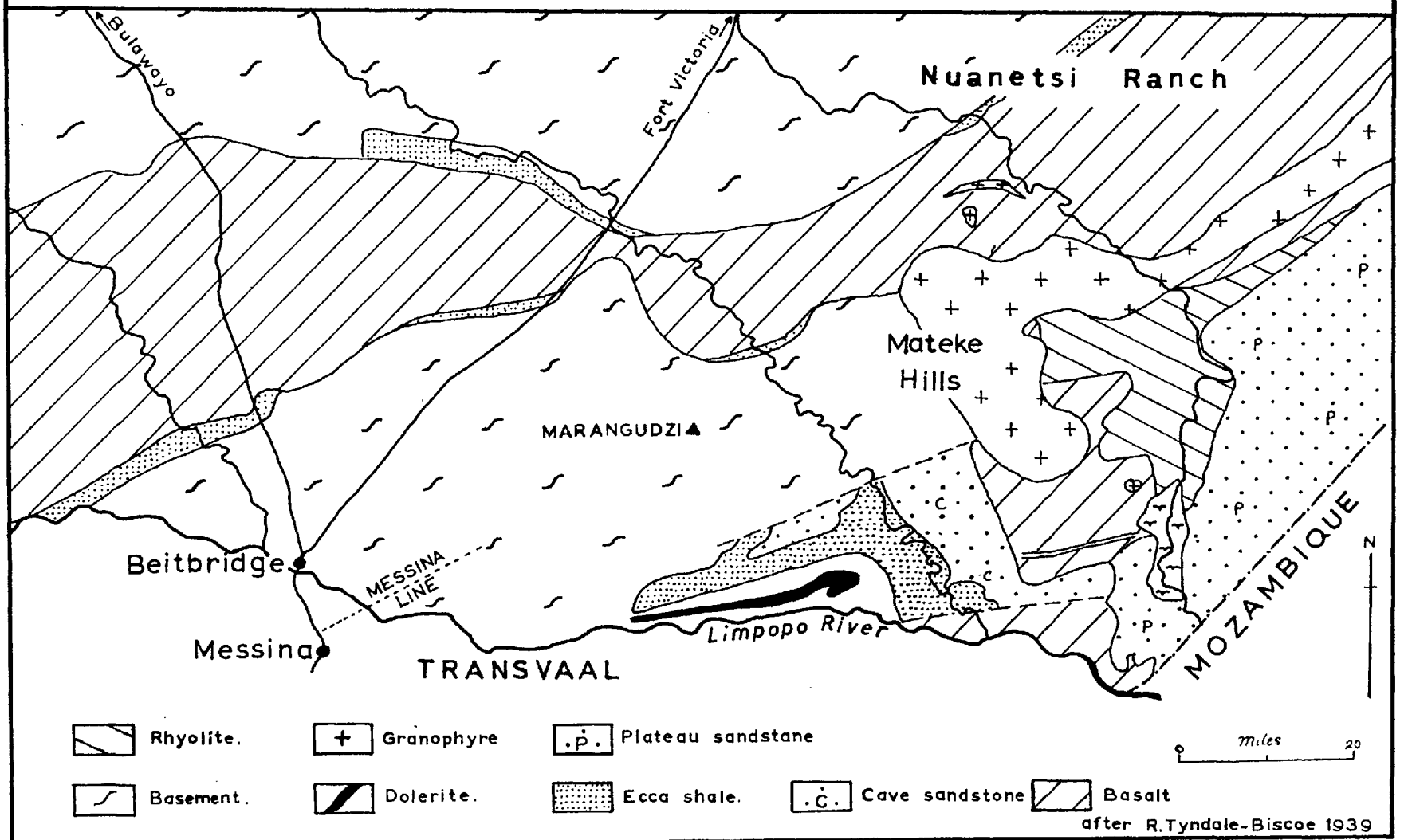
Location

The location of Marangudzi, and its relation to the surrounding country, are shown in figures 3 and 4. The southern limit of Rhodesia in the south-east is the course of the Limpopo river, which forms a natural boundary with the Union of South Africa. The road and rail links with the Union cross the Limpopo at Beitbridge, which is the name of the settlement on the Rhodesian side as well as the name of the bridge itself.

Marangudzi lies about fifty miles to the east of Beitbridge, and twenty miles north of the Limpopo river. The area is reached by taking the Fort Victoria road out of Beitbridge and turning right on to a Native Department dirt road after a distance of twelve miles; this road passes south of Marangudzi after a further forty miles. Beitbridge is the nearest point at which supplies can be obtained, but as it has only one store, necessary purchases (in excess of the goods originally transported from Bulawayo in the Land-Rover at our disposal) were made in the copper mining town of Messina, ten miles to the south, in the Union.

A survey beacon has been erected on the highest of the Marangudzi hills, at an altitude of 2480 feet above sea level. The approximate latitude and longitude of the trig. beacon are 22° south and 30° 40' east. The area lies in the native province of Matabeleland, the border with Mashonaland lying along the Bubye river a few miles to the north-east. The boundary of the Nuanetzi cattle ranch which

Fig. 4 REGIONAL SETTING OF MARANGUDZI.



extends northwards traverses the complex east to west, and the land lying to the south is a native reserve.

Climate and Vegetation

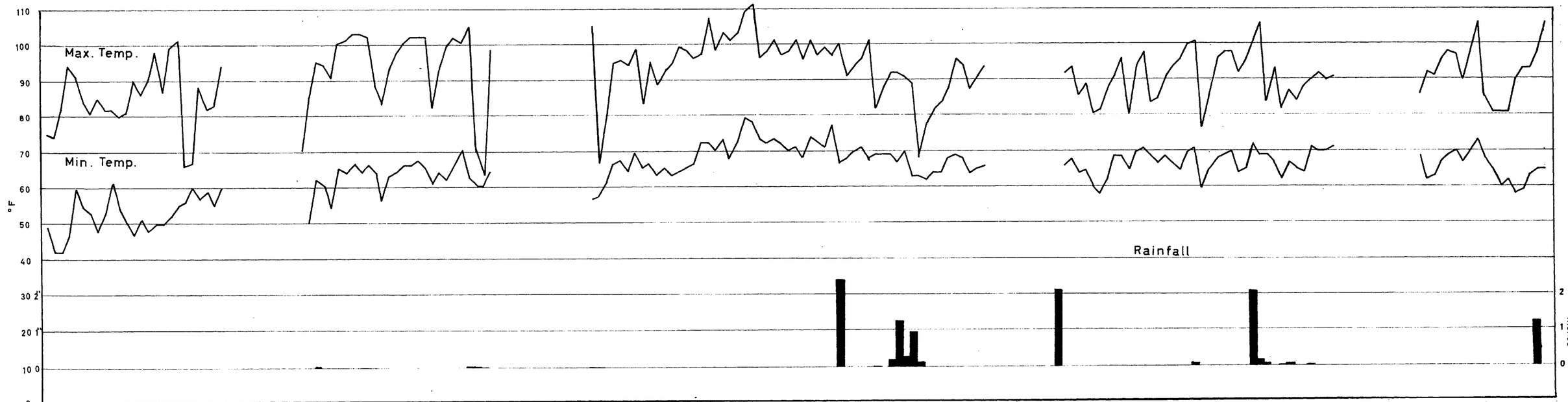
The general level of the district, which is classified as low-veld, is less than 2000 feet above sea level. The climate of this relatively low district is warmer and drier than that of the major part of Southern Rhodesia, which is over 4000 feet high.

During the period of field work, records of the rainfall and daily maximum and minimum temperatures were kept, and these figures are plotted on the graph figure 5. As far as is known, these are about the average. However, the rainfall varies considerably from year to year. About twice as much rain fell in the previous year (1957-58), while the following year (1959-60) was abnormally dry.

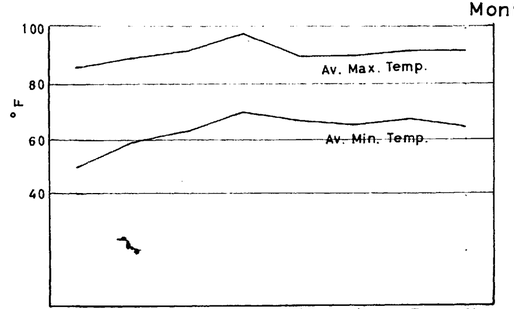
The poor and undependable rainfall makes the region unsuitable for the growing of crops, although the natives do clear the land in places. On the small fields they attempt to grow mealies and kaffir corn, despite the low yield and occasional total loss of crops as a result of drought. On the other hand, where water supplies are adequate, conditions generally favour the raising of cattle: herds both graze and browse, and are able to find fodder all the year round. The lack of natural watering places is a persistent problem: the resettlement of natives in the area has necessitated the drilling of numerous boreholes to supply the villagers and their cattle with

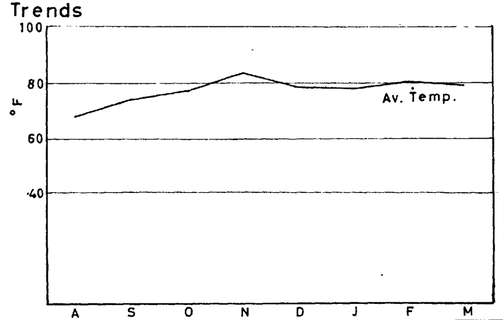
Fig.5

Daily Maximum and Minimum Temperature, and Rainfall Readings - Marangudzi, S. Rhodesia for period August 1958 - March 1959



Monthly Trends





Monthly Recorded Rainfall (inches)

A	S	O	N	D	J	F	M
Trace	·04	·115	Trace	5·455	2·22	3·735	1·30

Total = 12·865"

water. The native settlements are commonly situated at the boreholes, although native women will carry water one, two, or even three, miles from a watering place to the village. One or two boreholes were put down within the confines of the complex, but unfortunately no geological records were kept. Drill cores lying on the surface did provide some fresh specimens.

The Marangudzi area is by no means devoid of wild life, and some distance to the east, near the Portugese East Africa border, is a game reserve. The activities of native and European hunters have affected the animal kingdom considerably, but the smaller buck, impala, kudu, etc., are relatively common and we caught sight of an eland on several occasions. During the first month we saw a leopard, and baboon and elephant passed through the region in the wet season. Small reptiles abound: there are various species of lizards and iguanas, and the country to the east has been described as a natural snake park by a leading authority. The insect population is large.

The vegetation of the area makes an interesting study in relation to the geology. The mopanie is undoubtedly the most common species and occurs in several growth forms. Most of the granitic rocks are covered by mature mopanie bush with a few acacias and other species, including baobabs. The gabbroic rocks, on the other hand, are covered by secondary mopanie scrub over large areas. The main stream courses are lined with numerous species of larger trees,

many of them acacias such as the fine specimen of a fever tree (Frontespiece).

The hill slopes support a variety of smaller plants, especially the smaller thorny acacias and many climbers and creepers. The vegetation tends to be particularly dense on the hill slopes, and even more so on the southward facing slopes where the plants escape the full force of the sun for much of the year. In extreme cases, the northerly facing slopes are practically devoid of plant life, as on Madawula Hill where there is only a blocky scree with a few trees finding roothold amongst the fallen blocks.

Several of the trees bear edible fruit, but of these only one, the marula, was useful. Known poisonous fruits were, of course, avoided, and some of the edible ones proved unpalatable.

Previous Work

Very little geological work has been done in this part of Southern Rhodesia, and prior to May, 1958, when the Rhodesian Schools Exploration Society organised an expedition to the area, the existence of a major intrusion of igneous rocks was generally unknown. Dr G. Bond was a leader of this expedition, which established the presence of alkaline rocks and appreciated for the first time that the intrusions formed part of a ring complex. A cyclostyled report of the expedition's findings appeared in 1959.

The published works deal with the basement and Karroo rocks of

the area. The earliest of these is by F.W. Voit (1905), entitled 'Gneiss Formation on the Limpopo' and it gives a general description of the basement. The only paper dealing specifically with the area under discussion is by Tyndale-Biscoe (1949). This gives a brief account of the work he carried out in 1939 which resulted in the map shown in figure 4. The following is the abstract from this paper:

> The area described in these notes lies along the north side of the Limpopo river, between Beitbridge and the border of Portugese East Africa, at the southernmost point of the colony of S. Rhodesia.
>
> The Basement Complex shows high grade regional metamorphism, comprising garnetiferous paragneisses, with coarsely crystalline banded ironstone layers and some serpentinites. The Karroo System is represented by shales and sandstones of presumed Ecca age, overlain by basaltic and rhyolytic flows, which are intruded by a mass of granophyre considered to have the form of a sill. In a small area between the Nuanetsi and Limpopo rivers, at and near the Portugese border, loosely consolidated conglomerates are believed to be of Cretaceous age.
>
> An important fault striking E.N.E. with a downthrow to the south is responsible for the preservation of the Karroo sediments, while another one striking E. and W., throws the basic and ultrabasic lavas down against the sediments near the Limpopo river. The granophyre and supposed Cretaceous conglomerate are later than the faulting.
>
> Certain alkaline (trachytic) dykes are also thought to be of Cretaceous age.

The alkaline dykes mentioned at the end of this abstract are associated with the Marangudzi complex and outcrop along the road to the west of the complex. The major intrusions were not mentioned.

Prospecting has, of course, been carried on in the area, both by individuals and companies. Goldfields Ltd., is at present prospecting the Karroo which contains coal measures, and also has claims

staked on Marangudzi. This company has prospected the annular outcrop of marble to the south of the complex (figure 2) believing its annular form to indicate an igneous origin. Extensions of the copper mineralisation at Messina have been searched for by Messina Mines Ltd. These might be expected, since the area lies along the extension of the 'Messina Line', the fault line along which the copper mineralisation has been localised. An insignificant amount of mineralisation was found in the serpentine body two miles to the west of the complex (figure 2) which has also been prospected for asbestos fibre on another occasion. So far nothing of economic importance has been found.

Scope of the Work

The work has divided itself into two main parts. A field study in Rhodesia, including collection of samples of rock, followed by a laboratory study of these samples in London.

A map on the scale of 5 inches to the mile was made of the complex. The writer mapped east of an arbitrary north-south line drawn through the complex; the western portion was mapped by a fellow student, Mr G. Rees. When the dividing line was originally decided upon, it was thought to divide the complex into two approximately equal portions, but the mapping has shown that it extends much farther to the east than was believed. The results of the field work are given in Chapter 2.

The laboratory study consisted mainly of a petrological ex-

amination of the material collected, much of which has been sectioned. This has enabled an accurate classification of the various rock types to be made and their mineralogy to be described. These results are given in Chapter 3. A certain amount of analytical work has been done but the geo-chemistry of the complex as a whole remains to be studied. The results are summed up in the final chapter, and the complex is compared and contrasted with complexes of a similar nature in Africa and elsewhere.

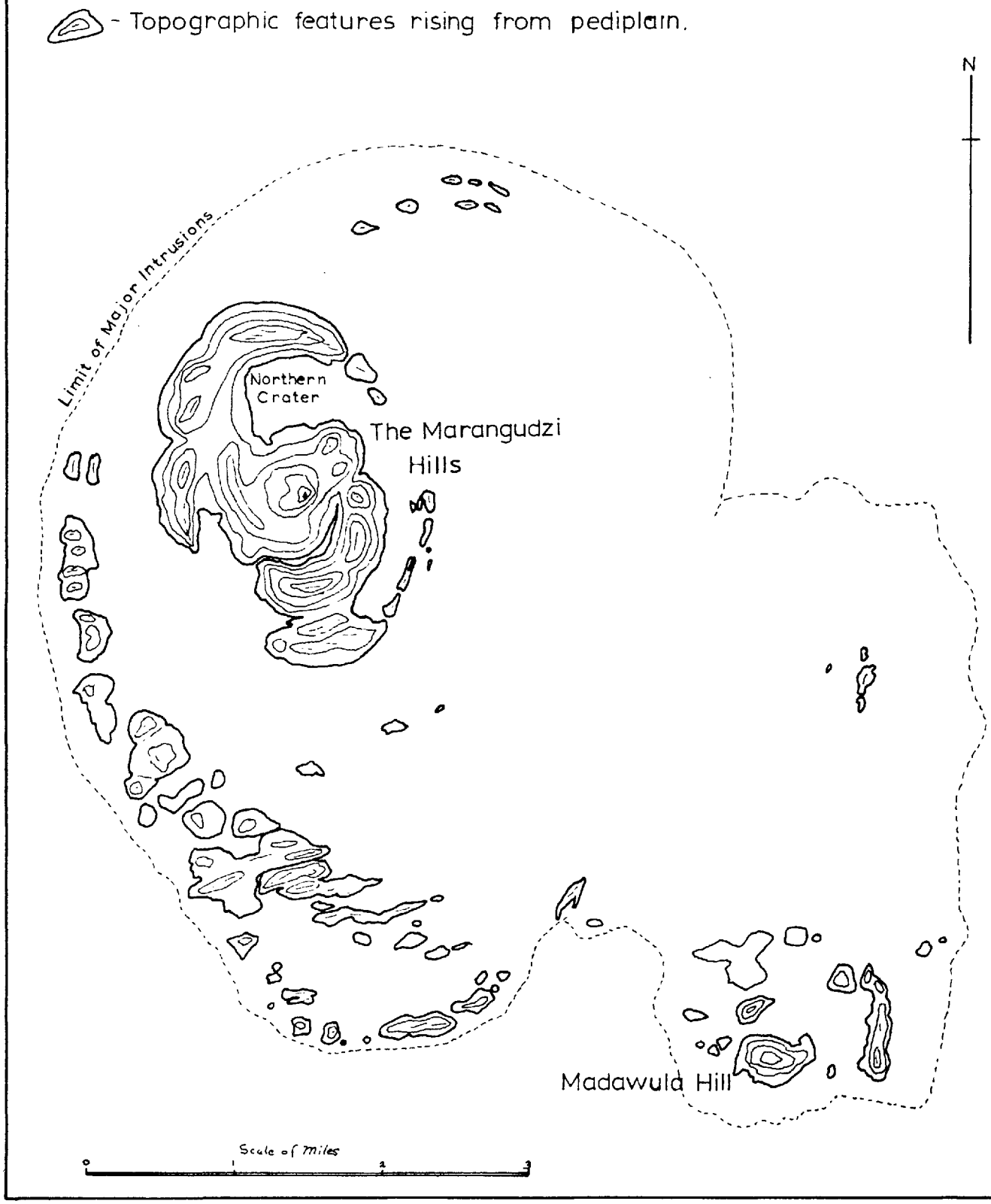
Physical Geology

The Sabi-Limpopo basin, in which the area under consideration lies, forms a low region along the southern border of Southern Rhodesia. The country to the north rises steadily up to the plateau which comprises the major portion of the country. Evidence of two peneplains, one pre-Triassic and the other Tertiary, is found on the plateau, the Sabi-Limpopo basin being excavated by denudation in step with uplift of the later tertiary peneplain during Pliocene times.

Topographically, the Marangudzi area is composed of two distinct forms. An almost completely flat countryside, with little or no relief, out of which rise the hills and kopjes which are generally steep sided and make a striking contrast with the surrounding, gently undulating, surface. The distribution of these two forms is shown in figure 6.

The main hills are formed by the central rings of the complex.

Fig.6 Geomorphology of Marangudzi.



These are undersaturated syenitic rocks characterised by the presence of nepheline. The hills rise approximately 500 feet above the general surface, and the relief of this central mass bears a close relationship to the geology in that it reflects the ring-like nature of the intrusions.

The outer rings of granite and quartz syenite typically form kopjes. This is especially the case in the south, where the crescent shape of the ring is very well defined by kopjes, a number of which mark the limit of the intrusion in the south.

The gabbro forms a few kopjes, although it tends to be featureless. In the south-east, a group of kopjes surrounds a hill. The hill, known as Madawula, rises about 300 feet above the plain and is composed of gabbro, as are several of the kopjes apart from the easterly ones which consist of varied undersaturated rocks.

The drainage of the area bears a relation to the geology in part. The drainage pattern of the igneous rocks shows control by the radial and concentric joint system, and the forms of the major intrusions. The main stream courses tend to show a concentric control and the tributaries a radial one. (See figure 1).

Comparison of the stream courses on the granitic rings and on the gabbro reveals characteristic differences. The stream courses on the gabbro have many more tributaries than those flowing on the granitic rocks, which are singularly lacking in tributaries and show very simple drainage patterns. This contrast is attributable to the

difference in weathering between the basic and acid rocks. The basic rocks give rise to a brown soil which is finer and has a higher clay content than the red sandy soil typical of the acid rocks. This causes a quicker run off on the gabbro than on the granite, whose sandy soil is able to absorb appreciable amounts of water, and so lessen the effect of the sharp falls of rain.

The drainage over a larger area is shown in figure 2. It will be seen that the watershed between the Bubye river to the east and the Limpopo river to the south (about 3 miles south of the ground shown in this figure) passes through the southern part of the complex. Structures in the basement assert little influence on the drainage pattern. Occasionally Karroo faulting governs the course of parts of individual streams. The Malapi river, and its tributary, which flows along the faulted Karroo contact in the south-east corner of the ground shown in figure 2, provides an example of this.

The present relief of the area is largely the product of peneplanation by the process known as pediplanation. This process does not pass through the same stages of erosion as are found in temperate climates, but produces a similar planed surface at maturity.

Considering the formation of a new base level (the inception of a new cycle) in the simplest case, a planed surface, the pediplanation cycle may be outlined as follows. The rivers rapidly incise themselves to the new base level, forming steep sided valleys.

The valley sides now retreat from the river courses, maintaining an almost constant slope. This retreat continues until the scarps meet and finally a new peneplain is produced. The diagram figure 7A shows the main features of the cycle, the steep scarp with scree, the pediment, and the planed surface extending back to the stream courses. Variations are imposed on this simplified cycle by differences in the country rock, its structure, the climate, etc.

L. King, 1951 A, from whose map figure 7B is taken, describes pediplanation in Rhodesia, and the map shows the surfaces recognised by King is this part of Rhodesia. The plain immediately around Marangudzi forms part of the Lowveld surface of King (see figure 7B). The lower Limpopo surface does not reach the area considered here. However, a third surface, not mentioned by King, appears to be indicated by the summits of Marangudzi, Madawula, and the hills to the north-west. This surface would be the oldest recognised in the region. The Lowveld surface, which is by far the most prominent near Marangudzi, is thought by King to date from the Victoria Falls cycle. (L. King 1951). At Marangudzi this surface is 2000 feet above sea level, but rises northwards; it is clearly shown in plate 1, which brings out the advanced stage of pediplanation attained in the area. Figure 8 shows the form of the hills overlying the Marangudzi complex.

Regional Geology

The observations made on the regional geology by Tyndale-Biscoe

Fig.7a. Mechanism of Pediplanation.

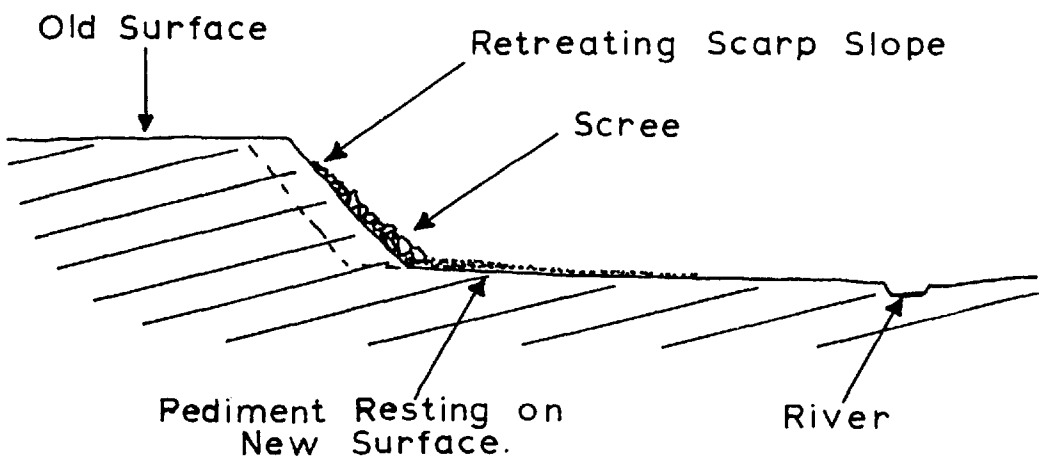


Fig.7b. Erosion Surfaces at Beitbridge

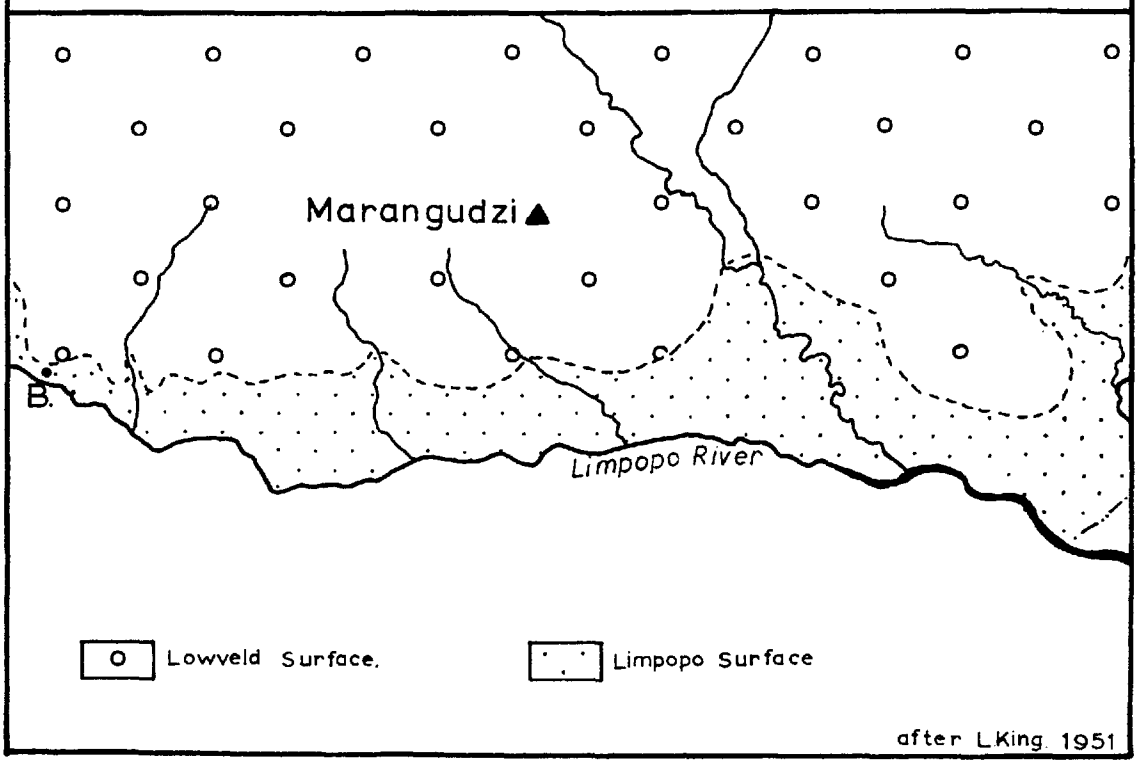


Fig. 8. Block Diagram of Complex.

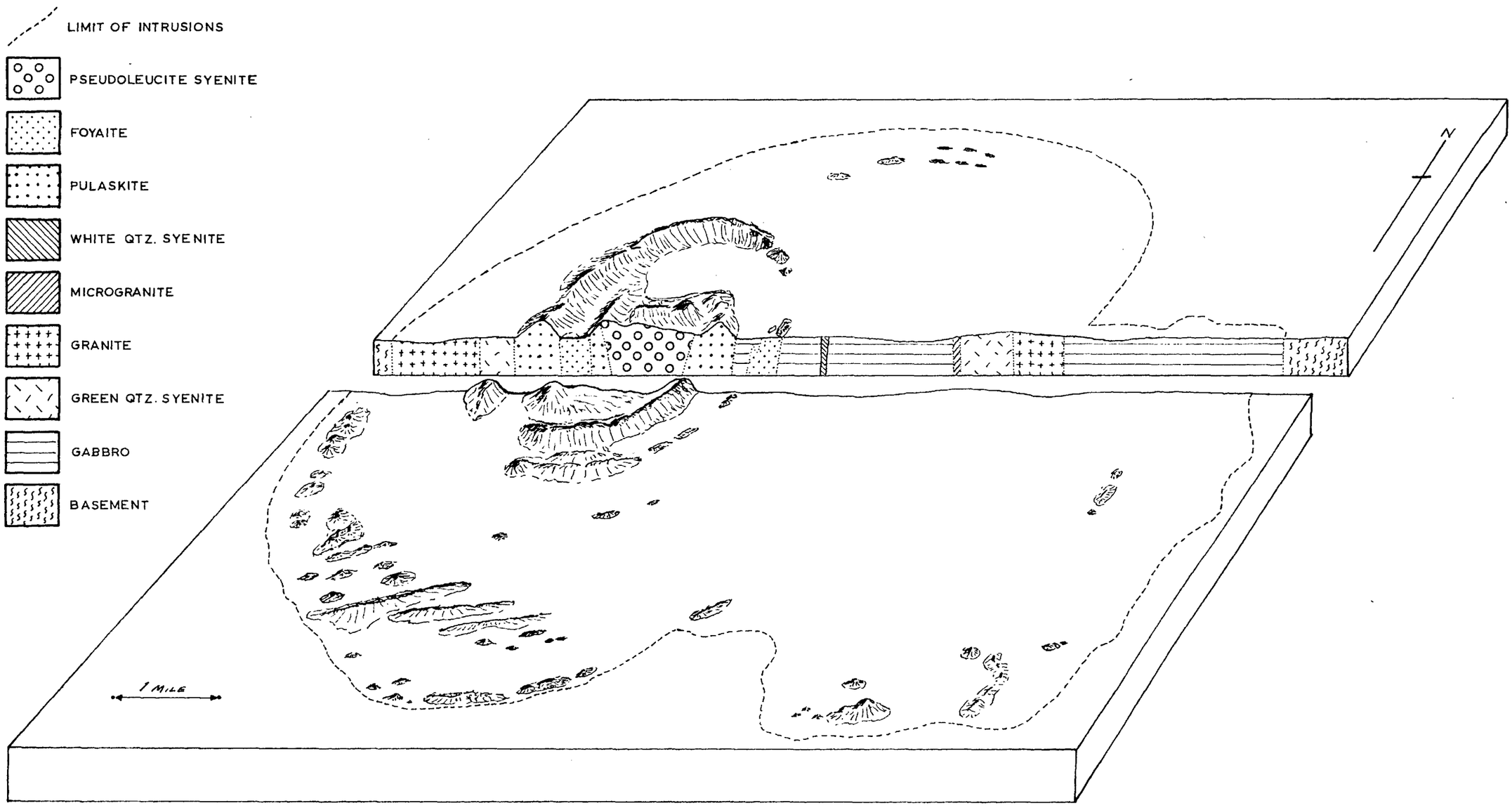
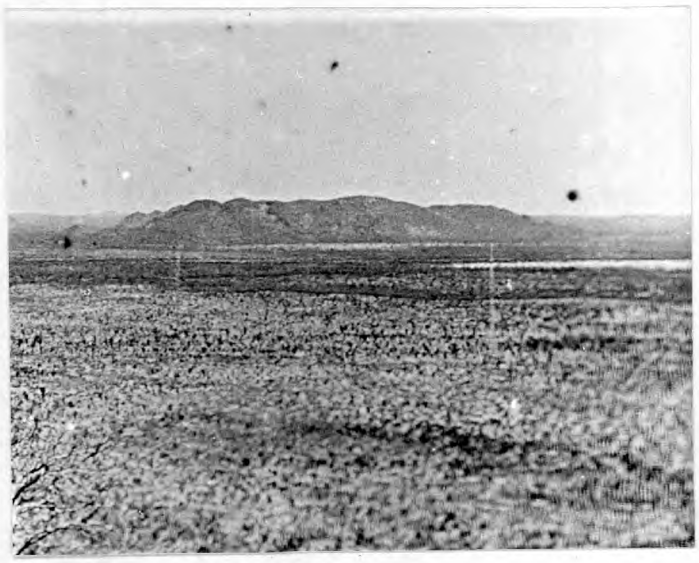
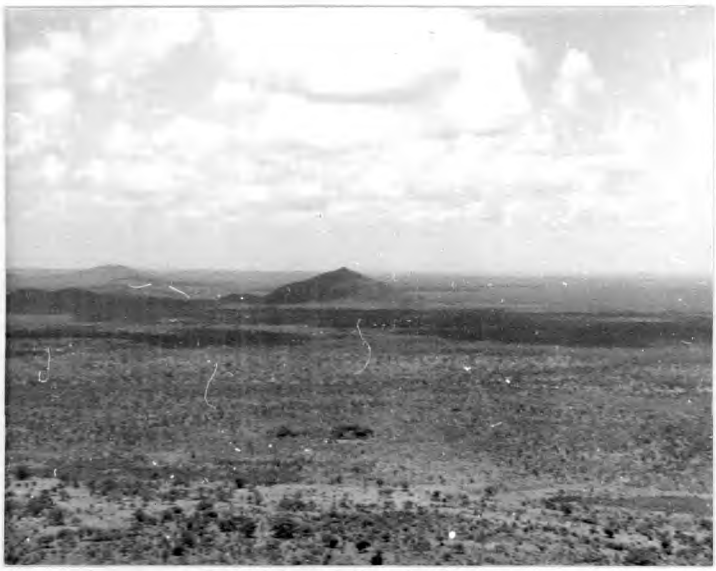


PLATE I

A. View of the Marangudzi hills looking north-west from Madawula. The hills rise approximately five hundred feet above the almost mature pediplain termed the 'Lowveld Surface' which is at a height of two thousand feet at Marungudzi.

B. View of Madawula from the Marangudzi hills illustrating the advanced stage of pediplanation attained in the region. The hill rising above the horizon to the left of Madawula is Nyalangundi.





have already been referred to on page 6. A more detailed map of the area immediately surrounding Marangudzi appears as figure 2; it has been prepared from the aerial photographs (uncontrolled) together with information gained from visits to specific parts of the basement in the course of the field work.

The basement occupies the major portion of the area covered by figure 2. The trend lines on this map have been traced from the photographs where they are shown up by changes in the concentration of vegetation across the strike. Observations at a number of places in the field show that in general these trend lines follow the lithology of the rocks. But north of the Mucumbwe hills it will be seen that an anomaly occurs, two sets of trend lines crossing: the north to south trend marks the strike of a quartzite; what the east to west trend represents has not yet been ascertained.

The typical rocks of the basement are metaquartzites (including banded ironstone), various gneisses and granulites (containing pyroxene, garnet, sillimanite, cordierite, spinel, epidote, etc.), amphibolites, serpentinites, and marbles. These rocks have all been highly metamorphosed and folded and show little evidence of their pre-metamorphic state. The quartzites, together with some of the other rock types, are believed to be of sedimentary origin, but show no sign of a sedimentary texture being so recrystalized as to have the appearance of vein quartz. Other types, such as the amphibolites and serpentinites,

are of igneous origin.

As can be seen from the map, the structure of the basement rocks is complex. They must have been subject to at least two major periods of folding to produce the closed structures such as that shown by the marble to the south of the ring complex, and most probably suffered more than two. In the vicinity of the Marangudzi complex, the srtike of the basement is found to be approximately parallel to the margins of the complex, and, where measured, the foliation dips steeply.

The metaquartzites are the best exposed of the basement rocks, and tend to form features such as Nyalangundi and Mucumbwe. The serpentinites to the west and south of the complex are also well exposed, and form low hills. The majority of the basement is poorly exposed and the trend lines are drawn, for the most part, in ground where cursory examination on foot might suggest that no solid rock is to be seen. However, as explained below, aerial photographs reveal the original trend.

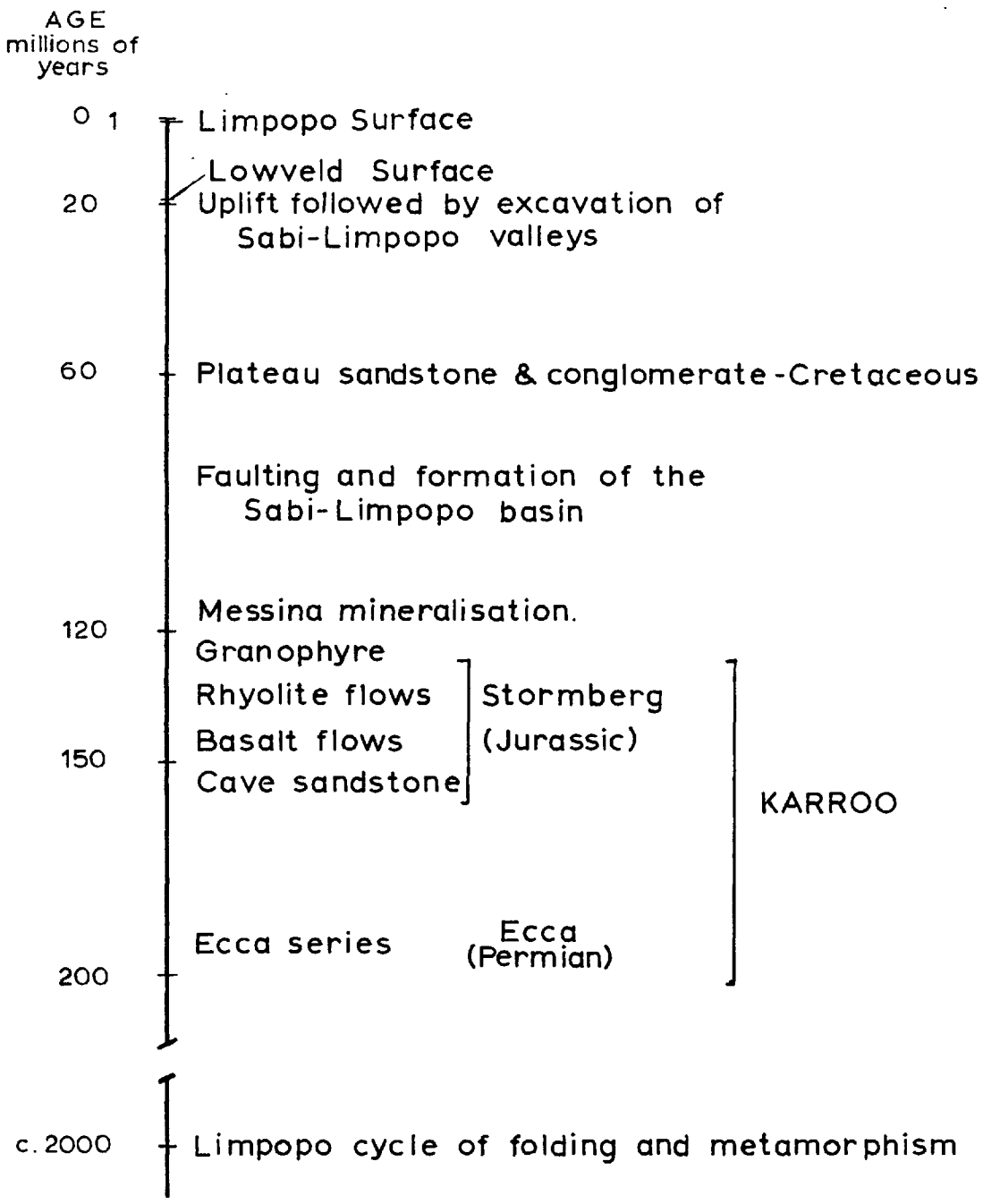
From what is known of the basement, it can be said to resemble that south of the Limpopo. These rocks to the south are much better known than those to the north of the river, mainly because copper mineralization in the area has stimulated research and resulted in a greater volume of available literature: Trevor and Mellor (1908), Rogers (1926), and Sohnge (1946).

Compared with the rest of Rhodesia, the basement in the Limpopo valley is of a higher metamorphic grade than that of the so-called gold belts (see Macgregor [1947]). But the general character and range of rock types is very similar to those basement rocks grouped together as the Bulawayan system.

The age of the Limpopo gneisses has not been finally ascertained. The results of radioactive dating (of the Limpopo gneisses and of other Rhodesian cycles too) have undergone several different interpretations - see Macgregor (1948), Holmes (1948), Macgregor (1951), Macgregor (1952), and Holmes and Cahen (1955). The most recent of these references is also the most comprehensive and gives a date for the Limpopo cycle of 2080 million years. The date ascribed to the Shamvian cycle is 2650 million years, this being the date for the close of the composite cycle of three basement systems - Shamvian, Bulawayan, Sebakwian. These dates are believed to be a fairly good guide to the periods of metamorphism in these rocks.

The Karroo rocks outcropping in the area are of several types, as can be seen from the table in figure 9. In the immediate vicinity of Marangudzi, the Karroo is represented by sandstone and shale, and minor intrusions of dolerite. The sediments can be seen in the south-east corner of figure 2, and have been downfaulted to the south along and E.N.E.-W.S.W. fault. It is to this downfaulting that the sediments owe their preservation, while the remainder of the formation, which

Fig.9 Table of Geological Formations and Events



must have covered much of the area at one time, has been eroded.

The Karroo sediments are cut by dolerite dykes and sills, many of which are several tens of feet in thickness. Karroo dykes are also found cutting the basement rocks. One of the more prominent dykes runs parallel to the karroo fault and about three miles to the north of it, (see figure 2). This dyke is over 100 feet thick and can be followed for over twenty miles on the photographs. More karroo dolerites can be seen in the north-easterly corner of the map.

The majority of the dykes that extend to the east and west of the major intrusions of the Marangudzi complex are believed to be associated with the Marangudzi intrusions. Those in the west and along the eastern margin of the complex are known to have formed at the same time as the complex, but the existence of the large dyke swarm crossing the Bubye river was not discovered during the field mapping. The presence of this swarm was only established when a more extensive coverage of aerial photographs was obtained to plot the trend lines in the basement. The most southerly dykes that cross the Bubye river near the point where the Cherera river joins it, show characteristics on the aerial photographs which suggest to the writer that they may be Karroo dykes, and not part of the swarm to the north. In the first place, they form discontinuous outcrops, in contrast to those in the north, and secondly, they appear less distinctly in the aerial photographs than the sharply defined dykes known to be associated with the Marangudzi complex. For these reasons, the

writer prefers to group them provisionally with the long Karroo dyke, which, as has been mentioned, runs west-south-west parallel to the Karroo fault and which crosses the Bubye river near the dykes under discussion.

The geological history of the area is summed up in the table figure 9, which shows the absolute ages as far as they are known.

CHAPTER 2

THE FIELD RELATIONS

Field Work

The Marangudzi ring complex consists of major and minor intrusions of basic, acid, and undersaturated rocks. The major intrusions cover an area of thirty square miles, and minor intrusions extend up to sixteen miles into the basement complex in which the igneous rocks have been intruded.

The earliest and largest of the major intrusions is of gabbro which was originally an elongate body trending northwest - southeast. This was subsequently divided into two by a large acid ring intrusion which encircled the northwesterly portion of the gabbro. A number of nepheline bearing syenites were then intruded into a circular area which lies within the acid ring, but which is offset to the northwest of the centre of that intrusion. Undersaturated rocks have also been intruded at the southeasterly extremity of the gabbro.

Dykes are associated with the various major intrusives, their trend being predominantly east - west. They cut the rocks of the complex and surrounding basement, and form a swarm to the east of Marangudzi.

The following intrusions have been recognised:

Major Intrusions

The Basic Intrusions

Gabbro
Orthoclase Gabbro
Microgabbro
Anorthosite
Peridotite

Essexite

The Acid Intrusions

Green Quartz Syenite
Granite
Microgranite
White Quartz Syenite
Central Quartz Syenite

The Undersaturated Syenites of the Marangudzi Centre

Pulaskite
Foyaite and Contaminated Foyaite
Microfoyaite
Pseudoleucite Syenite

The Undersaturated Intrusions of the Madawula Centre

Nepheline Syenites
Malignite

Minor Intrusions

Basic Dykes

Porphyritic Dolerite
Altered Dolerite
Dolerite
Basalt

Acid Dykes

Microgranite Dykes
Aplite

Trachyte Dykes

Undersaturated Dykes of the Marangudzi Centre

Phonolite
Felspar Phonolite
Pseudo-leucite Phonolite
Nepheline Syenite
Nepheline Vogesite

Undersaturated Dykes of the Madawula Centre

Syenitic Dykes
Nepheline Lauprophyres

Before describing the field relations of the various rocks, an outline of the field techniques employed will be given, since they differ from those used in this country.

Aerial photographs of the area were obtained. These were at a scale of 1:40,000 and had been flown three years before, but were not significantly out of date. Enlargements of these photographs were made and mapping was carried out on them by means of overlays. The scale of these was approximately five inches to the mile, but as much detail had been lost during enlargement one's position usually had to be found on the standard photographs and then transferred. Overlays were necessary because it was impossible to work directly on the photographs. Tracing cloth was used in the making of the overlays, its durability under prevailing field conditions compensating for its relative lack of transparency.

The area consists of an almost mature pediplain and on the plain itself exposures are poor. The outcrops in this ground are mostly of the more resistant rocks such as granite and some of the dyke rocks. On the other hand, loose blocks and soil type provide reasonably reliable information about the rock type at a particular place. This may not be specific, for example a soil bearing quartz might indicate granite or basement gneiss. However, used with caution such evidence can yield results which are reliable and which could not be obtained if the exposures alone were considered.

The vegetation growing in thevicinity of thecomplex may show control by the underlying bedrock, which, even when not noticeable in the field, is apparent from the aerial photographs. Control by the bedrock of the type of vegetation growing on it is best demonstrated by comparison of the flora of the granitic ring with that of the gabbro, and control of the density is especially remarkable in the case of the dykes. (Concentrations of trees along the dykes stand out as dark lines on the aerial photographs, and these are often readily seen at ground level).

Differential weathering causes some unusual effects in places, as in the poorly exposed ground just east of the Marangudzi hills. Here several dykes (see figure 1) have been plotted for some distance. These dykes are fairly well exposed and are frequently overlain by lines of trees which serve to link the exposures rogether. In contrast, no exposure of the rock into which the dykes have been intruded could be found and it is apparent this rock (probably gabbro) has weathered much more thoroughly than the dykes. It seems most likely that the situation is reversed in the granitic ring, farther east, where only one or two loose blocks of dyke rock were found although there is evidence to suggest that many of the dykes probably cut this ring.

Exposure is better on the hills in spite of the fact that the slopes are covered in scree. The surface relief of the central mass

of undersaturated rocks is controlled by the underlying intrusions to a great extent, and this was of assistance in mapping the syenite rings.

When the field work was completed a topographical map was made from the photographs, on our return to Britain. A control in the form of a compass and mileometer traverse around the roads of Marangudzi was used. Contouring was not feasible, owing to the lack of altitude control and the relatively low relief, and form lines have been used to give a general idea of the relief. This map was made at a scale of four inches to the mile.

The geological information recorded on the field slips was then transferred on to the topographical map. This could be done quite satisfactorily as several of the geological features mapped in the field are clearly apparent on the aerial photographs, and were plotted on to the topographical map as it was made. This map, reduced to a scale of three inches to a mile, appears as figure 1. For the most part, one type of ornament is used for each rock type, but in the case of the gabbro two types are used, the paler ornament indicating the probable geology of the unexposed areas as suggested by the photo-geology. A lighter ornament is also used for part of the undersaturated intrusions originally mapped as pulaskite, but which petrological study suggests might be classed with the foyaite.

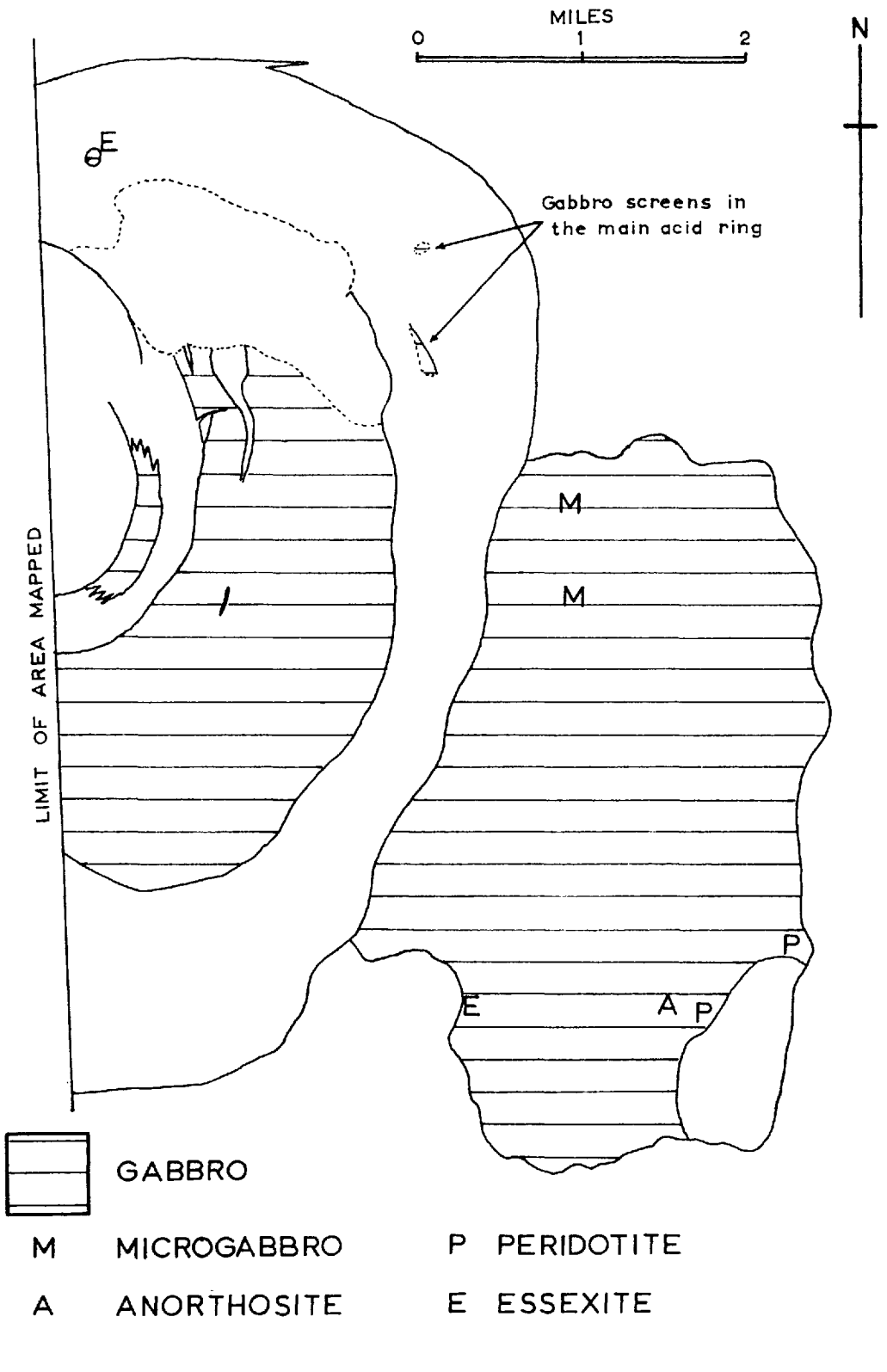
The Basic Intrusions

The basic intrusions, mainly gabbro, occupy nearly half the outcrop area of the igneous rocks of Marangudzi. For the most part the ground underlain by the gabbro is featureless, but in the south-east, gabbro forms the hill named Madawula and the surrounding kopjes, and also some small kopjes about two miles to the north. The extent of the basic rocks is shown in figure 10.

In general, the gabbro is a medium grained rock (grains between 1 and 5 millimetres), no coarse grained examples being found. At some localities the rock borders on the fine grained (below 1 millimetre), and a true microgabbro is found to have intruded and broken up the coarser grained rock in the eastern gabbro mass. The gabbro is usually a grey rock with colour index from twenty-five to fifty. It is frequently olivine bearing, although the olivine is often present in minor quantities only. Biotite is common, and at most localities is readily noticeable in the hand specimen even when it is present only in accessory amounts.

The main body of the gabbro shows no outstanding variations in the field, excluding the varied assemblage of basic rocks occurring around the Madawula centre. At one or two localities flow banding was noted, but in general the rock is even textured and no banding resulting from gravity separation was observed. Many specimens have an even grain, but some show a porphyritic texture.

Fig. 10. Outcrop of the Basic Intrusions



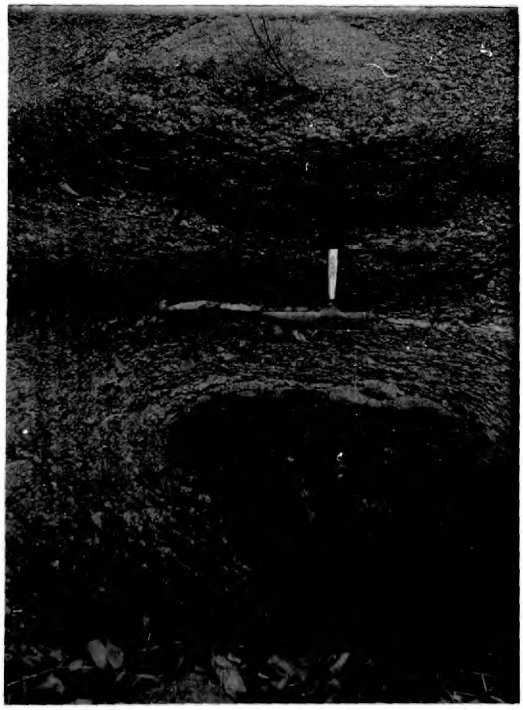
When well exposed, the gabbro shows strong although variable jointing. Frequently this is obscured as a result of attack by weathering agents along the joint planes, fine examples of spheroidal weathering being produced. In fact, a typical exposure of gabbro consists of a few rounded boulders of fresh rock isolated from fresh rock in depth but even so more or less in situ. A photograph of an exposure in a stream bank, illustrating this well, is shown in Plate IIa. When exposed, the gabbro shows two or three sets of vertical joints, and also a strong horizontal jointing. This jointing causes the formation of very angular blocky scree on the hill slopes.

In some places, the gabbro was found to be veined by later material. North of well 551, nepheline bearing veins were found filling the joints, and in the stream section just east of the granitic ring, pegmatitic quartz-felspar veining was observed. Here the gabbro had joints at 24°, 46°, and 96°, with those striking at 96° filled with acid vein material, the others being open. This suggests that an east-west jointing existed prior to the acid phases of intrusion or was possibly induced by the intrusion of the main granite/quartz-syenite ring. Along the inner margin of this ring at the junction of the microgranite and the gabbro, the latter is found to have been invaded by the microgranite. The extent to which this invasion has taken place can be judged from Plate IIa. This is a photograph of a core from a borehole showing the numerous, almost

PLATE II

A. Spheroidal weathering of gabbro. The exposure is in the bank of a stream and illustrates the weathering of the gabbro underlying the pediplain.

B. Core from borehole showing gabbro being veined by, and becoming xenolithic in, microgranite, at the contact of the gabbro and microgranite.





vertical, tongues of microgranite, and the remnants of the gabbro. The latter has suffered alteration.

Between the main pulaskite ring and the foyaite ring in the south-east, exposures of gabbro are found. Here the rock is veined by syenitic material. Moving east, the gabbro is found to have been more and more veined and broken up by syenite until it is seen only as xenoliths in the syenite. This arrangement is represented on the map by a sawtooth boundary between the two types of rock. The same relationship appears to occur in the north although exposure is poor there. The syenite that absorbed these gabbro xenoliths typically contains biotite and was named biotite syenite in the field, but has since been termed 'contaminated foyaite'.

The microgabbro mentioned earlier, occurs in several localities. It is especially prominent along the stream section in the northern part of the eastern gabbro, just east of the granite ring (figure 1). When the microgabbro forms a major part of an exposure it has been indicated on the map by a letter M. The microgabbro first appears as joint fillings and dyke-like bodies in the gabbro just south of the large granitic dyke. It rapidly becomes more prominent to the north, until the gabbro is reduced to large xenolithic masses set in microgabbro. Further north still, as one approaches the contact of the basic rocks with the basement, the microgabbro is no longer found. This fine grained variety of the gabbro was not mapped as a separate

rock type in the field as the complex relationship with the true gabbro made this impossible. In several places, the microgabbro showed a certain amount of flow banding. This banding was controlled by the local form of the intrusion and was usually vertical with a variable strike.

North-east of Madawula the gabbro appears to have undergone differentiation not found elsewhere. Here at the northern end of the long kopje east of Madawula, a peridotite outcrops and makes up the whole of the northern end of the kopje (the southern part consisting of later undersaturated rocks). On the small kopje just west of the peridotite a pyroxene bearing anorthosite was found. Each kopje appeared to consist entirely on one rock type. It was not possible, due to bad exposure, to discover the nature of the contact between them, or their relation to the surrounding gabbro. Peridotite is again exposed along the northern contact of the nepheline bearing rocks of the Madawula centre, and several exposures of mafic rich rocks were found surrounding the leucocratic rocks of this centre. It was not at all clear in the field whether these ultramafites, many of which contain small amounts of nepheline, were directly connected with the Madawula centre or were originally gabbroic rocks which had been subsequently metasomatically altered during the intrusion of the Madawula mass.

Isolated from the main gabbro and intruded into the granite

green quartz syenite ring were found two intrusions of basic rocks. These occur in the north, and the largest is of the order of one hundred yards across. These two intrusions, together with a small area of basic rocks on the southern boundary of the eastern gabbro, have been found to be nepheline bearing gabbros or essexites. They are marked on the map (figure 1) with an E. Two of these exposures, the larger of those in the north and that in the south, show evidence of brecciation. They consist of angular fragments of a finer grained variety of the rock in a slightly coarser grained matrix of similar composition. Boundaries with the surrounding rocks are not exposed, but it would appear that the intrusions are roughly circular in form and later than the granitic rocks.

In the north-easterly part of the main acid ring intrusion three exposures of gabbro are found. These exposures are of normal gabbro, although somewhat altered, and one of the outcrops is long and narrow and has a trend which parallels the strike of the ring at this point. This gabbro is believed to be part of the original gabbro intrusion which has remained as 'screens' in the granitic intrusions. Gabbro screens have also been observed by Mr G. Rees in the western part of the complex. Whenever exposure is good, numerous dykes are seen to cut the gabbro. Recognition of the dykes is assisted by the fact that differential weathering frequently causes the latter to stand up above the gabbro. In some localities,

as for example east of the Marangudzi hills, the dykes may be readily recognised although the surrounding gabbro is badly exposed. The majority of the dykes have an east-west trend, but in the area within the granite ring they do show a radial pattern, although there is a predominance of those striking westwards. The dykes which cut the gabbro range from acid to basic types, and also include a large number of felspathoid bearing varieties. The granitic dykes are confined to parts of the gabbro adjacent to the granitic ring, and are associated with the granite intrusion. Some of the dykes give rise to a large quantity of blocky debris which tends to give a misleading idea of the size of the dyke. The above phenomena make it possible to trace dykes for considerable distances in otherwise poorly exposed ground.

The contacts of the gabbro with the basement are almost entirely unexposed, but granitic rocks were found along the contact at several places in the north and again in the south. The granitic rocks in the north might be a part of the basement, but those in the south would appear to be younger than the basement for they contain gabbroic xenoliths at one point. This suggests that these granitic rocks at least are connected with the Marangudzi complex.

It is concluded from the field evidence that the gabbro is the earliest of the major intrusions and was originally a slightly elongated body running roughly northwest-southeast. It was divided

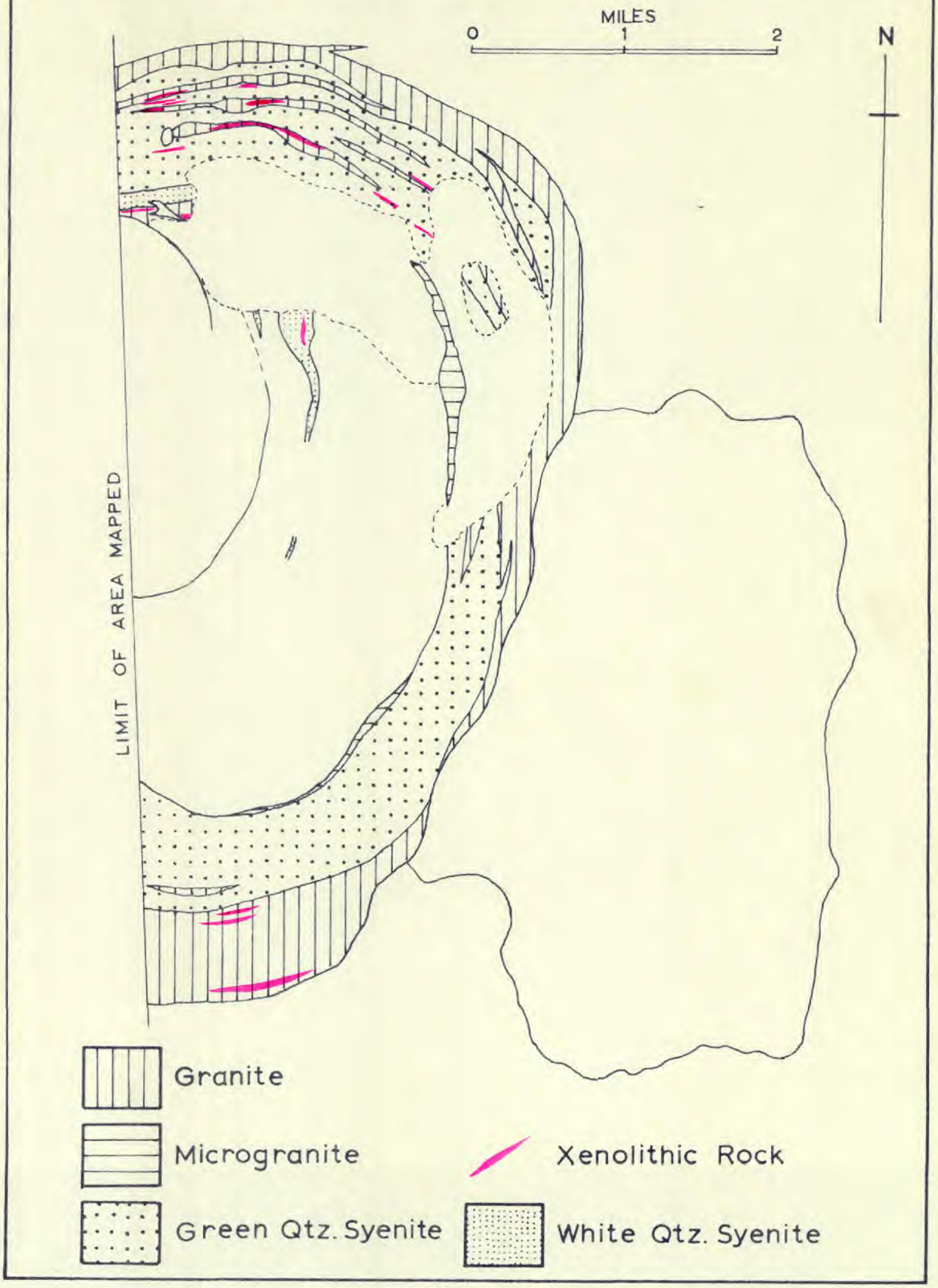
into two by the emplacement of the granitic ring intrusions and was later intruded by undersaturated rocks at two centres, the major centre in the north-west and the smaller at Madawula in the south-east. The gabbroic rocks are cut by all the main dyke types, many of which can be associated with stages in the emplacement of the various major intrusions. The latter have also been found to contain xenoliths of gabbro in several localities.

The Acid Intrusions

The outcrop of the acid intrusions occupies approximately three eighths of the total area of the complex. Their extent can be seen on figure 1, and is brought out more clearly in figure 11.

The major portion of the acid rocks occurs as a large ring intrusion approximately five miles across from east to west and seven miles across from north to south, and which is up to one mile wide. The outermost part of the ring consists of granite and the innermost of quartz syenite. About two thirds of this ring lies within the author's area. Along the inner contact of the eastern portion of this ring is found a narrow discontinuous intrusion of microgranite (shown in figure 1). The remaining acid rocks are quartz syenites which occur as an irregular discontinous ring intrusion in the gabbro between the main granitic ring and the undersaturated intrusions of the Marangudzi, and also an outcrop of quartz syenite in the northern crater of the Marangudzi hills.

Fig.11. Outcrop of the Acid Intrusions



The main granitic ring intrusion divides the gabbro into two and encircles the north-western portion. Except for the eastern side which is in contact with the gabbro the outer margin of this ring is in contact with the basement (see figure 1).

The granite and quartz syenite of the main ring are frequently deeply weathered, as can be seen in Plate IIIa. The quartz content of these rocks varies from about thirty per cent in parts of the granite, down to almost zero in much of the syenite. Weathered specimens of these rocks can be difficult to separate, but when fresh the felspar of the quartz syenite is deep green in colour. To distinguish it from the quartz syenite of the inner discontinuous ring, this has been called the green quartz syenite.

The green quartz syenite is a medium to coarse grained rock consisting mainly of green potash felspar with accessory amounts of quartz and mafic minerals. At some localities, the green quartz syenite is xenolithic, the xenoliths being in an advanced stage of digestion. On the map figure 11, the presence of xenoliths is indicated by an ornament. The xenoliths are especially abundant in certain bands which will be called xenolith trains. One of the best exposed outcrops of xenolith trains is seen where the stream flowing north from the old village two and a half miles east of Marangudzi crosses the acid ring in the north-west. The xenolithic rock is more resistant to weathering than the normal rock, and is richer in mafic

PLATE III

A. A typical exposure of green quartz syenite. The rock is deeply weathered and crumbles when hammered. The weathering has penetrated most deeply along the numerous joints.

B. Xenoliths in granite (left) and green quartz syenite (right) showing the development of porphyroblastic potash felspar within the xenoliths.





constituents. The trend of the xenolith train suggests that it is the same xenolithic band as that which is exposed in a tributary to the west of the main stream. The trend of these trains parallels the granitic bands in the green quartz syenite and the edges of the intrusion. Further discussion of xenolith trains will be found in later pages.

In the hand specimen the green quartz syenite appears to be of constant composition, and no mineralogical variation was observed in the field to account for the green quartz syenite forming a number of kopjes in the south, whereas it is featureless in the north and east. In the north along the inner parts of the intrusion, the green quartz syenite is found to be veined by aplitic material. The aplite veins are usually one or two inches in width, although some are up to a foot wide. They occur as joint fillings and show no particular trend. The green quartz syenite immediately adjacent to the veins has been somewhat hardened by them and is more resistant to weathering than rock further away.

The granite of the main ring is more variable in composition and in grain size than the green quartz syenite. The percentage of quartz varies from about thirty to a little below ten in some specimens. Mafic constituents generally make up less than fifteen per cent of the rock, and may be amphibole or pyroxene, with ore. The granite occurs along the outermost portions of the ring and also intrudes

the green quartz syenite as narrow concentric bands and offshoots of the main intrusion. These granitic bands are particularly common in the north. They are variable in width, the wider sections forming low kopjes. The granite of these bands often contains trains of xenoliths.

Each xenolith train consists of a band of acid rock set with large numbers of basic xenoliths. The bands can range from one or two feet to over fifty feet in width, and may be followed for a quarter of a mile, in some cases. The contacts of the xenolith train and the surrounding rock are sharp, as is well seen in plate XI. The trains appear to be vertical and parallel the sides of the acid rock in which they occur. The xenoliths are fine grained doleritic rocks. Many of the xenoliths have an elongated cross-section as seen in horizontal surfaces, and lie with their long axes parallel to the trend of the train as a whole. The smaller trains show a higher degree of alignment than the very broad trains. Usually the xenoliths range in size up to a foot across, but in two localities in the north some large xenoliths up to ten and fifteen feet across were seen.

The matrix consists either of quartz syenite or, more commonly, of granite, and the train may be intruded into either quartz syenite or granite. Granitic xenolith trains have been found in the green quartz syenite, but no quartz syenite trains were seen in the granite. It was seen that some xenoliths contain large potash felspar crystals

PLATE IV

A. Granite packed with sub-angular xenoliths. North of 'Deserted Village' northern Marangudzi.

B. Rounded xenoliths in granite near the southern margin of the main acid ring.





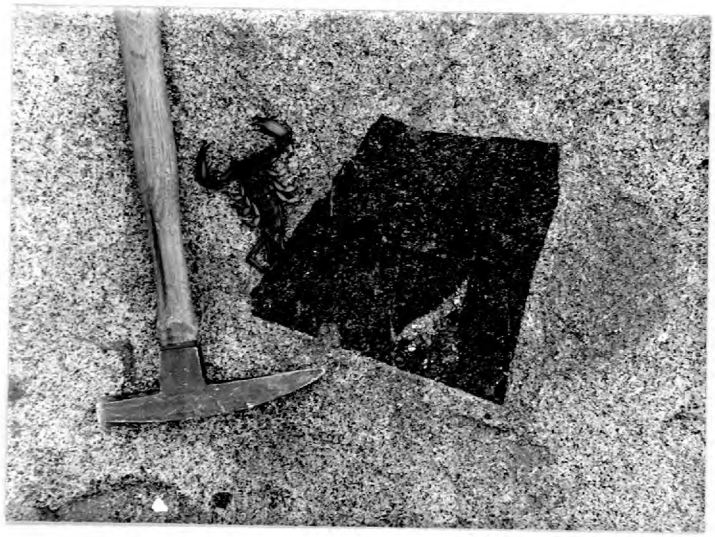
and that these matched the large felspar of the acid matrix. Thus xenoliths in the green quartz syenite contain green potash felspar and those in the granitic rock contain flesh coloured felspar.

The origin of the xenoliths was not satisfactorily explained in the field. In the northern part of the granitic ring (about four hundred and forty yards north of the larger intrusion of essexite shown in figure 1) two dolerite dykes with a concentric trend were found. These are unusual, for all other dykes in the granite have a radial trend from the centre of the ring. Along the strike of one of these dykes, after a short unexposed stretch, a xenolith train was found and no continuation of the dyke could be seen. Although it is not completely certain, the field evidence strongly suggests that this dyke gave rise to the xenoliths in the train. It is possible that the other xenolith trains have a similar origin. Other xenoliths than those occurring in trains are found in the granite. Examples of these isolated xenoliths are shown in plate V. Compared to those just described, these xenoliths are angular and have a coarse gabbroic texture. They are rare and restricted to parts of the granite just north of the undersaturated intrusions of the Marangudzi centre. They would appear to be undoubtedly of gabbroic origin, and their presence suggests the gabbro extended as far north as this prior to the intrusion of the granite.

PLATE V

A. Angular xenolith of gabbro in granite just north of the Marangudzi hills. Xenolith shows no visible sign of alteration.

B. Basic xenolith in granite with slightly rounded corners and with well defined marginal zone showing alteration. Fragments of xenolithic material also present in granite.





The Microgranite

Along the inner margin of the granite/green quartz syenite ring in the south and east, a narrow intrusion of microgranite was found. The relation of the microgranite to the green quartz syenite was not discovered, but cores from a borehole in the south showed that it had veined the gabbro extensively in places. Plate 11b is a photograph of a core from this borehole at a point where the gabbro only remains as narrow tongues in the microgranite. Although field evidence does not give an age relationship with the green quartz syenite and granite, it seems probable that it is later than these and is the last intrusion in the main acid ring.

Minor Intrusions in the Main Acid Ring

No pegmatites were found to be associated with the granitic rocks of the main ring, although some very coarse grained pegmatites were found in the basement in the north and in the stream section south of the gabbro. These pegmatites would appear to form part of the pre-Cambrian basement, and to be entirely separate from the igneous rocks of the complex.

Very few minor intrusions were found to cut the granite/green quartz syenite ring, although it seems reasonable to suppose that differential weathering might account for the lack of exposed dykes. This is especially so along the eastern portion of the ring where exposure is particularly poor, and one or two loose blocks of dyke rock were found.

In the northern part of the ring, about a quarter of a mile west of the deserted village (figure 1), were found some dykes with a rather unusual form. These are illustrated in plate XI and figure 12. In the field they were named 'meandering dykes', since their sinuous nature was reminiscent of a meandering stream. Two examples of this type of dyke were also found in the southern part of the ring. Meandering dykes cut both the granite and the green quartz syenite. They are of dolerite and are essentially radial in trend; they cut several xenolith trains in the north, as can be seen from plate XI, and they also cut individual xenoliths within the trains. From plate XI it can be seen that the meandering dyke rock has been veined by lighter material. This is shown more clearly in figure 12, where the fracturing and veining of the dyke rock is seen to be well developed where the dyke bends sharply. The veining was found to be quartz-felspar veining. The conclusion drawn from the above observations is that the meandering dykes were intruded during the final stages of consolidation of the green quartz syenite and granite, but before movement in the almost cooled 'magma' had completely ceased. Slight movements along the strike of the granite bands and parallel to the edges of the intrusion displaced sections of the dyke and gave rise to the characteristic 'meandering' form. The dykes, which have proved to be dolerites, fractured at this stage, whereas the granite rock was still able to undergo plastic deformation. The brecciated

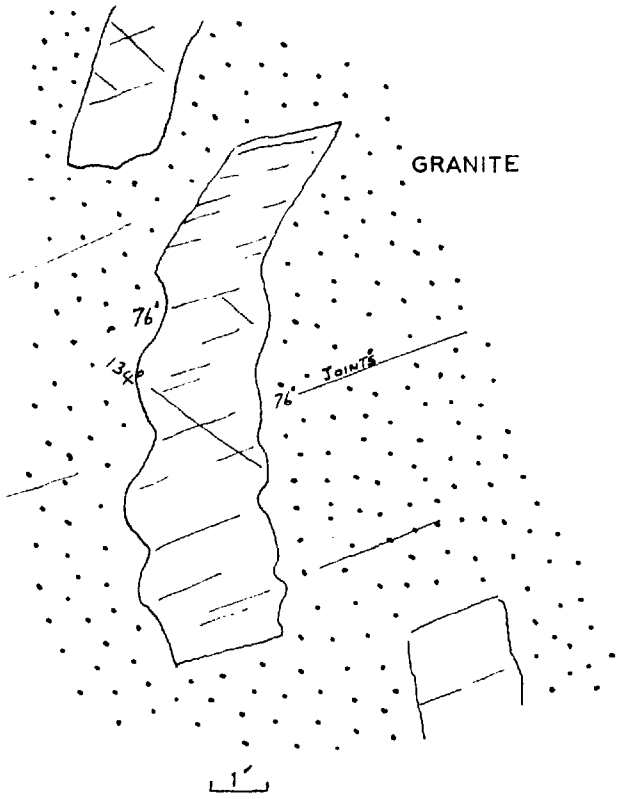
fragments of dyke were then cemented by quartzo-felspathic vein material during the final stages of cooling (see Plate XI).

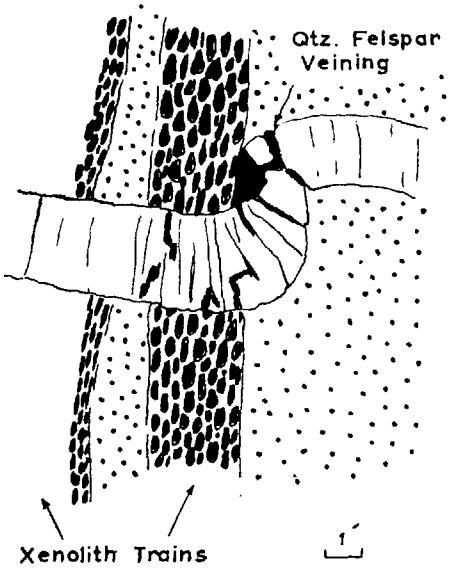
In the south, late movement in the granite has been such that sections of one of the meandering dykes have been considerably displaced as shown in figure 12.

The meandering dykes are from two to three feet wide and are of constant width if measured at right angles to the general trend of dyke. The apparent thickening and thinning of the dykes is due to the shearing which has caused their unusual form.

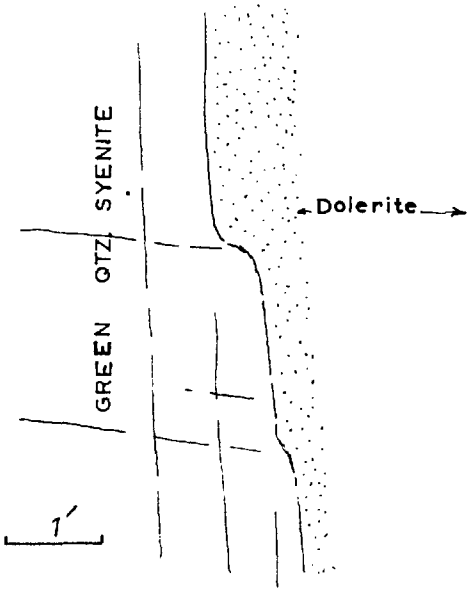
Fig.12. Dykes in the Acid Rocks

Meandering Dykes (dolerite).





Joint controlled walls



Curved cooling joints

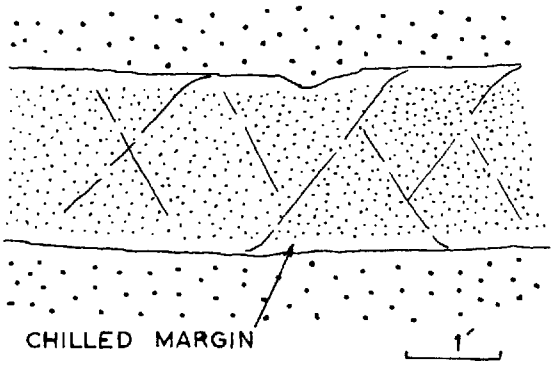
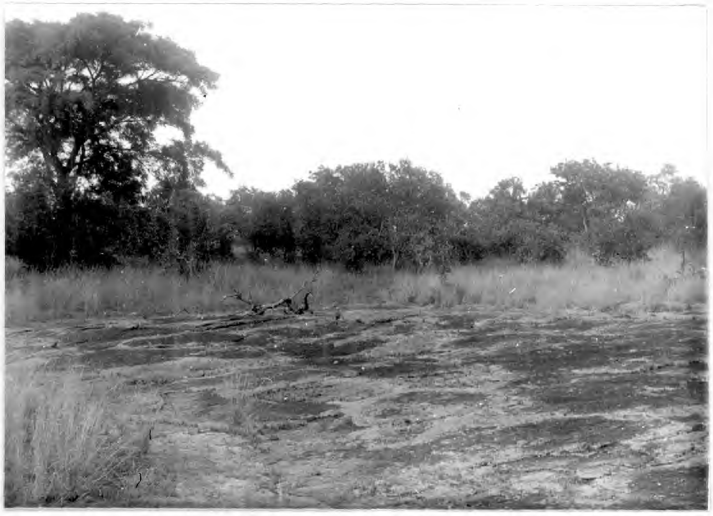


PLATE VI

A. Pavement-like exposure of granite. This type of exposure is found in all parts of the granite ring. Weathered material exfoliates from fresher rock below, leaving a gently undulating surface.

B. Well developed jointing in granite. The strong jointing is radial in trend and the weaker joint in the foreground is concentric.





Structure of the Acid Ring

The acid ring is steep sided, but the actual dip of the contacts is not known. Some evidence is provided by the smaller granitic bands which occur with the quartz syenite in the northern part of the ring. In places these can be seen to be approximately vertical and this may indicate the attitude of the ring structure as a whole in this part of the intrusion. Further evidence as to the probable form of the intrusion is provided by the attitude of the flow banding found in the granite. This banding is brought out by an orientation of the crystals of potash felspar which lie with their long axes subparallel. The degree of orientation may be low, and, while visible in the field on an exposed surface, it may not be discernable in the hand specimen. It is best seen in the narrow intrusions of granite and rarely appears in the broad intrusion of granite along the outer margin of the acid ring. This banding runs parallet to the edges of the intrusions of granite, and is approximately vertical.

When well exposed, the granitic rocks show good jointing which is usually vertical or very steeply dipping, (Plate VIb). The strikes of these joints at any point show two trends. One radial set trends roughly, but not as will be shown precisely, towards the centre of the ring, and the other parallels the sides of the intrusion. The geometrical centre of the granitic ring is a point south-east

of the trigonometrical beacon, but the focus of the joints is a point nearer the trigonometrical beacon. These two points are about 1200 yds apart. Figure 13 is a plot of the angle made by the trend of a joint with the radial from the postulated focus. This shows clearly that the joints are truly radial, although with respect to a centre offset from the geometric centre of the ring.

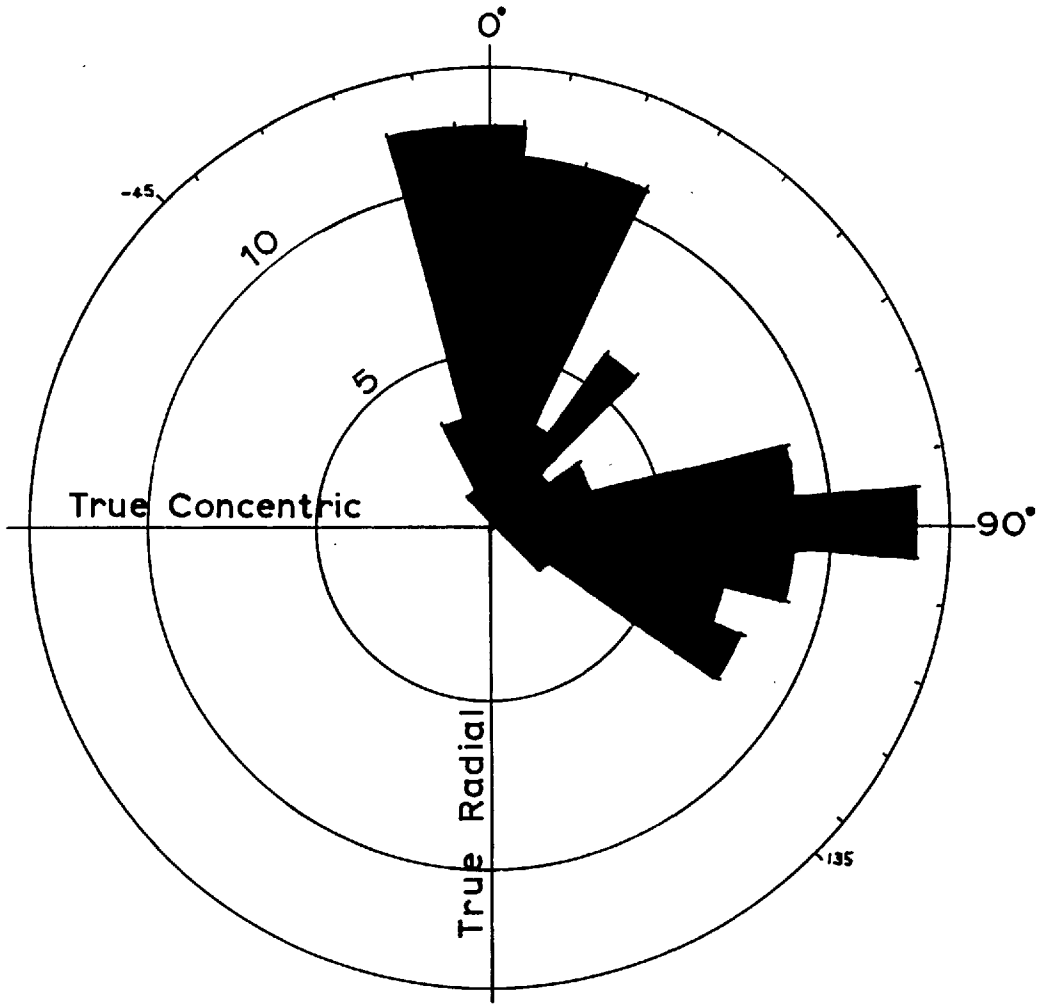
The White Quartz Syenite

Intruded into the gabbro between the main granitic ring and the central undersaturated intrusions of the Marangudzi centre is the discontinuous ring intrusion of white quartz syenite.

In the field this was termed the spotted white syenite because of the presence of small mafic 'spots' occurring throughout most of the intrusion. The outcrop of the white quartz syenite is shown in figure 11 and in greater detail in figure 1. In the north it cuts granite of the main granitic ring showing it to be later than this intrusion. The outcrop to the east of the Marangudzi centre is narrow in the south (about ten yards) but broadens rapidly to the north (up to four hundred yards). A small outcrop was found one mile almost due south of this easterly intrusion. Disconnected intrusions of white quartz syenite occur in the western portion of the complex being studied by Mr G. Rees. Taken as a whole, these intrusions form a discontinuous ring whose centre is offset to the north-west from the centre of the main granitic ring. The full

Fig.13. Jointing in the Main Acid Ring

This diagram is a plot of the angles between the joints and the line drawn from the Marangudzi trig. beacon to the locality at which the joint was measured; the frequency of joints with similar angles of deviation being shown.



significance of the centres of these ring intrusions will be discussed in the final chapter.

The white quartz syenite is rich in basic xenoliths at two localities, and contains scattered xenoliths throughout much of its outcrop. The rock is typically inhomogeneous in the field and the quantity of mafic minerals it contains shows a variation which is thought to be connected with the absorption of xenoliths. The more mafic rich parts contain mafic clots similar to those which can be seen in those xenoliths which are in a more advanced stage of alteration. Some of the xenoliths show little alteration in the hand specimen, retain a gabbroic texture, and have obviously been derived from the gabbro. With others it is not possible to state their origin with certainty, even with the help of a microscope, but most of the xenoliths appear to have been derived from the gabbro. The xenoliths are normally six inches to a foot across, but in some cases they may reach several feet across. The distribution of the xenoliths is shown in figure 11.

The white quartz syenite intrudes the gabbro as dyke-like bodies in the east. These 'dykes' extend eastwards from the easterly intrusion of the syenite for about five hundred yards. They are wider near the main intrusion (ten feet) and taper gently farther away (down to two feet wide before they cease to be exposed). The dykes of syenite, except in being slightly finer grained, are similar to

the main intrusion and were found to contain xenoliths of gabbro in places.

The main intrusion of white quartz syenite is cut by several phonolite dykes, but at one point in the southerly part of the eastern intrusion was found to cut a phonolite dyke. This dyke is the variety bearing porphyritic felspar and the significance of this will be discussed in the section on dykes.

The Central Quartz Syenite

Outcropping in the centre of the northern crater, surrounded by undersaturated intrusions, are several exposures of a syenitic rock which is quartz bearing in places. It is rather variable in type and in the stream section where the cut line crosses the stream it is seen to be cut by a pegmatite vein about nine inches wide, striking north-south, and also to be veined by aplitic material. The pegmatite consisted of potash felspar and plagioclase with lath shaped amphibole cystals extending from the walls of the vein towards the centre, little or no quartz being present. A dyke was also found cutting the syenite in this locality, and has since been shown to be a dolerite. In places, in the south-easterly parts of the area of outcrop, the syenite has been considerably altered. The weathered rock showed a certain amount of limonite staining, and limonite with traces of pyrite and chalcopyrite, suggesting that sulphide mineralization had taken place during a period of hydrothermal activity which also

affected the rock.

The origin of this body of syenite and its relation to the undersaturated intrusions is not at all clear. The presence of a dolerite dyke (see section on dykes) strongly suggests that this syenite is associated with the rest of the granitic rocks of the complex, and is older than the intrusion of the main mass of undersaturated rocks which are not cut by dolerites.

The Undersaturated Intrusions

The undersaturated rocks occur at two centres. The larger of these is a series of ring intrusions that form the Marangudzi hills, and the smaller a varied assemblage of undersaturated rocks in the south-eastern corner of the eastern gabbro. These have been termed the Marangudzi and Madawula centres respectively, and are shown in figure 14. The Marangudzi centre is much the larger of these, being approximately two miles in diameter, although slightly elongated along a north-south axis. The Madawula centre is also elongated along a north-south axis, being approximately a mile and a half long, by half a mile wide.

The Marangudzi Centre

The Marangudzi centre is displaced to the north-west with respect to the main granitic ring. The rocks of the centre are in contact with the rocks of the granitic ring in the north and west, and in the east and south are bordered by gabbro. As can be seen from figure 14

a little under half the area occupied by the rocks of the Marangudzi centre lies within the ground mapped by the author.

The rocks of the Marangudzi centre were divided into four groups in the field according to the content of nepheline, and have since been named following the classification proposed by Johanson (1938). The names of these groups in the order of intrusion are as follows:

(a) Pulaskite

(b) Varieties of Foyaite

Contaminated Foyaite

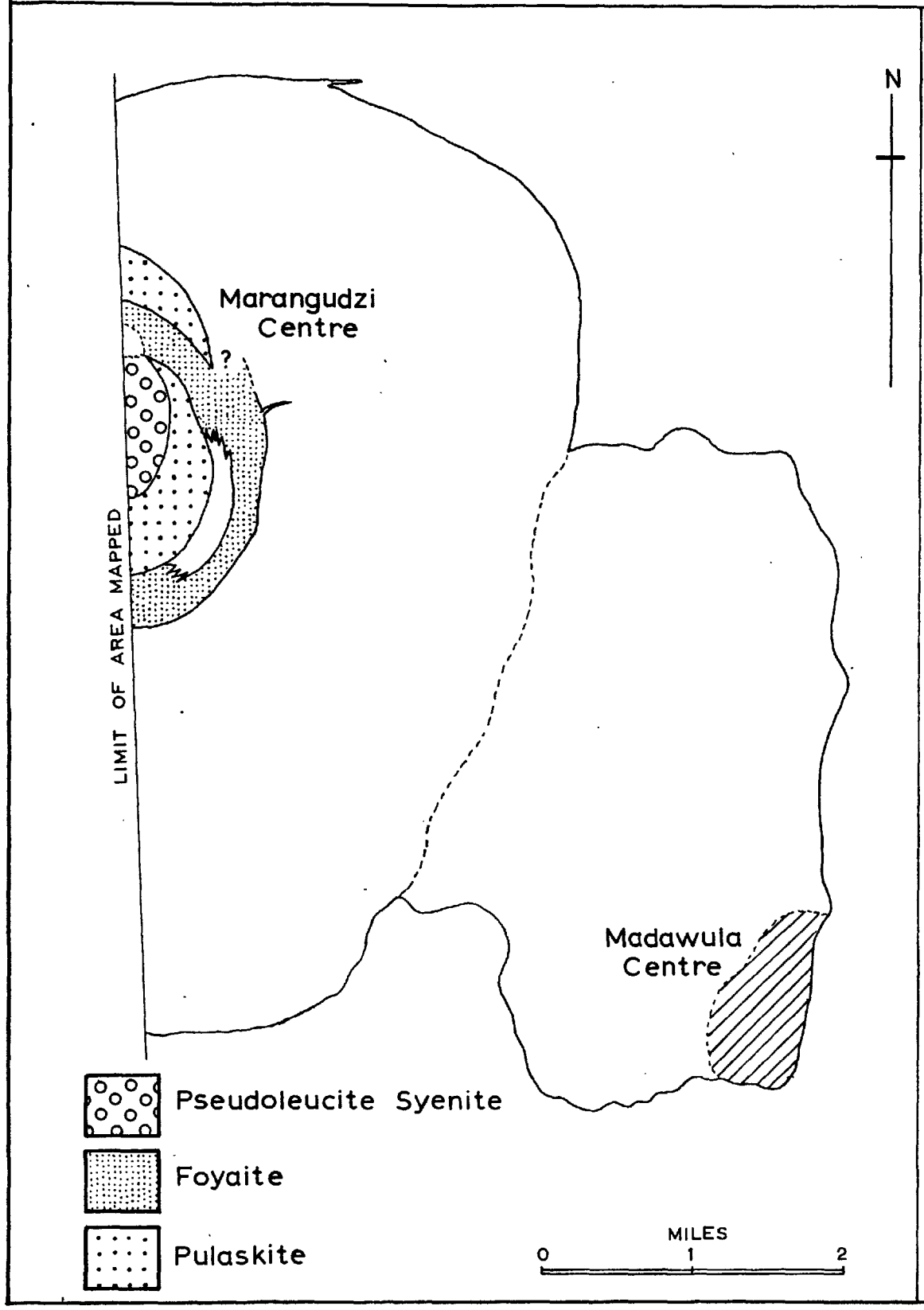
(c) Pseudo-leucite Syenite

The Pulaskite

The earliest of the undersaturated intrusions is the pulaskite. In the hand specimen, the rock contains little or no visible nepheline, and consists mainly of potash felspar with amphibole. The outcrop of the pulaskite is shown in figure 14. The intrusion does not form a complete half ring in the author's area, being separated by the foyaite rings into two crescent shaped outcrops. Most of the rock is even grained and structureless, but at some places banding was found. The banding is brought cut by concentrations of amphibole along certain planes, and by changes in grain size (see Plate VIIb). The banding was found to be vertical or to dip towards the centre of the intrusion at angles of about 85° and to parallel the outer margin of the

In the northern parts of the ring, the pulaskite is intruded

Fig.14. Outcrop of the Undersaturated Intrusions



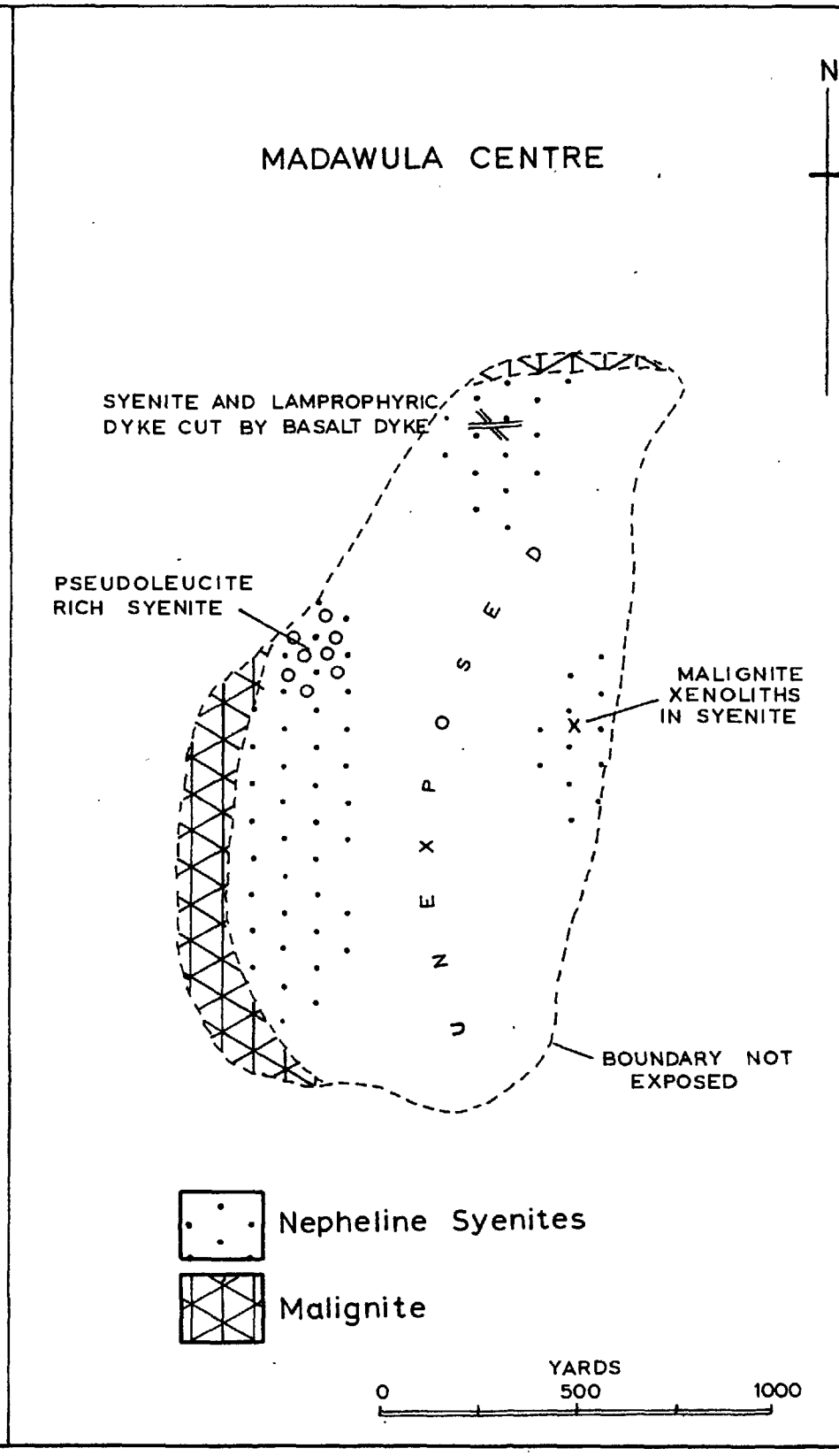


PLATE VII

A. Typical outcrop of pulaskite looking north along the ridge formed by the eastern part of the pulaskite ring.

B. Banding in the pulaskite. The banding is brought out by concentrations of amphibole along certain bands together with orientation of the minerals which lie with their long axes parallel to the banding.





by syenitic material in several places. These intrusions are very irregular in shape and often contain inclusions of pulaskite (Plate VIII) and frequently contain pseudo-leucites. In the field the intrusive rock was called 'grey syenite' but this has proved to be a microfoyaite and will be dealt with fully with the foyaites. In the south where the pulaskite adjoins the contaminated foyaite, it has been intruded by foyaitic rocks on a fairly extensive scale. The dense foliage and scree on the southern slopes of the pulaskite ridge made it impossible to clarify the relationship between the foyaitic rocks and the pulaskite, but the foyaites would appear to occur as irregular intrusions, similar to those of the 'grey syenite' in the north.

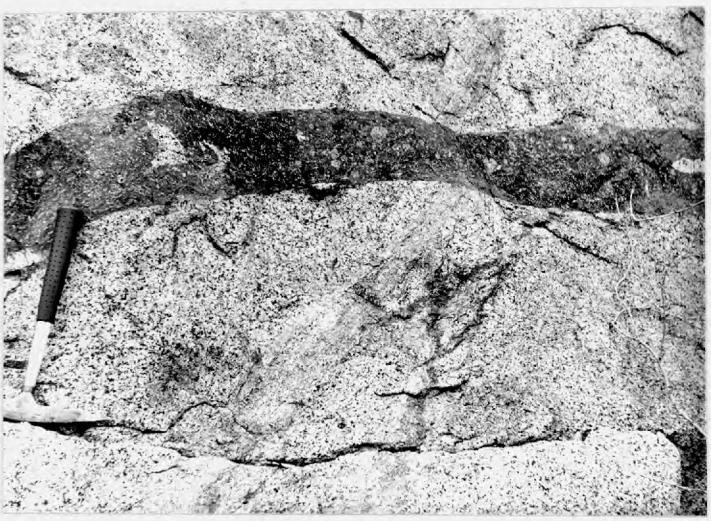
The pulaskite is generally even grained and proved to be a very consistent rock type throughout. Pegmatitic patches with large nepheline and amphibole crystals were found, but are rare, and much of the intrusion showed no signs of banding. In the north and east, and to a lesser extent in the south, the pulaskite shows massive radial jointing and less pronounced concentric jointing. This jointing causes the formation of huge blocks of rock on weathering, as can be seen in Plate VIIa, which is a view of the main or inner ring of pulaskite in the east. The boundaries of the pulaskite with the foyaite ring were difficult to place accurately in the field owing to the similarity between the pulaskite and some of the foyaites. The more resistant nature of the pulaskite, causing it

PLATE VIII

A. Grey syenite (fine grained and darker grey) intruding pulaskite (mottled) and including xenoliths of pulaskite.

B. Two narrow intrusions of grey syenite in pulaskite. Light grey variety running diagonally across photograph and dark grey variety packed with xenoliths of pulaskite.





to form prominent ridges in many cases, proved to be a fairly accurate guide in placing the boundary between it and the less resistant foyaites. In the east, however, the line of kopjes mapped as pulaskite would appear to consist of rock rather richer in nepheline than suspected in the field. Because of this and the rather poor exposures which link these kopjes with the main outcrops in the north, it is felt that the possible extension of the pulaskite ring as far to the south as indicated on the map cannot be regarded as proved, and that the syenite exposed here may turn out to be connected with the foyaite intrusions rather than with the pulaskite. Since this doubt as to the accuracy of the original mapping in this area exists, the rock has been lightly ornamented on the map.

The pulaskite is cut by phonolite dykes and also a few small dykes of lamprophyre, but no dolerite or acid dykes were found. Xenoliths were found along the inner part of the intrusion where it adjoins the pseudo-leucite syenite, but the major part of the pulaskite is free from xenoliths. The xenoliths that were found are of gabbroic origin, and although showing a certain amount of alteration are recognisable as gabbro xenoliths in the hand specimen.

The Foyaites

Between the two crescents of pulaskite in the north and east, and extending to the south of the pulaskite in the south, is a ring intrusion of nepheline syenites. These rocks, which are foyaitic

in composition, are later than the pulaskites which they cut. The intrusion is made up of several rock types, and in the field these were divided into two groups: mixed foyaites which form the major group and occur along the outermost parts of the ring, and contaminated foyaites which contain xenoliths and occur in the innermost parts of the intrusion.

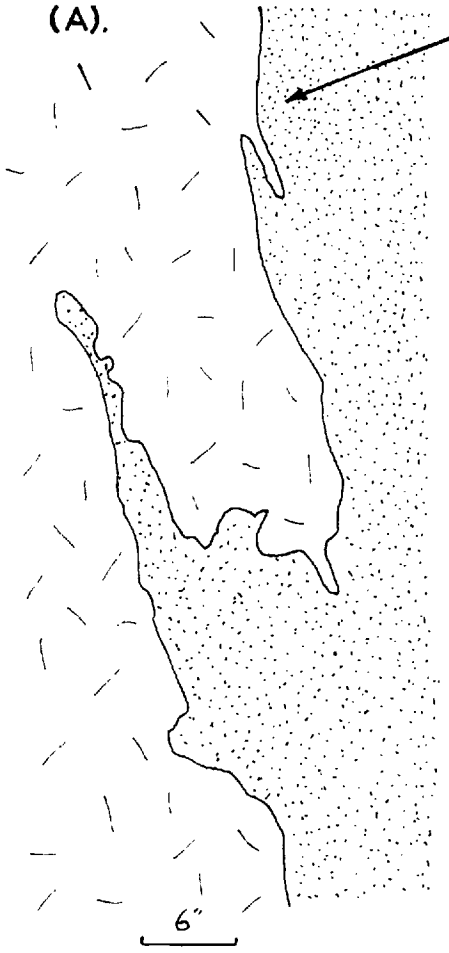
The foyaites range in texture from coarse grained granular rocks rather similar to the pulaskites, to medium and fine grained porphyritic types, in which porphyritic potash felspar occurs in a meium to fine grained grey groundmass. In places, the foyaites contain pseudo-leucites, but this is not common. These pseudo-leucites are up to two inches across and roughly spherical in form. They consist of an intergrowth of potash felspar and nepheline, and have a dense sugary appearance on a freshly broken surface. On the weathered surface, nepheline weathers out, showing the structure of the intergrowth which is typical of the pseudo-leucites (Plate XXI), and is reminiscent of the graphic intergrowth of quartz and felspar. Associated with the pseudo-leucites occurring in the foyaite are large prismatic crystals of potash felspar, up to one and a half inches long by a quarter of an inch wide, which extend into the enclosing rock with about one quarter of the crystal buried in the pseudo-leucite (figure 35). Small quantities of amphibole are present in some of the pseudo-leucites, although many are entirely free from mafic

minerals. In a few, small crystals of amphibole which were included in the crystal of leucite form zones concentric with the surface of the pseudo-leucite. Although mapped as a unit in the field, the foyaite ring is a multiple intrusion and certain time relations between the types were discovered. A porphyritic type was found as a dyke-like body cutting a course grained pseudo-leucite bearing variety. Another porphyritic type was found cutting pulaskite in the south. However, in general, the field relations between types remain obscure and it has seemed best to group all the varieties together simply as foyaites. The intrusion has therefore been called the foyaite ring, and variation in the rock types will be dealt with when their petrology is discussed, although they are not shown separately on the map.

In addition to the dykes of syenite and the syenitic veins which are found throughout much of the intrusion, the foyaites are cut by phonolite dykes in a number of places. Some of these are normal straight walled dykes, but others have features which suggest that they were intruded while the foyaite was still mobile. In the stream section in the so-called northern crater, a pseudo-leucite phonolite dyke was found exposed. The walls of the dyke are straight but at the contact the syenite was found to have developed a strong flow texture, whereas farther away from the dyke no texture was discernible. The pseudo-leucites were also found to show a greater degree of alteration than usual, and to have developed large porphyroblastic

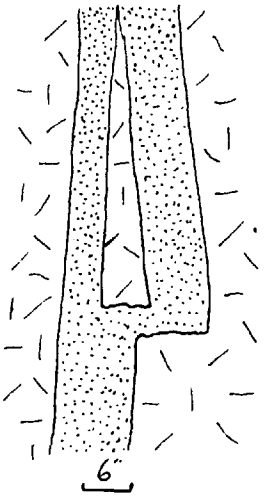
Fig.15 Dykes in the Foyaites.

(A).



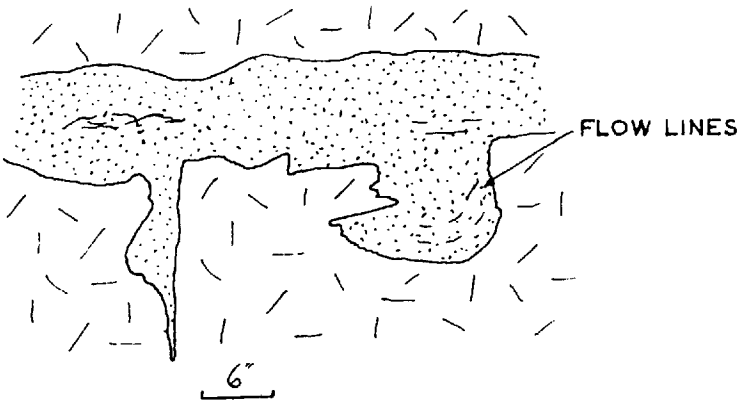
Margin of pseudoleucite phonolite dyke. The dyke is six feet wide and is finer grained towards the margins. The pseudoleucites are up to 3 inches across in the centre of the dyke but become smaller and rarer in the finer grained parts.

(B).



Joint controlled phonolite dyke.

(C).



Irregular porphyritic phonolite dyke.

crystals of potash felspar. Two other dykes in the foyaite are illustrated in figure 15. These differ from the other dykes in not being parallel sided but have the complex boundaries shown. The dykes showed a certain amount of chilling towards the margins, and also signs of banding in places. The dyke in figure 15a contains pseudo-leucites which are larger towards the centre of the dyke and smaller and rarer towards the margins. The pseudo-leucite phonolites will be described fully when the minor intrusions are dealt with. Some fifty yards away from the syenite, this same dyke was found cutting gabbro, and here it bears small xenoliths of syenite (Plate XXII). Where it cuts the syenite, no xenoliths were found, but small crystals of potash felspar can be seen, near the margins, at some points and would appear to be xenocrysts. The dykes were apparently intruded before the syenite was completely cooled, for the irregular nature of some of the offshoots from the phonolite dykes suggest that the surrounding syenite had not completely solidified. On the other hand, there are xenoliths of syenite in the phonolite dykes. The presence of the foyaite xenoliths in phonolite some distance from the foyaite suggests that the movement of the molten dyke rock was away from the centre or possibly upwards from below.

Xenoliths are not uncommon in the foyaites. In some cases they are xenoliths of an earlier foyaite intrusion and in others of gabbro. In the south near the inner margin of the ring, an alkaline syke cuts

a coarse grained foyaite containing gabbro xenoliths. The dyke itself has picked up xenoliths of the syenite and a few of these contain gabbroic xenoliths themselves.

The Contaminated Foyaite

The contaminated foyaite outcrops between the foyaite ring and the inner intrusion of pulaskite. It is exposed in the south and again in the north, but in the east there is an unexposed area between the rings which is believed to be mainly underlain by gabbro.

The contaminated foyaite is well exposed in the south and in the eastern parts of the outcrop is seen to have veined and broken up gabbro. This relationship is diagrammatically represented on the map by a zig-zag boundary. As one leaves the gabbro contact, the syenite at first contains large xenoliths up to ten or twenty feet across, which gradually become broken up and absorbed.

In several places a heavily veined rock of syenitic aspect was found but with a texture similar to a gabbro. This rock together with much of the syenite contained a certain amount of biotite and, although not demonstrable in the field, it appeared to be metasomatically altered gabbro.

These rocks grouped together as contaminated foyaite contain variable amounts of nepheline, but are usually poor in felspathoids. In places, however, the rock is foyaitic in composition and the rocks of this group are cut by similar dykes to those which cut the foyaite

ring, and in one or two cases it was possible to show that the dykes were in fact continuous. Although conclusive proof was not obtained, the age of the contaminated foyaites is believed to be the same as that of the foyaites.

The Microfoyaites

Intruded into the pulaskite and also into the granitic rocks to the north of the Marangudzi centre are a number of intrusions of a rock which was called grey syenite in the field. The grey syenites are fine grained rocks which in some places are so fine grained as to be classed with the phonolites. They range in colour from pale grey in the case of the coarser grained types to very dark grey in the finest grained varieties which are frequently found as xenoliths in the former, and may contain porphyritic crystals and/or pseudo-leucites. A number of intermediate types between such phonolitic varieties and the normal rock occur, and some of these can be matched with fine grained rocks occurring in the foyaite ring. Taken as a whole, the rocks might best be termed microfoyaites.

These microfoyaites are of considerable interest, as they provide a link between the plutonic and volcanic rocks, that is to say between the syenites and the phonolite dykes.

The microfoyaites found intruding the pulaskite usually occur as small irregular intrusions or dyke-like bodies of variable width, such as those shown in Plate VIII. They do not show a particular

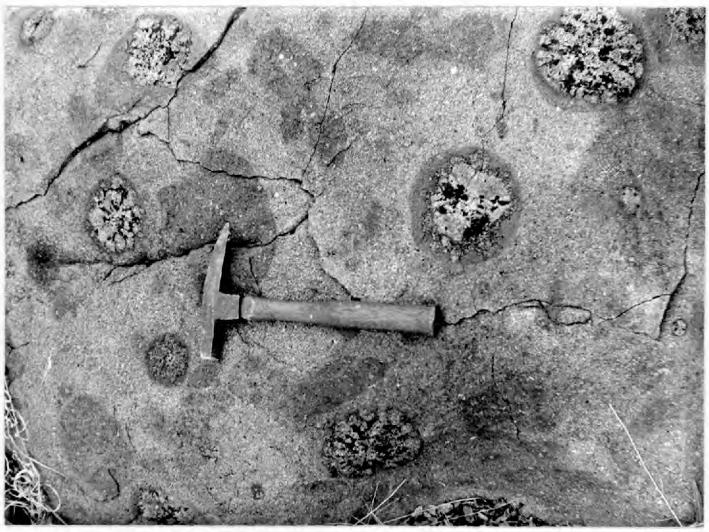
trend and are not controlled by the existing jointing. Intruded into the granitic rocks to the north of the pulaskite ring, a larger intrusion of microfoyaite, approximately five hundred yards long, is exposed. Similar sized intrusions of microfoyaite are also found to the north-west of the pulaskite ring (c.f. G. Rees, 1960). Parts of this large intrusion of microfoyaite are rich in xenoliths and xenoliths are also found in some of the smaller intrusions. The xenoliths are mostly of finer grained microfoyaite and are frequently found to contain pseudo-leucite, as shown in Plate IX. The pseudo-leucites are unusual in that they contain considerable quantities of amphibole in most cases, and many have a very irregular form. It seems probable that they represent altered clusters of leucite crystals that had porphyritic amphibole associated with them, and also leucite crystals which had included amphibole. Although original fine grained leucite-bearing microfoyaite is found in some places, most of it has been broken up by the later coarser grained varieties of microfoyaite, and become xenolithic in it. Xenoliths of an altered, mafic rich, porphyritic rock are also found in the grey syenite and are believed to be of lamprophyric origin, although none of the original rock was found to outcrop. This rock contains large euhedral crystals of pyroxene and althered olivine in a fine grained altered groundmass.

Since microfoyaite intrudes pulaskite, it must be later than the pulaskite, and the large intrusion in the north is cut by two

PLATE IX

A & B. Grey syenite (light grey) containing xenoliths of an earlier finer grained variety of grey syenite (dark grey) which contained numerous pseudoleucite crystals or aggregates. These pseudoleucites frequently contain a certain amount of amphibole presumably included in the original leucite crystals.





phonolite dykes, which further suggests that it is of approximately the same age as the foyaites but earlier than the pseudo-leucite syenite, which is not cut by phonolite dykes. Since the microfoyaites are of similar composition to the foyaites, it is reasonable to correlate them with foyaites and the foyaitic phase of intrusion.

The Pseudo-leucite Syenite

The pseudo-leucite syenite is intruded at the centre of the pulaskite and foyaite rings, and is the last of the major intrusions of the Marangudzi centre. It is circular in form, and the major portion of the outcrop of this rock type lies outside the author's field area, the section mapped being a strip along the inner boundary of the pulaskite in the east.

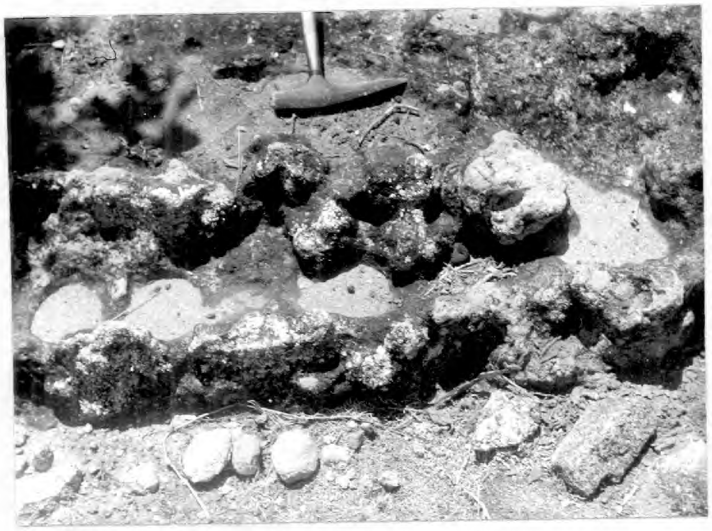
The pseudo-leucite syenite is a nepheline rich syenite which typically contains pseudo-leucites. Although pseudo-leucite is distributed throughout the intrusion, the amount varies from place to place, and locally small patches of rock without pseudo-leucite occur. In such areas, there is no evidence to suggest that pseudo-leucites were ever present. On the other hand, some evidence exists that pseudo-leucites have been resorbed , for in various parts of the intrusion pseudo-leucites in varying stages of resorbtion can be seen. As a result a variety of rock types have developed, of which two may be mentioned. The first is a medium grained rock (illustrated in Plate Xa) with pseudo-leucites which are clearly visible on the

PLATE X

A. Pseudoleucite syenite. Pseudoleucites standing out on weathered surface showing the crystal form of leucite.

B. Pseudoleucite syenite. Variety in which the pseudoleucites lack crystal form and weather out as knobs on the surface of the rock. In places they are easily removed with a hammer and some of these roughly spherical or oval pseudoleucites can be seen in the foreground.





weathered surface. However, since the pseudo-leucites consist of an intergrowth of potash felspar and nepheline, with a grain size approaching that of the rock, they are virtually invisible on a freshly broken surface, especially when they contain small quantities of mafic minerals. The second type shows a more advanced stage of alteration, and what was once the site of a leucite crystal is now a roughly spherical patch of a fine grained intergrowth of potash felspar and nepheline surrounded by rock bearing mafic minerals. On the weathered surface the felspathic areas stand out as knobs. The pseudo-leucites may be anything up to three inches across, but the majority are between one and a half and two inches in diameter.

Owing to the variable nature of the rocks of this intrusion, it was not possible to subdivide them for the purposes of mapping, and they were mapped as a unit.

Much of the intrusion is massive and structureless, but in the north east banding or layering was observed dipping towards the centre of the intrusion at an angle of forty degrees. This banding consisted of a concentration of mafic minerals along certain planes, and a structure in the rock produced by a tendency of the laths of potash felspar to lie with their long axes subparallel to the banding. At this locality jointing is present, parallel to the banding, but jointing is poorly developed or absent throughout much of the intrusion.

No phonolite dykes were found to cut the pseudo-leucite syenite

and minor intrusions are rare. One or two small dykes of nepheline vogesite were found, and leucocratic veins rich in felspathoids occur in parts.

Along the boundary of the pseudo-leucite syenite in the east, xenoliths of gabbroic material are found in several places, and it is thought that a strip of gabbroic rock may form a screen between the pseudo-leucite syenite and the pulaskite at this point. The age relationship between the pseudo-leucite syenite and the pulaskite was not elucidated in the field, but the central position of the former, the lack of minor intrusions cutting it, and its richness in nepheline and pseudo-leucite, indicate a late emplacement, and it is believed to be the last of the major intrusions.

The Madawula Centre

The Madawula centre is situated at the most south easterly point of the eastern gabbro, about five and a half miles south east of the Marangudzi centre. The rocks of the centre show a range of types, all of which are undersaturated, and most of which are syenitic. They vary from leucosyenites to melasyenites and pseudo-leucite bearing varieties are also present.

The rocks of the centre outcrop in an elongated area one and a half miles north to south and approximately half a mile wide. They are in contact with gabbro to the west and north, and basement to the east and south. The ground underlain by the rocks of the centre

is covered by dense bush and remains unexposed over a considerable part of the centre. Because of the thick covering of bush, the area was investigated by means of a number of traverses and the distribution of the groups of rocks distinguished in the field is shown in figure 14. These are:

1. Medium to fine grained nepheline syenite
2. Pseudo-leucite bearing nepheline syenite
3. Nepheline bearing ultramafic rocks - Malignites

A long low kopje running north-south provides good exposure of the western part of the centre, but the ground to the east is very poorly exposed. Some small kopjes to the north are formed by the most northerly intrusions of the centre, but large areas are covered by pediment with scattered exposures of dyke rocks.

The large kopje in the west consists for the most part of medium or fine grained leucocratic nepheline syenite. It frequently contains phenocrysts of nepheline and in places pseudo-leucites which become a prominent constituent of the rock in the northern part of the kopje. The pseudo-leucites become most abundant in a very distinctive rock of restricted occurrence, which consists of closely packed pseudo-leucites up to two inches across, with nepheline crystals up to half an inch in size between them, the interstices being occupied by fine grained mafic minerals.

Along the western margin of the kopje, between the kopje and the poorly exposed ground to the west, nepheline bearing ultramfic

rocks outcrop. Xenoliths of similar rock are found in the medium grained nepheline syenite outcropping in an area along the eastern boundary of the centre.

In the north, medium grained nepheline syenites bearing amphibole and pyroxene outcrop, and the most northerly exposrues are of varied rocks some of which have the appearance of altered gabbro. A study of the rock in this section has not elucidated the origin of the rocks, which have suffered a considerable amount of alteration.

Numerous minor intrusions in the form of dykes occur in the basement to the east of the centre, and also in the rocks of the centre. These will be described together with the minor intrusions of the rest of the complex.

The Minor Intrusions

The minor intrusions found in the field consist almost entirely of dykes. These are normally vertical and often maintain a constant strike for several miles. They can be seen particularly well on aerial photographs, where they show up as dark lines, these being the result of a concentration of vegetation along the dykes.

Structurally, the dykes connected with the Marangudzi centre fall into two groups: those within the ring intrusions which have radial trends, and those outside the ring intrusions which have east-west trends. Both these groups are concentrated in an east-west zone which includes the centres of the ring intrusions.

The radial dykes are most numerous in this zone; the east-west trending dykes are virtually confined to it. These features are illustrated in figures 1 and 2. In the western part of the complex, mapped by G. Rees, two large phonolite dykes were traced from the undersaturated intrusions of the Marangudzi centre out into the basement. Within the complex these dykes have radial trends, but, on crossing from the granite ring into the basement, there is an abrupt change of strike to an east-west trend (G. Rees [1960]).

A number of dykes were mapped near the Madawula centre. Most of these have been intruded into rocks of the basement complex, and have east-west trends. Excluding these dykes associated with the Madawula centre, which will be considered separately, the majority of the dykes may be classified within these five categories:

1. Dolerites
2. Granitic Dykes
3. Trachytes
4. Phonolites
5. Lamprophyres

A small number of syenite dykes are also associated with the undersaturated intrusions of the Marangudzi centre. In the field it was possible to classify the dykes in a general way, and to place them in one of four categories. Further division of the alkaline dykes into phonolites and trachytes was made after the specimens had been studied in the laboratory.

Owing to the subparallel arrangement of the dykes, no cross cutting relations were found between them. However, the age relation-

ships between a number of dykes and the major intrusives have been observed. A table (figure 16) has been drawn up which shows the numbers and types of dykes found in each of the major intrusions. The dyke types are arranged in order down the table, with the earliest at the top and the latest at the bottom. The major intrusives which are cut by the dykes are arranged across the table, with the oldest on the left and youngest on the right. The table provides a ready means of distinguishing dykes which were intruded early in the emplacement of the Marangudzi complex and which cut only the earliest of the major intrusions, from later dykes which cut nearly all the intrusions.

From this figure the following relationships can be established. Leaving aside the granitic sheets which have been included in the table for the sake of completeness, the minor intrusions fall into four groups chronologically. The earliest comprises the dolerites which cut the gabbro and the granite/green quartz syenite ring, but no later intrusion. The trachytes cut intrusions as late as the white quartz syenite, while the phonolites have been found to cut all the intrusions except the last, the pseudo-leucite syenite. The fourth group of dykes, the nepheline vogesites, appear to be restricted to the undersaturated intrusions. The sequence so established among the minor intrusions of dolerite, trachyte, phonolite and nepheline vogesite, can be compared with the intrusive sequence gabbro, granite, quartz syenite, undersaturated syenite.

Fig.16. Dyke Relationships.

DYKES \ HOSTS	Basement	Gabbro	Main Acid Ring	White Qtz. Syenite	Pulaskite	Foyaite	Microfoyaite	Pseudoleucite Sy.
Porphyritic Dolerite	3							
Altered Dolerite	4	9						
Dolerite	3	2	5					
Basalt +	2	4	6					
Granitic Dykes	1	7	1					
Trachyte	1	3	3	1				
Phonolite	✓	3	1	1				
Porphyritic Phonolite	✓	13	3	2 *	2	3	1	
Pseudoleucite Phon.	✓	10	6	3	3	3	2	
Ne. Vogesite					3		1	2

✓ Present.

\+ One dyke cuts quartz syenite in crater.

* One dyke cut by white qtz. syenite

The minor intrusions will now be considered separately and further evidence of their ages with respect to the major intrusions will be discussed.

The Dolerites

In general, the dolerite dykes are one to three feet wide (although larger dykes do occur). As they weather readily, the dolerites are rarely exposed in much of the ground underlain by the gabbro and basement, and the majority of exposures are found in the larger stream sections.

The dolerites have been divided into four groups as follows:

1. Strongly porphyritic dolerite
2. Altered medium grained porphyritic dolerite
3. Medium to fine grained dolerites
4. Porphyritic basalts

These four groups will be described when the petrology of the rocks is discussed.

From figure 16, it will be seen that the strongly porphyritic dolerite is only found cutting rocks of the basement. It occurs in large dykes ten to fifteen feet across, and in one locality was found intruded by two dolerite dykes, so that a multiple dyke resulted: the intruding dykes were classified as type number 3. The strongly porphyritic dolerite is believed to be the earliest of the dolerite intrusions and may have been intruded before the emplacement of the gabbro.

The altered medium grained porphyritic dolerites are only found cutting the gabbro. No examples of this dyke type were found to cut the acid rocks, and it is suggested that these dykes were intruded after emplacement of the gabbro, but before the intrusion of the granitic ring. The alteration may be the result of late stage emanations associated with the gabbroic intrusions.

The medium to fine grained dolerites are found to cut rocks of the basement, the gabbro, and the granite/green quartz syenite ring. Xenoliths of dolerite occur in the granite, and make up the basic component of the xenolith trains. The meandering dykes described earlier and illustrated in Plate XI are also of dolerite and were intruded during the final stages of consolidation of the granite. Thus basaltic magma was available for intrusion at the time the acid ring was emplaced.

The porphyritic basalts are found cutting the basement, gabbro, and the main acid ring. One dyke was also found cutting the quartz syenite, which outcrops in the northern crater of the Marangudzi hills, and another was discovered to cut the nepheline syenites of the Madawula centre. The porphyritic basalt dykes cutting the main acid ring are straight walled dykes, and are later than the intrusions of this ring.

No basic dykes were found cutting the undersaturated intrusions of the Marangudzi centre which suggests that basaltic magma was no

PLATE XI

A & B. 'Meandering' dykes west of the deserted village, northern Marangudzi. The sinuous form of the dykes can be seen in the first photograph and the second shows a dyke cutting two narrow xenolith trains. The quartz-felspar veining is also clearly seen in the second photograph which includes a particularly sharp dislocation in the dyke.





longer available for intrusion during the emplacement of the under-saturated rocks of this centre. If this is the case, the basalt dyke found cutting the nepheline syenite of the Madawula centre would appear to indicate that this centre is earlier than the Marangudzi centre. The basalt dyke which cuts the central quartz syenite indicates that this quartz syenite may be correlated with the other acid intrusions and has been isolated from them by the later ring intrusions of under-saturated syenites.

In the stream section in the gabbro, to the east of the granitic ring, the only sill of dolerite recognised during this work was found. Its thickness could not be determined since only the top part of the sill was exposed, but its attitude appeared to be horizontal. Although this was the only sill found, the poor exposure over large areas of the gabbro could easily account for the apparent lack of dolerite sills, and many more may exist.

The Granitic Dykes

The granitic dykes are usually medium to fine grained equivalents of the granites, although one or two have a microgranophyric texture. They are closely related to the main granitic ring, most of them being found in the gabbro just east of this ring. No granitic dykes are found cutting the undersaturated intrusions, and they are believed to be contemporaneous with the major acid intrusions.

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The Trachytes

The trachytes are porphyritic rocks with a dense texture. When fresh, they are grey in colour, but are generally deeply weathered to a pale pinkish brown.

Trachyte dykes are found cutting the basement, gabbro, granite, green quartz syenite, and also the white quartz syenite, but do not cut the undersaturated intrusions. The trachyte dykes are poorly exposed and in most cases could only be traced for a few yards.

The Phonolites

The phonolites are the least weathered of the dyke rocks. In the gabbro and basement, they are often well exposed and show up particularly well on the aerial photographs. Weathering produces a brown crust of the surface in some cases, but this does not penetrate far into the rock and fresh specimens are easily obtained.

The phonolite dykes range in width from one or two feet up to about thirty feet across in rare cases, but are generally between five and ten feet wide.

These rocks are divided into three groups according to the amount and nature of the porphyritic minerals which they contain:

1. Non porphyritic phonolite
2. Phonolite containing porphyritic potash felspar
3. Phonolite containing porphyritic pseudo-leucites

These will be termed phonolite, porphyritic phonolite, and pseudo-leucite phonolite respectively.

The phonolites are fine grained dark grey rocks with a dense texture, which break with a conchoidal fracture. They cut the basement, the gabbro, the major acid intrusions, and also the earliest of the undersaturated intrusions of the Marangudzi centre (see figure 16).

The porphyritic phonolites are similar to the non-porphyritic variety, except for the presence of small phenocrysts of felspar. The phenocrysts of felspar may be up to one centimetre long, but are generally shorter (three to four millimetres). They may be lath shaped or short prismatic crystals, and usually show no preferred orientation throughout the major portion of the dyke. However, in the few dykes whose contacts were exposed, the phenocrysts were orientated along the margins of the dykes in the region where chilling had occurred. Here, the phenocrysts tend to lie with their long axes parallel to the walls of the dyke. Phonolites bearing phenocrysts of felspar, and occasionally small phenocrysts of amphibole, are found cutting all the major intrusions of the complex, except the pseduo-leucite syenite and undersaturated rocks of the Madawula centre.

The pseudo-leucite phonolites are the most distinctive dyke rocks associated with the complex. Except for the presence of porhyritic pseudo-leucites they are similar in appearance to the phonolites just described, and may or may not bear other porphyritic minerals.

The pseudo-leucites which occur in the phonolites are usually well formed. Typically, they show an eight sided cross-section, although

rounded cyrstals do occur, and the original form of the leucite may not have been perfectly preserved. Individual pseudo-leucites may be up to four inches across in rare cases, but are usually about two inches across. Within a single dyke there may be a large variation in the size of the 'crystals' or they may be of similar size. The pseudo-leucites commonly occur singly, but in one or two dykes they show a tendency to occur in clusters which may be up to a foot across. These clusters are mainly composed of pseudo-leucites, which originally appear to have been 'cemented' together by nepheline crystals. Small quantities of amphibole are also present. The pseudo-leucites within these clusters usually show considerable recrystallisation and individual pseudo-leucites are rarely distinguishable.

The pseudo-leucites consist of an intergrowth of potash felspar and nepheline. In some cases, they contain porphyritic crystals of amphibole which appear to have been included in the original leucite crystals and in a few instances small crystals of amphibole are arranged zonally within the pseudo-leucites, parallel to the crystal faces. Porphyritic crystals of potash felspar and also nepheline occur along margins of some of the pseudo-leucites, and may be partly buried in them. These crystals of potash felspar are of similar size to the felspar phenocrysts occurring in the dyke rocks (three to four millimetres) and are believed to be phenocrysts which became attached to the leucite crystals.

The concentration of pseudo-leucites varies considerably from dyke to dyke. At one extreme pseudo-leucites may only be visible on the exposed surface of the dyke at intervals of several feet or even yards, while at the other extreme they are so numerous that they almost touch one another and the rock has the appearance of a conglomerate (Plate XII). The concentration of pseudo-leucites may vary across the width of the dyke, and also along the strike. Many of the dykes appear to be poorer in pseudo-leucites towards the margins and some have marginal zones free from them. In a few of the dykes, the pseudo-leucites become noticeably larger towards the centre of the dyke, but in others large and small pseudo-leucites occur from wall to wall. In only one case was the concentration of pseudo-leucites found to vary along the strike, but this may be found to be more common than would appear at present, if an accurate method of measuring the concentration of pseudo-leucites can be evolved. In the case mentioned, a phonolite dyke bearing phenocrysts of potash felspar was found to contain pseudo-leucites at some points; at other places none could be found. This dyke was cut by the intrusion of white quartz syenite.

The pseudo-leucite phonolite dykes cut all the intrusions of the complex, except the pseudo-leucite syenite and the undersaturated intrusions of the Madawula centre. (Since the Madawula centre lies to the south of the east-west zone in which the dykes are concentrated, the absence of phonolite dykes can not be considered as significant).

PLATE XII

A. Pseudoleucite phonolite particularly rich in pseudoleucites. The dyke contains numerous pseudoleucites varying in size from a fraction of an inch to over three inches across and usually showing good crystal form.

B. Typical pseudoleucite phonolite showing the scattered pseudoleucites up to an inch and a half across.





Examples of both pseudo-leucite phonolite and porphyritic felspar phonolite dykes have been traced up to the boundary of the undersaturated intrusions of the Marangudzi centre, but did not cross the boundary. This suggests that although some phonolite dykes are later than these major intrusions, a few at least are earlier.

Lamprophyric Dykes

Very few dykes were found cutting the pseudo-leucite syenite and these are lamprophyric in type. They consist of pyroxene, orthoclase, and nepheline, and are nepheline vogesites. Nepheline vogesites are also found in the pulaskite. They are generally irregular and rarely over a foot in width. An example of one of these dykes is shown in Plate XIII, which illustrates how they vary in width and in places have offshoots extending along joint planes. As can be seen from the table, figure 16, these dykes were found in the pulaskite and pseudo-leucite syenite, and they were restricted to the northerly parts of these intrusions. It is probable that they are present in the badly exposed foyaite in the north, although none were found.

Dykes of the Madawula Centre

A number of dykes cutting rocks of the basement complex are exposed in the stream sections one mile to the west of Madawula Hill, and in the poorly exposed ground to the east of the undersaturated intrusions of the Madawula centre. These dykes have predominantly east-west strikes, and appear to be restricted to an east-west zone which passes

PLATE XIII

A. Small irregular dyke of nepheline vogesite in pulaskite. Dyke being mainly controlled by jointing in the host rock, but also cutting across joints.

B. Small dolerite dyke in main acid ring. Jointing is common to dyke and host rock.





through the Madawula centre. However, they are not found to cut gabbroic rocks of Madawula Hill, or the surrounding kopjes, although dykes similar to those cutting the basement are intruded into the undersaturated syenites of the Madawula centre. The majority of the dykes occurring in the area are undersaturated, and are almost certainly associated with undersaturated intrusions of the Madawula centre. They may be divided into two main categories: porphyritic syenite dykes which may bear pseudo-leucites and felspathoid bearing lamprophyres.

The field evidence suggests that these dykes and hence the rocks of the Madawula centre, are earlier than the gabbro. However, considering the petrology of the rocks, this seems unlikely, and, since the existing evidence is not conlusive, more field work will be necessary before the relative age of the Madawula centre can be ascertained.

Other Dykes Associated with the Marangudzi Complex

Syenite Dykes

In the immediate vicinity of the undersaturated intrusions of the Marangudzi centre the gabbro was found to be intruded by a number of dykes of nepheline syenite. These dykes do not extend far into the gabbro, the largest being traced for about four hundred yards from the major undersaturated intrusions. The best exposed syenite

dyke lies to the west of the 'old village' and extends eastwards from the major undersaturated intrusions. This dyke tapers gently from about fifteen feet wide where it joins the pulaskite ring, to four feet wide before it ceases to be exposed. The dyke rock is similar to the rock of the major intrusion from which it extends, although it is slightly finer grained, and shows banding parallel to the strike of the dyke. The other syenite dykes were not as well exposed as this, but it is probably that they all have this tapering form, and are, in fact, tongues of syenite. In one or two places, a certain amount of veining is present in the gabbro, and this appears to be associated with the syenite dykes.

An Early Undersaturated Dyke

In the north, a large dyke is cut by the main granitic ring intrusion. This dyke is over one hundred feet wide, and has an east-west strike. One portion of the dyke is exposed in the banks of the Mafundengwe river where it flows on to the granite, and the other portion lies two miles to the east, where the tributary of the Mafundengwe, which drains the major part of the area enclosed by the acid ring, flows on to the basement.

The dyke was followed for about a quarter of a mile in the east before becoming unexposed, and is known to extend some distance to the west in the ground mapped by Mr G. Rees. The dyke rock is dark grey medium grained, and is even grained with mafic clots in some parts.

No variation was visible in the rock across the width of the dyke, and petrological study has shown that it consists of potash felspar, amphibole, and nepheline. Although the actual contacts of the dyke rock and the granite were not exposed, the dyke is definitely earlier than the granite which cuts it. This large dyke is therefore the only undersaturated intrusion which has been proved to be earlier than the main acid ring.

Jointing in the Dykes

The dykes commonly have two well developed joints and may have more. A few dykes have only poorly developed joints, and tend to be massive in character.

A type of jointing which is frequently found in the dykes is a simple cross jointing, with vertical joints arranged approximately symmetrically with respect to the strike of the dyke and intersecting at angles of between 45° and 90°. This type of jointing produces diamond shaped blocks which may lie with their long axes along the dyke or across it.

A second type of jointing which is fairly common consists of two joints, one of which lies approximately parallel to the walls of the dyke, and the other across the width of the dyke. A few dykes also show a well developed horizontal joint, but this is not common.

In many cases, it was not possible to compare the jointing in the dyke with the jointing in the wall rock, but some of the dolerite...

dykes in the acid intrusions, and some of the phonolites in the undersaturated intrusions, were found to have jointing which was common to dyke and host. A small dolerite dyke in green syenite illustrating this is shown in Plate XIII.

In most cases, the contacts of the dykes are not exposed, but the majority are believed to be vertical, straight walled dykes. Most of the dykes whose contacts are exposed are of this type, but a few have contacts which are controlled by the jointing in the wall rock. Two examples of this are shown in figures 12 and 15. In figure 12, a dolerite dyke in green quartz syenite shows a stepped margin, and in figure 15 a phonolite dyke encloses a jointed block of nepheline syenite. In both these cases, the dykes are virtually free from joints.

In one or two of the better exposed dykes, the jointing in the central portion of the dyke was found to change direction on entering the chilled margins of the dyke. A sketch of a dolerite dyke illustrating this is given in figure 12.

Although in many dykes the joints are arranged symmetrically with respect to the dyke, or nearly so, in others the joints are decidedly unsymmetrical. Since a close study has not been made of the jointing in the dykes, no detailed conclusions can be drawn. The varied joint patterns in the dyke rocks have obviously developed in response to more than one type of stress. Some of the joints are cooling joints, but others are the result of stresses of a more

regional nature. A detailed study will be necessary before any analysis can be attempted.

The Dyke Swarm to the East of Marangudzi

The dykes of this swarm have approximately east-west trends and extend up to sixteen miles to the east of the major intrusions. These dykes have been plotted from aerial photographs, and the major part of the dyke swarm can be seen in figure 2, although the swarm does extend farther to the east, beyond the limit of the map. The dykes occur in a belt five miles wide, but are most numerous in the northerly parts of this belt. The dykes occurring in the northerly part of the swarm show characteristics on the aerial photographs which suggest that they are phonolite dykes. Blocks of pseudo-leucite phonolite have also been reported in the bed of the Bubye river, downstream from the point where the river crosses the dyke swarm, and for these reasons it is believed that many of these dykes are of phonolite. The dykes occurring in the southern parts of the swarm show characteristics which suggest that they may be of a different type from those to the north.

Many of the dykes of this swarm have outcrops which can be traced, without breaks, for several miles. However, the known Karroo dolerites in the area, which have also been plotted from the aerial photographs, typically have disjointed outcrops. These features are clearly seen in figure 2. Future investigation of the

field relations of these dykes may give the relative age of the dykes of the swarm with respect to the large Karroo dyke with which they would appear to have cross-cutting relationships in the vicinity of the Bubye river. However, the disjointed nature of the Karroo dykes suggests that they have suffered dislocations which have not affected the dykes in the dyke swarm. This in turn indicates that the dykes of the swarm, and hence of the Marangudzi complex, may be later than the Karroo dykes.

C H A P T E R 3

PETROLOGY

In this chapter the petrology of the rocks of the Marangudzi ring complex is described. The major intrusives are described first, in order of intrusion, and an account of the dyke rocks follows.

The mineralogy of the ore minerals is dealt with at the end of the chapter, otherwise details of mineralogy are included with the petrological descriptions.

Modal analyses were performed on a number of specimens using a Swift point counter with points spaced at one third of a millimetre. The analyses were carried out with counts of at least one thousand points, and where necessary the slides were suitably stained. Potash felspar and felspathoids were the minerals which were stained, using techniques based on those described by Chayes (1952) and Keith (1939).

The Petrology of the Basic Rocks

In the field, the gabbroic rocks were divided into two types, the medium grained gabbro and the fine grained microgabbro. Laboratory study has enabled the medium grained gabbro to be further divided into two subdivisions, a potash felspar free variety and a potash felspar bearing variety. The three types have been termed

gabbro, orthoclase gabbro, and microgabbro, and they will now be described.

The Gabbro

In the hand specimen, the gabbro is an even coloured or mottled grey rock. The weathered surfaces are usually a dull grey or reddish brown, but in some cases weathering produces a rough surface of orangy red (olivine) crystals and green (pyroxene) crystals, set in a greyish white matrix of plagioclase.

The gabbro is a phaneritic medium grained rock with grain size ranging from one to five millimetres. It is even grained and rarely shows any structure. Olivine is present in most specimens and biotite can be seen frequently in the hand specimens.

In thin section the gabbro is found to consist of plagioclase, ranging from labradorite to anorthite, clinopyroxene with the augite field, and usually olivine. The common accessory minerals are ore, biotite, and apatite. Some specimens contain small quantities of orthopyroxene.

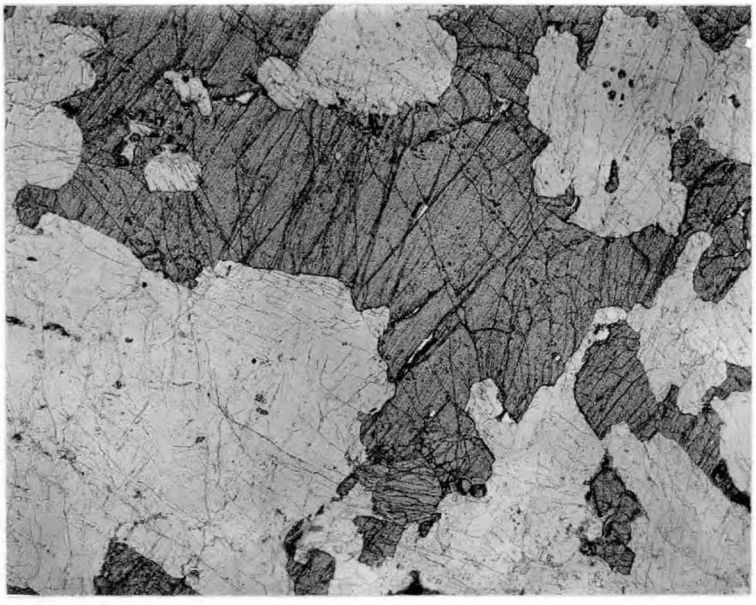
The texture of the rock is hypidiomorphic granular with plagioclase which tends to be prismatic, and granular pyroxene and olivine. In some specimens, the mafic minerals are irregular in form, and have a sub-ophitic relationship with the plagioclase. This is typical of the coarser grained varieties. Examples of differing textures found in the gabbro are shown in Plate XIV. Although the rocks do not

PLATE XIV.

A. Photomicrograph (x15 plane polarised light). Hypidiomorphic granular gabbro, consisting of plagioclase (light), clinopyroxene (dark, with cleavage) and olivine (dark, high relief - top right) (T 206)

B. Photomicrograph (x15 plane polarised light). Sub-ophitic texture in one of the coarser grained specimens of gabbro. Plagioclase (light grey) and clinopyroxene (dark grey). (T 131)





show an obvious porphyritic texture, the plagioclase crystals often vary in size, the larger crystals being more calcic and having cyrstalized earlier than the main bulk of the rock. The average grain size of the gabbros varies from one to five millimtres. A specimen having a grain size of two to three millimetres usually contains early plagioclase up to four millimetres long.

The felspar in the gabbro is calcic plagioclase and ranges from anhedral to euhedral in form. Crystals are usually elongated with parallel sides, but well formed ends are rare. The plagioclase tends to show good form against pyroxene in several specimens, but not against olivine. Albite twinning is well developed in most specimens, and carlsbad twinning in some. A few slides show an appreciable amount of plagioclase twinned on planes other than the carlsbad or albite twin planes, pericline twinning being common. Zoning in the felspar is fairly frequent, but is restricted to those rocks with more than one generation of plagioclase and to the early crystals in these rocks. The zoning is normal, that is, crystals have calcic cores with more sodic rims, and no reverse zoning or oscillatory zonging has been found. Generally, the plagioclase is clear and shows no sign of alteration.

The plagioclase varies in composition within the group, and also within individual specimens. In individual specimens differences in composition between the cores of early plagioclase crystals, which

are typically zoned, and late crystals, may amount to a twenty per cent change in the anorthite content. The major portion of the plagioclase in any specimen is of one size and the variation in composition of this portion is comparatively small (five per cent anorthite). The compositions of such medium sized plagioclase from a number of specimens is shown in figure 25, and ranges from An94.Ab6 to An62.Ab38. These results will be discussed fully when the petrology of the other gabbroic rocks has been described.

Determination of the plagioclase in thin section was carried out, where possible, by observations on the extinction of albite lamellae in combined carlsbad-albite twins, or alternatively by measurement of the maximum symetrical extinction. In both cases, the curves of Chudoba (1933) were used for the interpretation of results. Certain slides were studied with the aid of the universal stage, and in these the maximum symetrical extinction in the plane at right angles to the 010 plane was determined. In addition, refractive index determinations were carried out on a number of specimens. Determinations of the plagioclase composition of a sample by the different methods were found to agree within two or three per cent of the anorthite content in most cases.

The pyroxene in the gabbro is almost wholly clinopyroxene within the augite range of composition. In thin section the mineral is neutral in colour, and occasionally weakly pleochroic from pale pink to

Fig.17 Modes of the Gabbro.

Specimen Number.	% Plagioclase	% Pyroxene	% Olivine	% Ore	% Biotite.	Distance from Major Intrusion	General.
T397	70·8	21·7	—	7·2	—	1500 yds	
T220	76·7	11·4	1·7	5·4	3·5	250 yds	0·5% Apatite.
T196	43·9	39·2	7·2	3·8	5·9	200 yds	
T203	72·8	18·3	4·8	3·2	1·0	200 yds	
T396	65·4	25·7	4·5	4·1	✓	1600 yds	
T398	21·7	42·2	34·0	0·1	—	1200 yds	0·3% Apatite
T395	73·7	14·8	9·6	2·0	—	1800 yds	
T204	75·0	17·6	3·6	0·4	2·6	300 yds	
T206	49·6	38·5	9·9	0·4	1·5	350 yds	
T392	61·5	27·7	10·1	—	✓	2000 yds	
100	40·3	38·8	20·2	✓	1·0	1100 yds	
T229	66·2	19·8	8·4	0·6	4·0	500 yds	0·1% Apatite
T394	33·0	36·9	29·7	0·4	—	1500 yds	0·3% Apatite
T225	50·4	34·7	13·7	0·4	0·9	300 yds	
T241B	90·0	7·0	3·0	✓	✓	600 yds	
T209	✓	✓	✓	✓	✓	700 yds	
T399	65·9	29·0	4·0	0·1	1·0	1200 yds	
S6	31·3	32·8	33·9	✓	1·2	1200 yds	
T277A	44·0	26·1	29·3	✓	0·6	500 yds	

neutral. Small quantities of orthopyroxene are found along the borders of olivine and clinopyroxene in some specimens (figure 18).

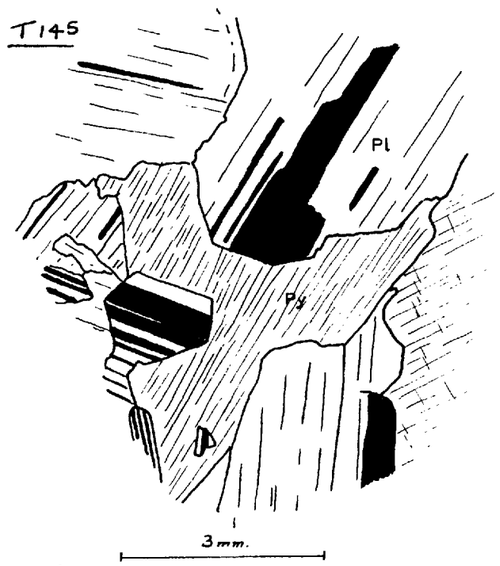
In most specimens, the augite crystals appear to be homogeneous and are usually untwinned. However, twinned pyroxene crystals are common in some specimens. In specimens T392 - T396 much of the clinopyroxene shows fine 'striations' under crossed nicols. These appear to be lamellae of orthopyroxene and show a lower birefringence than the host crystals, although in many cases they extinguish with them. The lamellae thin and disappear at the edges of many of the crystals, and generally show a regular distribution in those crystals of clinopyroxene that contain them. They appear to be exsolution lamellae of orthopyroxene and specimens containing them have also been found to contain orthopyroxene.

The augite is never euhedral and typically occurs as grains or irregular patches interstitial to plagioclase (see Plage XIV). It sometimes encloses small crystals of the other minerals and usually contains a small quantity of ore as small granules or minute plates arranged along the cleavages. These plates are sometimes concentrated along certain places in the crystals producing dark bands, or in zones. The pyroxene also occurs as small blebs included in the plagioclase.

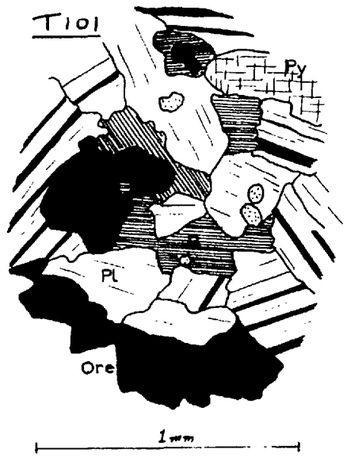
The composition of the pyroxene in certin specimens was determined by measurement of the optic axial angle and the refractive index Nβ. These results are plotted on the triangular diagram figure 19. As

Fig.18 Textural Features of the Gabbroic Rocks

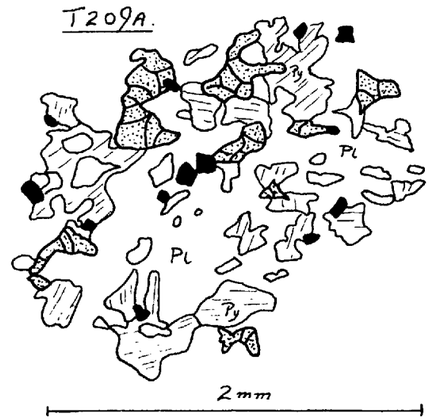
(A) WELL FORMED PLAGIOCLASE AGAINST PYROXENE



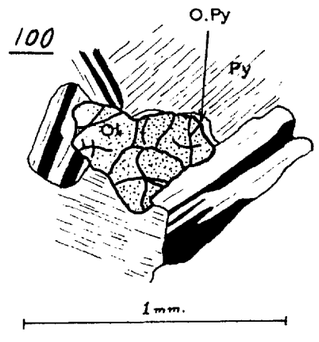
(B) OCCURRENCE OF BIOTITE



(C) TYPICAL TEXTURE OF MICROGABBRO



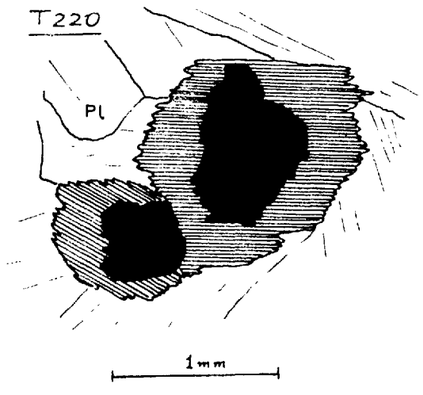
(D) ORTHOPYROXENE RIMS ON OLIVINE



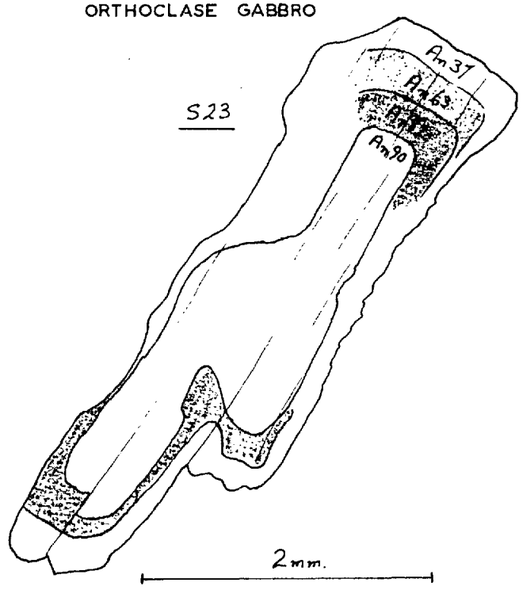
(E) ROUNDED PLAGIOCLASE AGAINST OLIVINE



(F) BIOTITE RIMS ON ORE



(G) ZONED PLAGIOCLASE IN ORTHOCLASE GABBRO

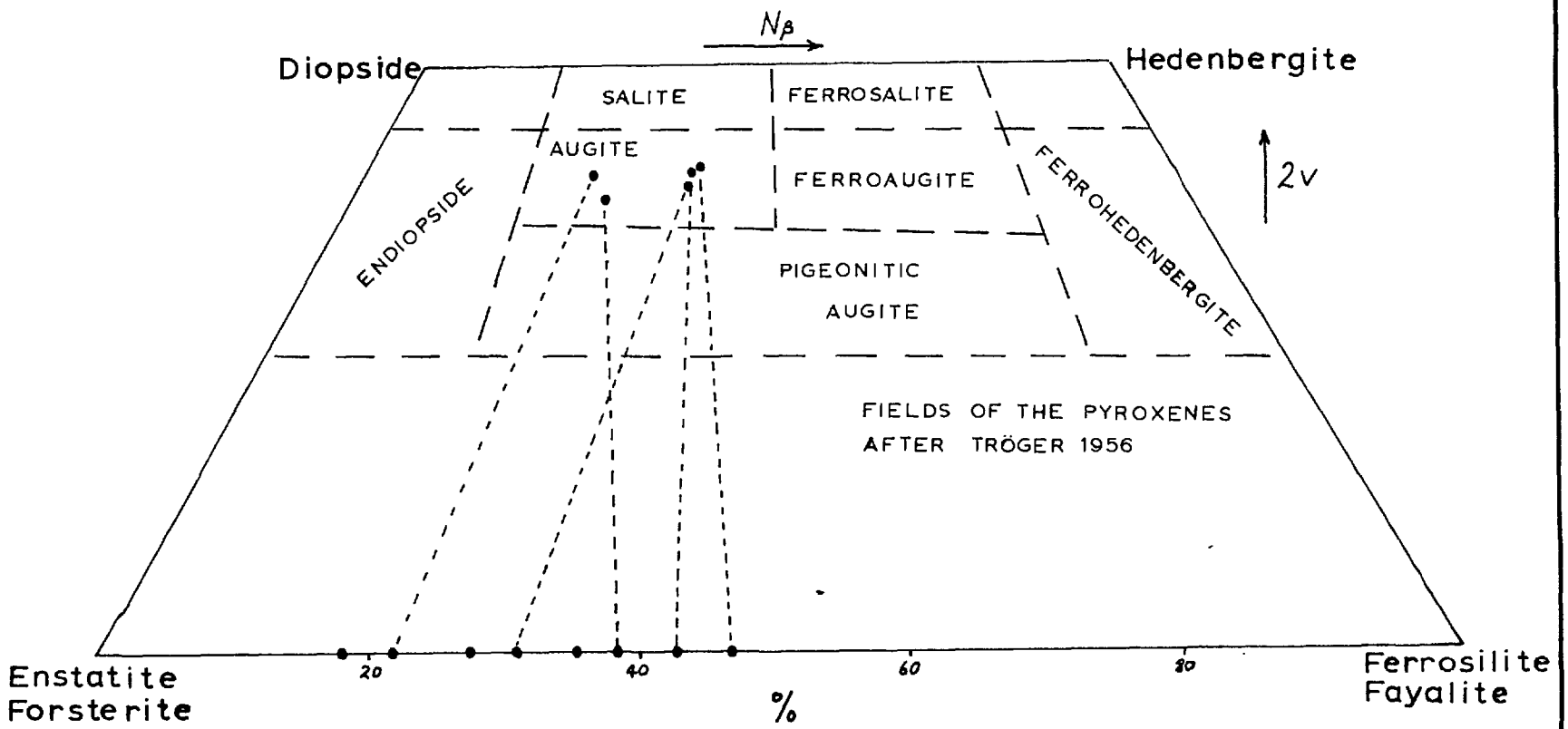


Brown (1957) has pointed out, there must be some uncertainty in the interpretation of optical data from augitic pyroxenes which have not been analysed, and where the place of minor constituent cations in the crystal structure is not known. Hori (1954) had shown earlier that the Al, Ti, and Fe''' in tetrahedral co-ordination decrease the refractive index and increase 2V, whereas in octohedral position they have the opposite effect. In the examples from Marangudzi, the principal uncertainty introduced concerns the lime content of the augite. It is possible that the monoclinic pyroxenes fall in the salite field. On the other hand, the interpretation of the optical data offered here indicates relative changes in composition and probably correctly indicates the iron and magnesia content of the pyroxenes.

The orthopyroxene is pleochroic from pink to neutral and has a lower birefringence than the clinopyroxene. The orthopyroxene typically occurs as narrow shreds along the edges of olivine, and is often found at the contact of olivine and monoclinic pyroxene. In two specimens, orthopyroxene was found to occur as discrete crystals, but it never forms more than five per cent of the rock, and is included with the clinopyroxene in the modal analyses.

The olivine in the gabbro is clear in thin section, and rarely shows significant alteration. It occurs as grains and irregular interstitial patches in the same way as the monoclinic pyroxene.

Fig.19 Compositions of the Pyroxenes and Olivines in the Gabbro.



It commonly shows one and sometimes two cleavages, together with irregular fractures. The composition of the olivine was determined from observations of the refractive index and was found to range from $Fa_{18}.Fo_{82}$ to $Fa_{47}.Fo_{53}$. The compositions of the olivines are plotted on the triangular diagram figure 19. Tie-lines with coexisting monoclinic pyroxenes have been drawn where pyroxene and olivine have been determined in the same specimen. These results will be discussed later.

The gabbro generally contains accessory amounts of ore and biotite. Apatite is present in many specimens. The ore rarely shows any crystal form, consistently occuring as irregular patches. It is frequently accompanied by biotite and is partially or completely rimmed by biotite in several cases.

The Orthoclase Gabbro

In the hand specimen, the orthoclase gabbro is a medium grained grey rock and shows the same range of grain size as the gabbro. It is even grained and structureless and frequently contains visible olivine and biotite. It is not distinguishable from the gabbro in the hand specimen, and the orthoclase is not sufficiently abundant for the rock to be placed in the syeno-gabbros. The orthoclase gabbro outcrops to the west of the undersaturated intrusions of the Marangudzi centre, and in the northern part of the eastern gabbro, but is not entirely restricted to these areas.

In thin section, the orthoclase gabbro is found to consist of plagioclase ranging in composition from labrodorite to anorthite, clinopyroxene, olivine, and small quantities of potash felspar with the usual accessory minerals.

The texture is typically hypidiomorphic granular with prismatic plagioclase and granular mafic minerals. The potash felspar occurs in small quantities forming well under five per cent of the rock and is interstitial to the plagioclase. In some specimens, it is found as small blebs in the plagioclase.

The plagioclase in the ortholcase gabbro ranges in composition from An90.Ab10 to An60.Ab40 throughout the group (figure 26). As in the gabbro more than one generation of plagioclase can be recognised, the earlier crystals tending to be zoned, and even in one specimen the anorthite content may vary by twenty or thirty per cent. A strongly zoned crystal of plagioclase with a core of anorthite An90.Ab10 and outermost zone of bytownite An37.Ab63 is shown in figure 18. The textures shown by the plagioclase in the orthoclase gabbro are similar to those of the gabbro. Modes of the orthoclase gabbro are shown in figure 20, and it will be seen from the table that the percentage of felspar shows less variation in this rock than in the gabbro.

The potash felspar is present in small quantities and is included with the plagioclase in the modes. The potash felspar normally forms

Fig.20 Modes of the Orthoclase Gabbro.

Specimen Number	% Felspar	% Pyroxene	% Olivine	% Ore	% Biotite	Distance from Major Intrusion	
T 168	69·4	13·7	11·7	2·3	2·9	400 yds	
A 12	52·5	25·2	9·7	1·4	9·9	200 yds	
64	58·2	15·6	11·9	0·6	12·3	150 yds	
T 131	68·7	21·5	6·2	1·1	1·3	150 yds *	
T 132	57·7	30·2	8·1	2·7	1·1	100 yds *	
S 34	73·6	21·6	1·1	0·9	1·9	1500 yds	
75	70·5	21·5	2·1	1·7	3·8	1200 yds	
S 23	89·0	7·6	0·4	0·5	2·1	2000 yds	
T 126	74·2	19·1	3·7	1·6	1·6	100 yds	
T 123	53·8	39·8	4·1	0·5	1·8	200 yds	
T 145	67·5	23·7	1·0	—	2·2	200 yds *	
A_4	60·8	31·9	7·2	✓	✓	300 yds *	

* These distances are measured from the small intrusion of white quartz syenite.

under five per cent of the rock. In some specimens it is only present as a trace, but as will be seen when the trends of the gabbroic rocks are discussed, the members of this group show different characters from those of the gabbro.

The potash felspar typically occurs as irregular patches between plagioclase, and in some cases as blebs within plagioclase. Optical measurements on the larger areas of potash felspar indicate that it is orthoclase.

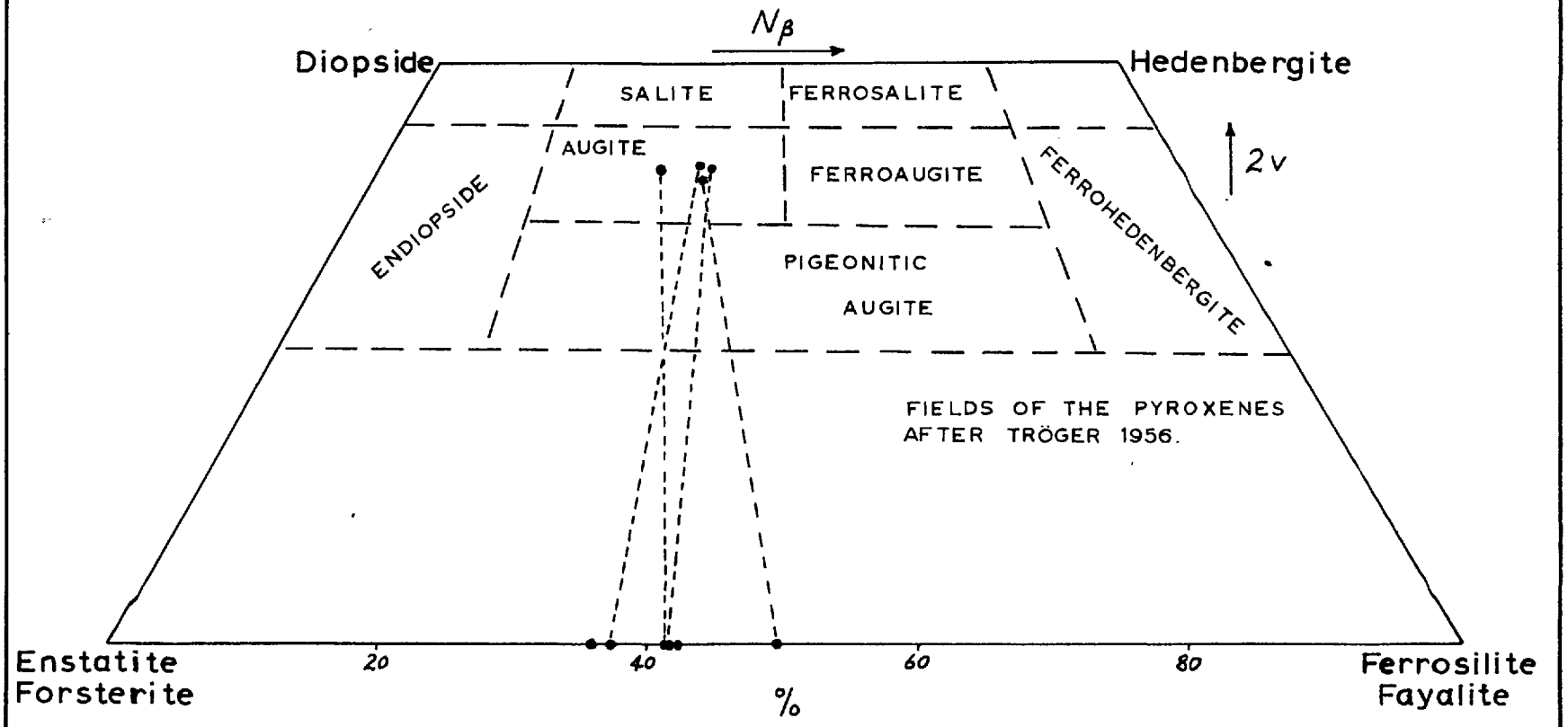
The clinopyroxene of the ortholcase gabbro is similar to that of the gabbro. It is neutral in colour and usually non-pleochroic. It shows similar textures to the clinopyroxene of the gabbro and the compositions of certain specimens as determined by optical measurements are shown in figure 21.

Orthopyroxene is present in some samples and is found rimming olivine and monoclinic pyroxene. In one specimen it occurs as discrete grains.

The mode of occurrence of the olivine in the orthoclase gabbro is also similar to that in the gabbro. The composition of the olivine varies from Fa35.Fo.65 to Fa50.Fo50 and the results of the optical determinations are plotted on figure 21.

The orthoclase gabbro has ore, biotite, and apatite as common accessory minerals, and the modes of this rock type appear in figure 20. The compositions with respect to plagioclase, pyroxene, and

Fig.21. Compositions of the Pyroxenes and Olivines in the Orthoclase Gabbro.



olivine, are plotted on the triangular diagram in figure 25.

The Microgabbro

In the hand specimen, the microgabbro is a fine grained (below one millimetre) grey rock. In many cases the rock is porphyritic. Several specimens show a planar structure in the hand specimen which in the field was commonly vertical, or nearly so. This structure is the result of flow banding, and in thin section many of the specimens show it to a greater or lesser extent.

Under the microscope, the rock is fine grained with grain size ranging from one millimetre to one tenth of a millimetre. It is holocrystalline with a hypidiomorphic to alltriomorphic granular texture. Some of the coarser grained varieties show a sub-ophitic texture.

The essential minerals are plagioclase and clinopyroxene with or without olivine. Orthopyroxene is present in some specimens. The common accessory minerals are ore, biotite, and apatite.

In those specimens which show a porphyritic texture, plagioclase is the most common phenocryst, although both pyroxene and to a lesser extent olivine are also found as phenocrysts. A specimen with plagioclase and pyroxene phenocrysts is illustrated in Plate XVa.

The plagioclase of the microgabbro is generally less well formed than in the coarse grained gabbroic rocks and becomes granular and anhedral in the finer grained varieties. The composition throughout the group ranges from An88.Ab12 to An52.Ab48, but within each sample

Fig.22 Modes of the Microgabbro.

Specimen Number	% Plagioclase	% Pyroxene	% Olivine	% Ore	% Biotite.	Distance from Major Intrusion	
T234	59·5	26·7	—	5·3	8·5	300 yds	
T230	53·3	33·2	4·0	3·6	5·9	500 yds	
T229	61·4	26·5	1·6	3·4	6·9	200 yds	
T242	✓	✓	✓	✓	✓	600 yds	
T265	60·8	28·7	2·8	6·5	1·2	800 yds	
T209A	56·3	36·6	5·4	1·3	0·5	800 yds	
T266	✓	✓	✓	✓	✓	700 yds	
T273b	50·8	37·9	✓	8·7	2·6	600 yds	
T146	50·6	40·0	8·3	1·4	✓	100 yds *	
T374	52·1	41·4	6·5	—	✓	300 yds	
T375	44·3	44·9	9·9	0·9	—	300 yds	
T130	52·9	27·7	17·8	1·1	0·7	50 yds *	

* These distances are measured from the small intrusion of white quartz syenite.

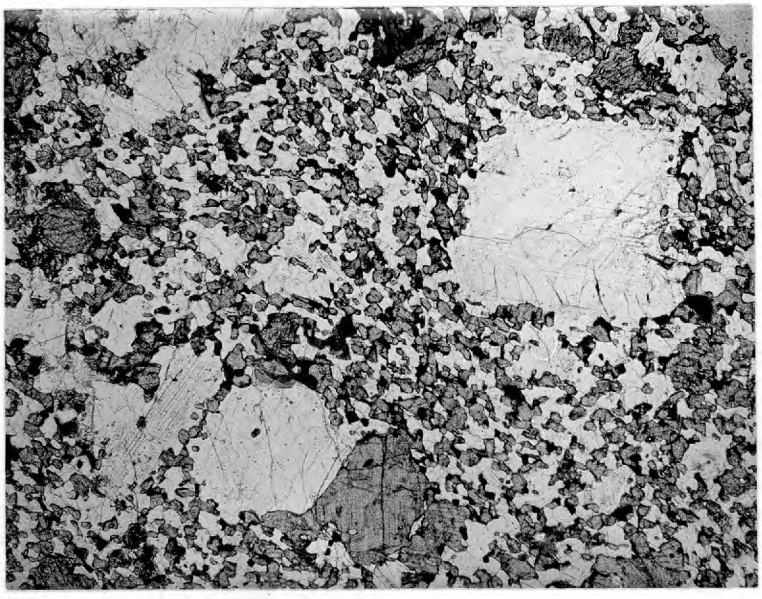
PLATE XV

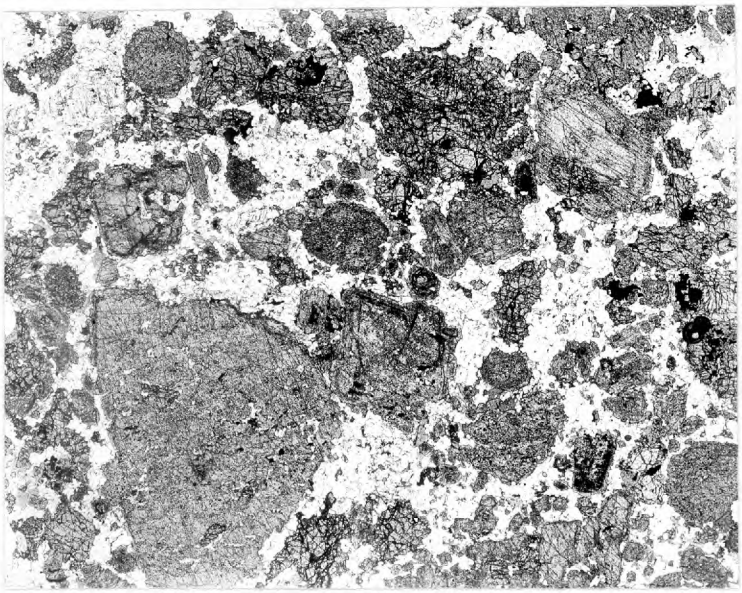
A. Photomicrograph (x15 plane polarised light). Porphyritic microgabbro. Phenocrysts of plagioclase and pyroxene set in a groundmass of plagioclase, pyroxene, small amount of olivine and biotite (dark grey).

(T 266)

B. Photomicrograph (x5 plane polarised light). Porphyritic essexite. Large phenocrysts of pyroxene with smaller phenocrysts of pyroxene, olivine and plagioclase set in a groundmass of plagioclase, pyroxene, olivine, and a little nepheline.

(T 380)



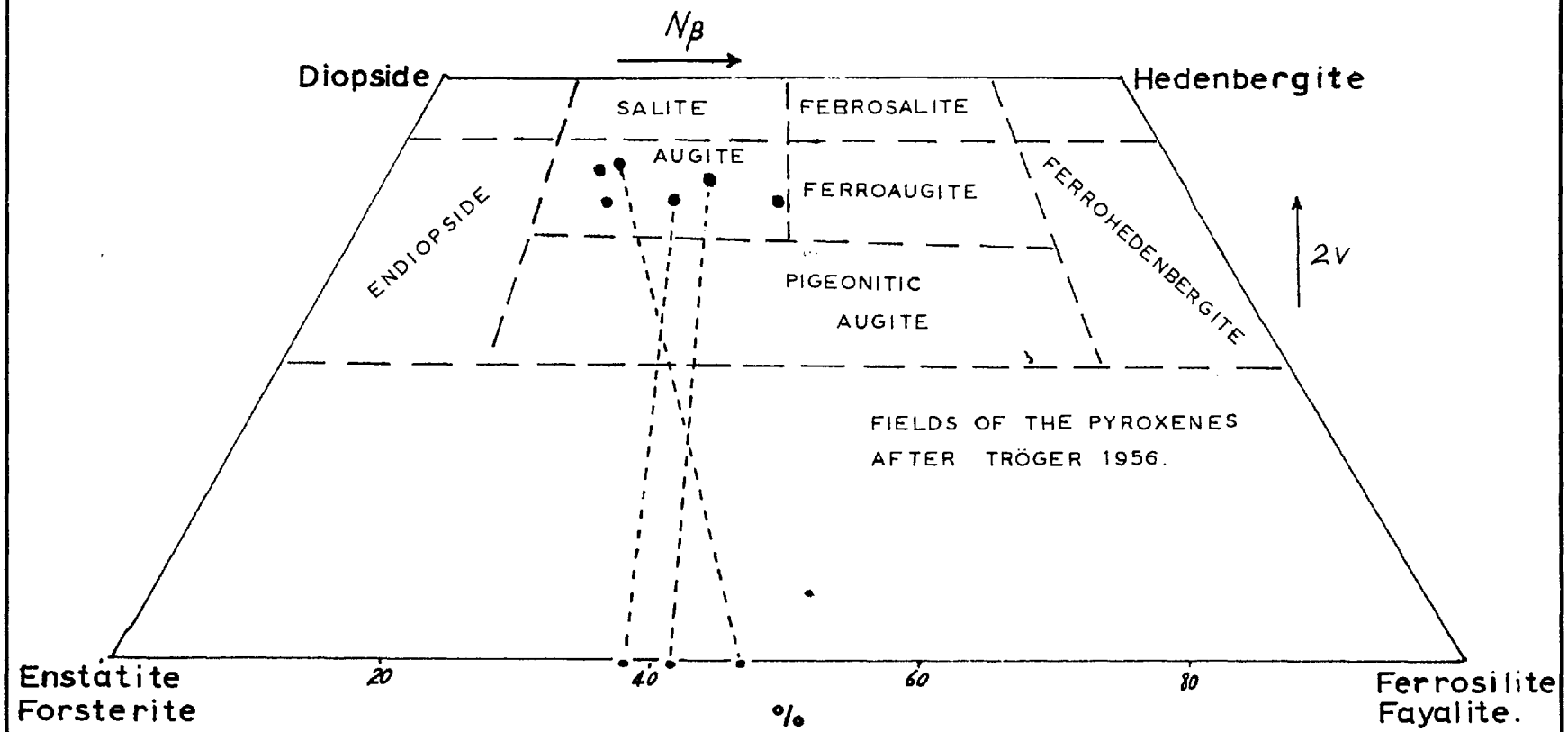


shows less variation than that found in the coarser grained gabbroic rocks. The phenocrysts are well formed and are typically of a uniform composition, except for a narrow zone round the margin of a more sodic composition. This outer zone has the same composition as that of the most abundant plagioclase in the groundmass, and may be regarded as an overgrowth on the original phenocrysts, which are from twenty to twenty-five per cent richer in anorthite than the groundmass plagioclase.

The pyroxene of the microgabbro is mostly clinopyroxene, although orthopyroxene is present in some specimens. It was not possible to determine the abundance of orthopyroxene in these specimens, owing to the fine grain size. The clinopyroxene and also orthopyroxene of the groundmass occur as small oval grains in the finer grained varieties, but become more angular and irregular in the coarser grained specimens. The phenocrysts are of clinopyroxene and do not show good crystal form, usually having irregular boundaries. The compositions of the clinopyroxene of the groundmass are shown in figure 23. Measurements of the optic axial angle were carried out on the phenocrysts, but it was not possible to determine the refractive indices of the phenocrysts satisfactorily. The optic angles were two or three degrees higher than those of the groundmass clinopyroxene, indicating a higher calcium content in the earlier crystals.

Olivine forms less than ten per cent of the rock in most varieties

Fig. 23 Compositions of the Pyroxenes and Olivines in the Microgabbro



of the microgabbro. It occurs as irregular shreds and grains, and in some of the banded specimens shows a concentration along certain bands. This concentration of biotite is associated with an increase in the proportion of biotite (in one specimen) and a decrease in the proportion of ore.

Determination of the composition of the olivine in the microgabbro was made difficult by the low content of the mineral in many specimens, and also the small grain size of the rock. Three successful determinations, however, were obtained - these are plotted on the triangular diagram in figure 23.

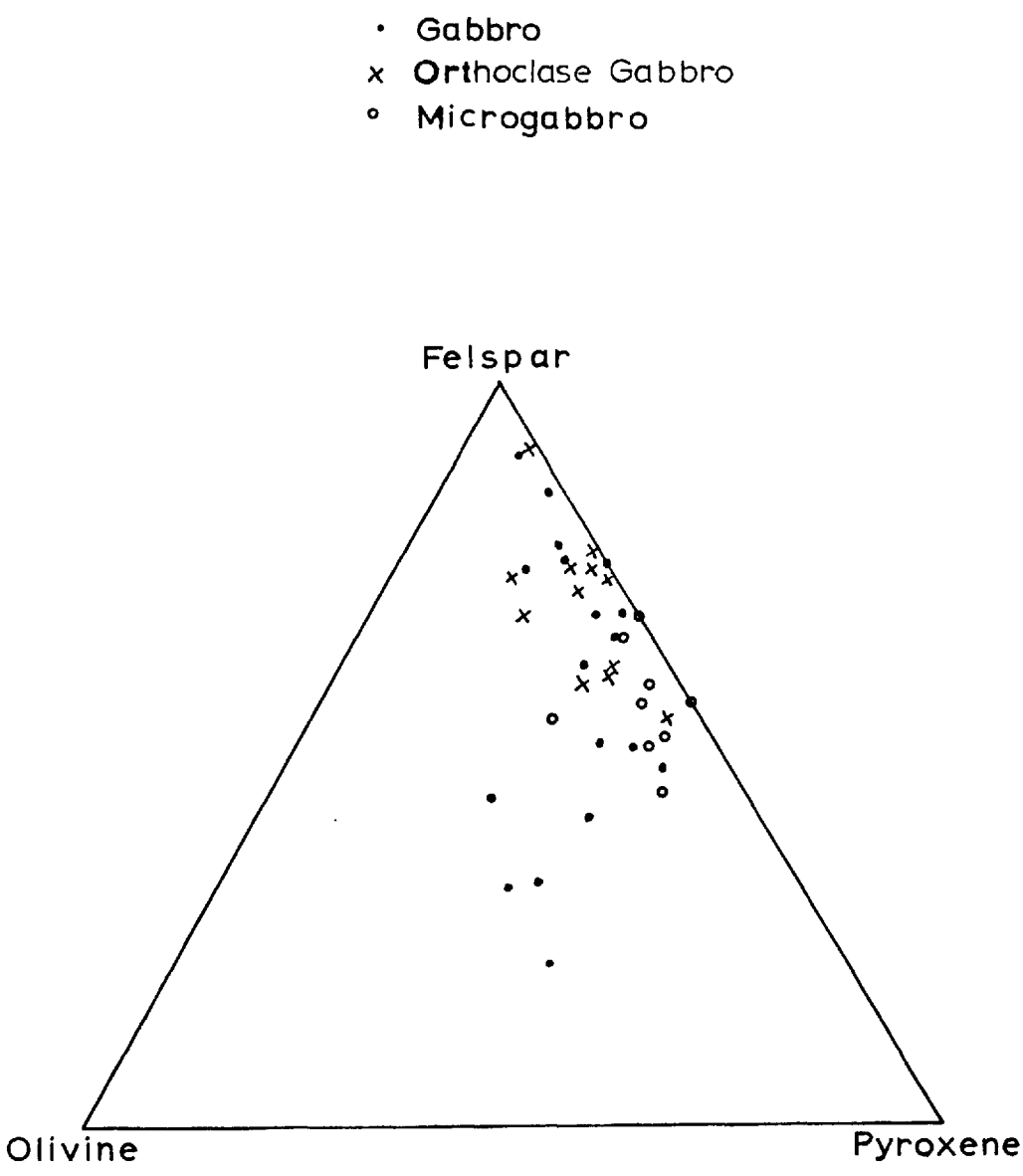
The common accessory minerals are ore and biotite. In those specimens showing flow texture, the biotite shows a high degree of orientation parallel to the flow banding. In one of the banded specimens alternate bands consisted of pyroxene and ore, and pyroxene, olivine, and biotite.

Modal analyses were carried out on the coarser grained varieties and the results are shown in figure 22.

Mineralogical Trends in the Gabbroic Rocks

A study of the modal analyses and the mineralogy of the three groups into which the gabbroic rocks have been divided, shows that certain mineralogical trends exist within these groups. Before these trends are discussed, it should be pointed out that the specimens studied were collected from various parts of the gabbroic intrusion

Fig.24 The Composition of the Gabbros



and that the division of the coarser grained rocks into gabbro and orthoclase gabbro depends only on the presence or absence of small quantities of potash felspar.

The compositions of the essential minerals and proportions of the mafic constituents have been plotted in the tables figures 25, 26, 27, which relate to the gabbro, orthoclase gabbro, and microgabbro respectively. The specimens are presented in the tables in an order determined by the composition of the plagioclase, and are not in any geographical order. It should be emphasized that the rocks of any given composition are not confined to a single part of the complex, and the specimens do not represent a series as collected in the field.

The gabbro, orthoclase gabbro, and microgabbro show similar ranges in the composition of the plagioclase, although the plagioclase of the orthoclase gabbro and microgabbro are more sodic. The average compositions of the measured plagioclase from the three groups are An 78, An 68, An 68, respectively.

The monoclinic pyroxenes show a restricted range of composition (for details see figures 19, 21, 23) and with the small number of determinations available it is not possible to draw definite conclusions, but in the gabbro and microgabbro increasing soda content in the plagioclase appears to be accompanied by iron enrichment in the pyroxene.

The olivine shows a very definite compositional trend in the

Fig.25 Mineralogical Trends in the Gabbro.

Specimen Number	Plagioclase Composition	Pyroxene		Olivine Composition	% Ore	Olivine to Pyroxene Ratio	% Olivine + Pyroxene
		Nβ	2V				
T397	An_{62}				7.2	0	21.7
T220	An_{64}				5.4	0.15	13.1
T196	An_{66}	1.699	51.5°	Fa_{47}	3.8	0.18	46.4
T203	An_{67}				3.2	0.26	23.1
T396	An_{72}				4.1	0.18	30.2
T398	An_{72}	1.692	45.5°	Fa_{38}	—	0.8	76.2
T395	An_{73}				2.0	0.65	24.4
T204	An_{78}				0.4	0.21	21.2
T206	An_{75}	1.698	50.5°	Fa_{41}	0.4	026	48.4
T392	An_{81}			Fa_{35}	—	0.37	37.8
100	An_{82}			Fa_{27}	✓	0.52	59.0
T229	An_{82}				0.6	0.43	28.2
T394	An_{85}				0.4	0.8	66.6
T225	An_{88}	1.698	48.5°	Fa_{30}	0.4	0.4	48.4
T241B	An_{88}				✓	0.43	10.0
T399	An_{90}				0.1	0.14	33.0
S6	An_{90}	1.690	49.9°	Fa_{22}	✓	1.04	66.7
T227A	An_{94}			Fa_{18}	✓	1.12	55.4

Fig. 26 Mineralogical Trends in the Orthoclase Gabbro.

Specimen Number	Plagioclase Composition	Pyroxene		Olivine Composition	% Ore	Olivine to Pyroxene Ratio	% Olivine + Pyroxene
		N_β	2V				
T168	A_{N} 58	1·698	49·5°	F_A 50	2·3	0·85	25·4
A12	A_{N} 63	1·698	51·0°	F_A 37	1·4	0·45	34·9
64	A_{N} 67				0·6	0·75	27·5
T131	A_{N} 68				1·1	0·29	27·7
T132	A_{N} 70	1·699	51·0°	F_A 42	2·7	0·27	38·3
S34	A_{N} 73				0·9	0·5	22·7
75	A_{N} 78			F_A 35	1·7	0·1	23·6
S23	A_{N} 80				0·5	0·05	8·0
T126	A_{N} 87	1·695	50·0°	F_A 42	1·6	0·2	22·8
T123	A_{N} 87				0·5	0·1	43·9
T145	A_{N} 88					0·04	24·7
A4	A_{N} 91			F_A 43		0·23	39·1

Fig.27 Mineralogical Trends in the Microgabbro.

Specimen Number	Plagioclase Composition	Pyroxene.		Olivine Composition	% Ore	Olivine to Pyroxene Ratio	% Olivine + Pyroxene.
		N_β	2V				
T234	$A_{N}52$	1·707	50°		5·3	0	26·7
T230	$A_{N}55$				3·6	0·12	37·2
T229	$A_{N}57$				3·4	0·06	28·1
T242	$A_{N}60$						
T265	$A_{N}60$	1·690	47°		6·5	0·1	31·5
$T209_A$	$A_{N}60$	1·697	48°	F_A38	1·3	0·15	42·0
T266	$A_{N}65$						
$T273_B$	$A_{N}65$				8·7	Low	38·0
T146	$A_{N}76$	1·698	51·5°	F_A41	1·4	0·2	48·3
T374	$A_{N}85$				✓	0·16	47·9
T375	$A_{N}86$	1·688	53·5		0·9	0·22	54·8
T130	$A_{N}88$	1·691	51·5°	F_A47	1·1	0·64	45·5

case of the gabbro (figure 25) with iron enrichment in the more sodic members. Thus the fayalitic content rises from Fa 18 to Fa 47, while the anorthite content of the plagioclase falls from An 94 to An 66. In the orthoclase gabbro there is not a significant change in the composition of the olivine associated with the changing composition of the plagioclase. As figure 26 shows, the fayalitic content varies erratically from Fa 35 to Fa 58 as the anorthite content falls from An 91 to An 58. There is not enough evidence to reveal any trend in the composition of the olivine from the microgabbros.

The percentage of ore in the specimens shows an increase in the more sodic gabbros, but is variable in all three groups. In the course of studying the proportions of olivine and pyroxene it was noted that the ratio of olivine to pyroxene varied systematically. This ratio is plotted in figures 25, 26, 27.

In the gabbro and microgabbro, the ratio of olivine to pyroxene decreases with increasing soda content in the plagioclase, but in the orthoclase gabbro it increases. There is a certain amount of irregularity in the change of the ratio, but except for four specimens of gabbro, the ratio shows a reasonably steady trend in each group. The four specimens of gabbro which show a marked dissimilarity from the rest in this respect were all collected from a low ridge to the north of Madawula which suggests that these specimens may

have a different origin from the remainder.

In discussing the mineralogy of the gabbroic rocks, the distribution of orthopyroxene should be considered. In the modes it is included with clinopyroxene. Orthopyroxene is present in half the specimens, but rarely occurs as discreet crystals. It is usually present as incomplete rims round olivine and clinopyroxene, and forms one or two per cent of the rock. In four specimens, it was found as discreet grains, but forms under five per cent of the rock even when most abundant. Orthopyroxene shows a random distribution in the gabbroic rocks and its occurrence cannot be correlated with the trends in the other minerals.

The mineralogical trends which have just been discussed indicate that some form of differentiation operated during the formation of the gabbroic rocks. In the gabbro and microgabbro, differentiation has produced a steady reduction in ferro-magnesian minerals present together with an increase in the ferro/magnesian ratio in pyroxene and olivine, and in the soda content of the plagioclase. The orthoclase gabbro shows mineralogical trends that differ from those of the gabbro, and microgabbro, and the rock appears to contain a higher percentage of potash than is normally to be found in rocks of this type. This is indicated by the presence of small quantities of potash felspar and the high proportion of biotite found in some of the specimens (figure 20). The relation of the gabbro and ortho-

clase gabbro in the field has not been elucidated, but the two rocks are not entirely restricted to specific areas, and occur together in several parts of the intrusion. However, it would appear that the orthoclase gabbro is a distinct part of the gabbroic intrusion and that its mineralogy indicates a different history from that of the gabbro, and microgabbro. Owing to the limitations of the modal analyses and the determinations of the compositions of the minerals, chemical analysis of a fresh suite of specimens will be necessary before the mineralogical trends in the orthoclase gabbro can be investigated fully. The main problems with respect to this rock type, raised by the present investigation, are as follows:

1. The considerable range of compositions in the plagioclase felspar which suggest a high degree of differentiation leading to marked enrichment of sodium with respect to calcium.

2. The restricted range of composition of the olivines (which are iron rich) and in the clinopyroxene indicates little change in the amount of iron with respect to magnesium.

3. The increased proportion of olivine in the more sodic specimens.

4. The high potash content of rocks of this type, indicated by the presence of small quantities of potash felspar and considerable quantities of biotite in some specimens.

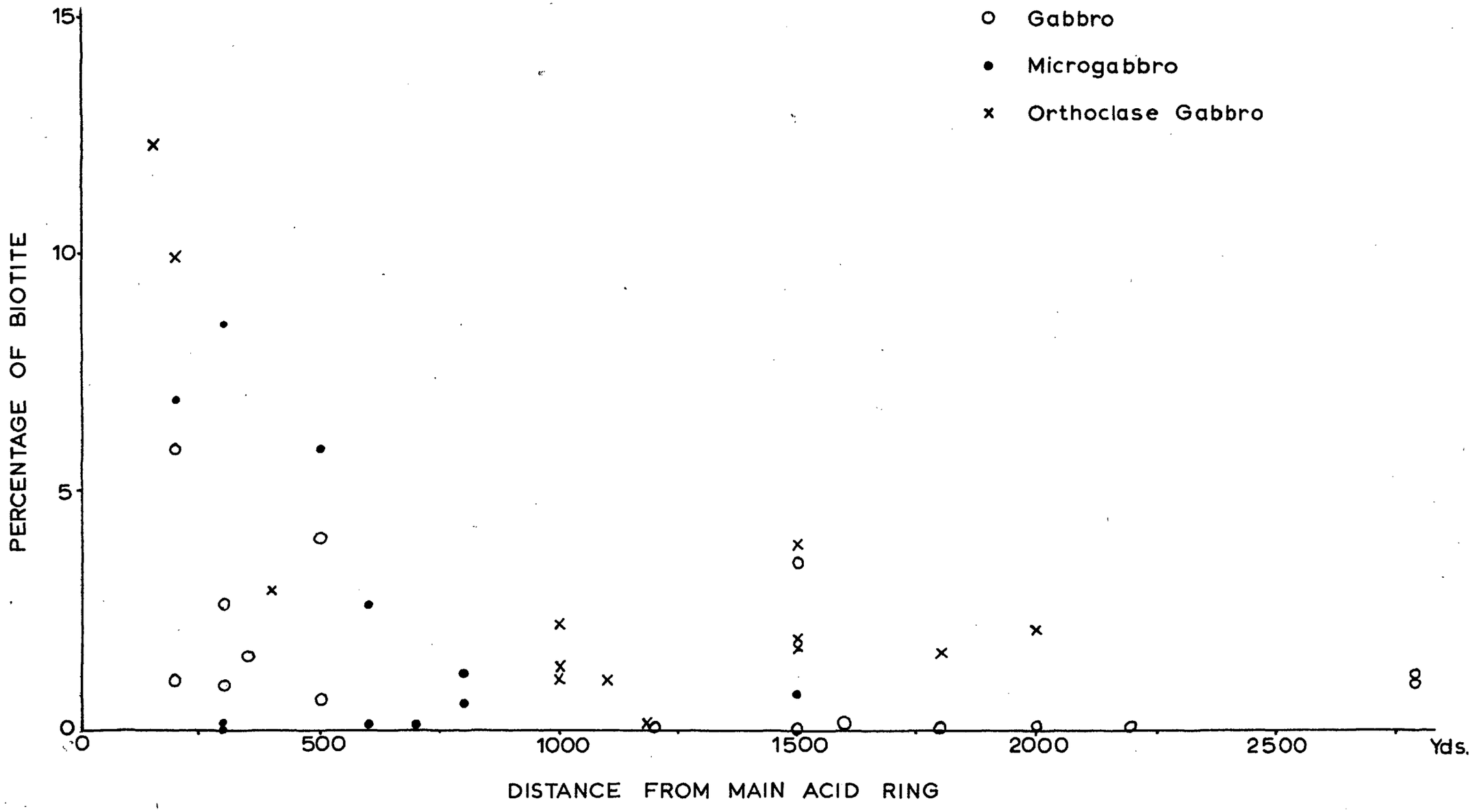
The presence of potash in the rock may be the result of contamination or metasomatism since it would appear to be unlikely that this is the result of differentiation in rocks of such character.

Some relationship between the development of biotite in the gabbroic rocks and the proximity of the specimen to the main granitic ring exists (figure 28). Whether this is the result of metasomatism or thermal alteration is not clear, but the development of biotite is not restricted to the orthoclase gabbro (figure 28), which fact suggests that metasomatism may be responsible.

Alteration in the Gabbroic Rocks

Near their contacts with later intrusions, the gabbroic rocks have been altered. The most widespread effect is the development of biotite mentioned above, which can be correlated with the proximity of the locality from which the specimen was collected to the main granitic ring. In figure 28, the percentage of biotite in the specimens is plotted against distance from the granitic ring. The correlation is not perfect, and the development of biotite may be controlled by other factors than a purely thermal one, but the graph suggests that the main acid intrusion is a major influence in the formation of biotite. Since the granitic ring cuts the gabbro, the specimens tend to be concentrated in the first part of the graph, and are not evenly distributed with respect to distance. However, it can be seen from figure 28 that all specimens occurring within a thousand feet of the main acid ring contain some biotite and all those with over five per cent of biotite are found within five hundred feet of it. The undersaturated intrusions also appear to

Fig.28. Proportion of Biotite in the Gabbroic Rocks Related to the Distance from the Main Acid Ring



have caused the development of biotite in some parts of the gabbro, close to the intrusions of the Marangudzi centre, but their effect is not nearly so widespread as that of the acid intrusions. Certain of the apparent anomalies in the graph (figure 28) are explained by the presence of the undersaturated intrusions.

In the majority of specimens of gabbro, the plagioclase is clear, but one specimen collected close to the outer margin of the granitic ring in the east was found to contain clouded felspar. The clouding is not resolvable under the microscope, and in zoned crystals is prominent in the more calcic zones. This clouding is similar to that described by A.G. Macgregor (1931) as being the result of thermal metamorphism, and is believed to be caused by the nearby intrusions of granite in this instance, although no other examples have been found.

South of the undersaturated intrusions of the Marangudzi centre, the plagioclase in some parts of the gabbro has been sericitised to a small extent. This sericitisation is believed to have been caused by the syenite dykes and a certain amount of syenite veining in the area.

Where the gabbro has been intruded by the microgabbro, it has been considerably altered. The plagioclase is sericitised and the mafic minerals have been altered to patches of amphibole and chlorite with little of the original pyroxene remaining. The texture of the

rock has not been entirely destroyed, but the development of secondary minerals tends to mask the gabbroic texture.

The Peridotites

In the field several outcrops of ultramafic rocks were found in the vicinity of the Madawula centre. Two specimens have been studied. Strictly speaking, the rocks fall between melagabbro and peridotite.

In the hand specimen, they are medium grained dark rocks with a high specific gravity. They consist of pyroxene and olivine for the most part, these minerals comprising over eighty per cent of the rock. Biotite is present in both specimens, and so is plagioclase, although none occurs in the thin section of specimen A.

In thin section specimen A is wholly crystalline, with a grain size between one and two millimetres. The pyroxene and olivine are granular, with interstitial biotite. The pyroxene shows good form against the biotite in some cases. The pyroxene is clinopyroxene and the crystals are commonly zoned. Some also show the lamella twinning. The olivine occurs as grains up to two millimetres across, and is usually partially or wholly rimmed by biotite. Specimen B consists of large crystals of monoclinic pyroxene up to five millimetres across, with smaller clinopyroxene crystals and olivine between them. The small crystals are about one quarter of a millimetre across, and all the pyroxene shows a strong tendency towards idiomorphism. In plane

polarised light, it is flesh coloured and variations in the colour show up the zoned nature of the pyroxene. The olivine is filled with dusty inclusions of ore, and occurs interstitially to the clinopyroxene and is also included in it. When adjacent to felspar, the olivine shows alterations to serpentine minerals which replace the surrounding plagioclase. The plagioclase is sericitised throughout much of the slide, and it has not been possible to determine its composition. Apatite is present in specimen B, but little is found in specimen A. The modes of the two specimens are given in figure 29. The plagioclase in these specimens shows an uneven distribution and the section of specimen B contains a higher proportion than is present in most of the hand specimens, having been cut from a part unusually rich in plagioclase.

The Anorthosite

In the hand specimen, the anorthosite is a grey rock with a saccharoidal appearance when fresh. The mafic minerals can be seen as dark spots in the hand specimen.

In thin section, it is holocrystalline with grain size ranging from a tenth of a millimetre to just over a millimetre. The major part of the rock is made up of plagioclase $An_{90}Ab_{10}$ and the remainder of clinopyroxene. The mode of the rock is given in figure 29. The clinopyroxene occurs as irregular grains between the grains of plagioclase. The general texture is hypidiomorphic granular. Small

Fig. 29.

The Essexite

MODE

Specimen.	Felspar and Felspathoid	Pyroxene	Biotite	Olivine	Ore
T24	33·2	44·6	11·3	10·1	0·6

MINERALOGY

Specimen	Plagioclase		Pyroxene		Olivine
	Phenocrysts	Groundmass	2V	Nβ	
T24	An 70	An 59	52°	1·688	Fa 31
T24A *		An 72			
T26	An 90	An 66			
T26A		An	50°	1·683	Fa 44
T26B		An 55			
T379 *	An 85	An 55			
T380		An 66	52°	1·685	Fa 24

Anorthosite

MODE

Specimen	Plagioclase	Pyroxene
S9	91·0	9·0

Peridotite

Specimen	Pyroxene	Olivine	Biotite	Plagioclase	Accessories
T431	73·2	5·9	—	18·7	2·2
T435	63·6	21·7	14·7	—	—

blebs of pyroxene are included in the plagioclase in places, and the rock is cut by a small vein (about 0.05 millimetres) which consists of felspathic material with a low refractive index, possibly potash felspar.

The Essexite

Although it is not correlated with the basic intrusions just described, the petrology of the essexite is included in this section. In the field this rock type was only found at two localities. At both, the rock showed evidence of brecciation in certain parts, angular blocks of finer grained material being cemented by coarser. In the northern intrusion the rock showed a certain amount of leucocractic veining, and in the south, some specimens which appear to have been originally of the same type, have been veined and sheared to such an extent that they have the appearance of a gneiss.

In the hand specimen, the rock is almost indistinguishable from the common gabbroic rocks, except for the presence of large porphyritic pyroxene crystals up to one centimetre across in the some cases.

In thin section, the coarser grained varieties are strongly porphyritic with large subhedral pyroxene, and olivine phenocrysts, and smaller plagioclase phenocrysts (Plate 15b). The groundmass is fine grained and has an intricate texture, making accurate modal analysis virtually impossible. The plagioclase is generally zoned

and intergrown with potash felspar and nepheline. Granular pyroxene and olivine with ragged biotite are the mafic constituents of the groundmass. The outer margins of the larger pyroxene individuals contain numerous small inclusions and the pyroxene shows alteration to amphibole in some of the veined specimens. Some pyroxenes show exsolution of iron ore in restricted zones. The accessory minerals are biotite, ore, and apatite.

Modal analysis was carried out on a specimen from this group of rocks and the result of this, together with details of mineralogy, is shown on figure 29. The properties of plagioclase, pyroxene and olivine from seven essexites are shown in the table. The two specimens marked with an asterisk are the fine grained varieties which were found as angular xenoliths in the coarser essexites. One of these contains small porphyritic plagioclase crystals up to two millimetres long, but the other is even grained. They appear to be very similar in composition to the coarser grained essexites, and probably represent a chilled variety of the latter which was subsequently broken up and became xenolithic in it.

The veining found in some of the specimens consists of potash felspar, sodic plagioclase (generally oligoclase) and nepheline with small amounts of pyroxene, olivine, and ore.

The Petrology of the Acid Rocks

The acid rocks are divided into five groups: the green quartz syenite, the granite, the microgranite, the white quartz syenite, and the central quartz syenite.

The Green Quartz Syenite

In the hand specimen, the green quartz syenite is a medium grained rock with the major part of the rock consisting of sage green potash felspar. This colour is readily lost on weathering, the felspar becoming a pale reddish brown. Amphibole and pyroxene are the common mafic minerals, and quartz is present in small quantities.

In thin section, the green syenite is medium grained with felspar making up eighty per cent of the rock. The felspar may be perthitic potash felspar alone or potash felspar with discreet plagioclase. The mafic mineral may be amphibole or pyroxene. The modes of six specimens of the green syenites are shown in figure 30. Quartz makes up ten per cent or less of the rock, several specimens having no quartz. Common accessory minerals are biotite, zircon, and allanite. When the rock is xenolithic, olivine and apatite may also be present. Ore is to be found in most specimens.

The texture of the green syenite is hipidiomorphic granular with large potash felspar crystals, smaller amphibole plagioclase and pyroxene individuals, and intergranular quartz.

The potash felspar is usually perthitic. In some cases very

Fig.30. Modes of the Green Qtz. Syenite

Specimen	Potash Felspar	Quartz	Plagioclase	Amphibole	Ore	
T 5	84·3	7·3	—	7·6	0·8	
T 49	72·7	9·8	6·9	9·6	0·5	
T 52 B	48·2	9·3	29·2	11·1	0·9	Xenolithic 0·8% Biotite
T 79	60·6	2·1	33·3	1·7	2·0	Xenolithic 0·4% Biotite
T 212	75·0	0·5	22·1	0·9	0·9	0·6% Pyroxene
T 283	85·0	—	—	2·2	1·8	9·6% Pyroxene 1·6% Altered mafic
A 6	80·7	—	12·8	—	✓	2·7% Pyroxene 0·8% Olivine 3·0% Acc. + Altered mafic

Modes of the White Qtz. Syenite

T 42	79·5	1·9	7·5	10·8	0·2	0·2% Acc.
T 43	67	—	17·4	12·3	0·7	2·6% Biotite
T 127 B	73·0	6·6	8·8	10·8	0·8	3·1% Biotite
T 143	67·3	8·5	15·0	—	2·2	5·9% Pyroxene.

strongly so. A typical example of perthitic potash felspar is shown in Plate XVI. The felspar crystals are usually elongated and are up to five or six millimetres long. Vein perthite is common, but patch perthite also occurs. The potash felspar is usually cloudy.

The plagioclase, occurring as discreet crystals, lies within the oligoclase-andesine range, and is more calcic in the contaminated specimens. In these specimens it sometimes shows zoning due to reaction, and the larger plagioclases in the xenoliths are sericitised.

The amphibole is hornblende with the pleochroic scheme X pale brown, Y greenish brown, Z dark greenish brown, but it is rather variable and is present in syenite which has been contaminated, although small amounts are found in the other samples not known to be xenolithic.

Olivine is only found in the xenolith rich specimens which are non quartz-bearing. It shows alteration to serpentine along cracks and crystal boundaries.

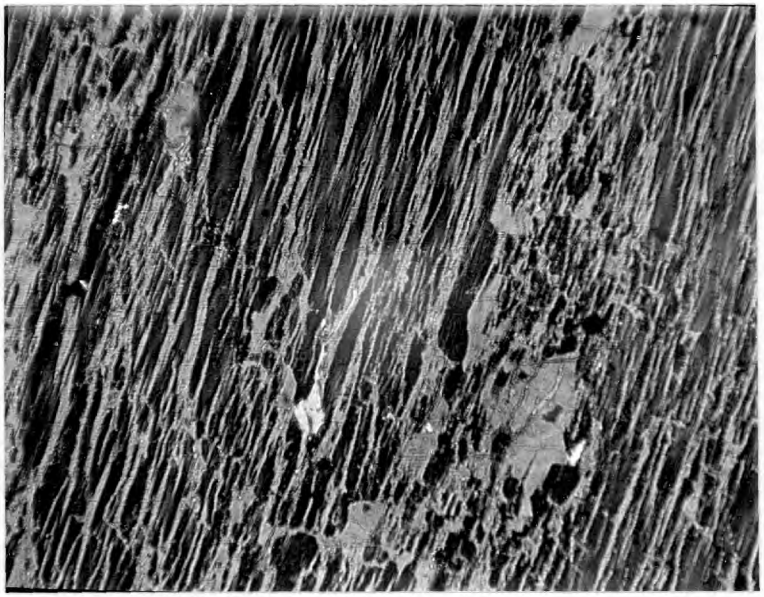
Quartz is present in the majority of specimens, but several are quartz free and the percentage of quartz is generally well below ten per cent.

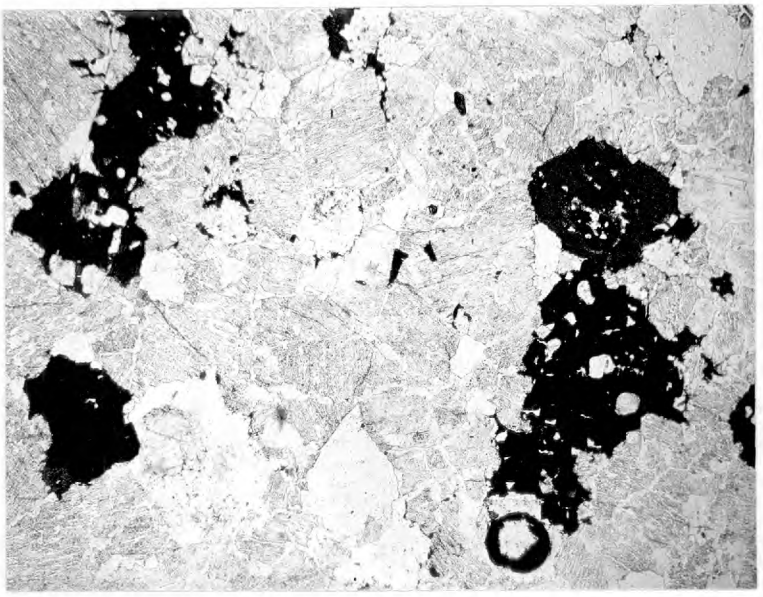
The petrology of the xenolithic rocks and the xenoliths is described under the heading 'The Xenoliths of the Acid Rocks'.

PLATE XVI

A. Photomicrograph (x55 crossed nicols). Typical vein perthite formed in the acid rocks. Potash felspar (dark grey) exsolving albite (light grey) in veins and small patches. From green quartz syenite. (T 17)

B. Photomicrograph (x15 plane polarised light). Medium grained granite. Perthitic potash felspar (light grey) amphibole with inclusions (dark grey) quartz (white).





The Granite

In the hand specimen, the granite is a medium grained leucocratic rock, consisting essentially of potash felspar, which is frequently pinkish in colour, and quartz. The mafic constituents usually make up less than ten per cent of the rock, amphibole and ore being the prominent minerals.

In thin section, the rock is seen to be inequigranular with grain size ranging from four millimetres down to half a millimetre. The potash felspar is found to be almost entirely perthitic and forms the larger crystals with the quartz, mafics, and plagioclase tending to be interstitial. The perthite is usually vein perthite, but grades into patch perthite in crystals showing a considerable amount of exsolution. The perthite is 'normal' with a host of orthoclase and an exsolute of sodic plagioclase within the albite oligoclase range (Plate XVI).

The quartz occurs as anhedral grains between the potash felspar. In some cases the potash felspar includes grains of quartz, but is not intergrown with it.

Modal analysis was carried out on the least weathered specimens, and the results are shown in figure 31. These results will be discussed before the accessory minerals are described. It will be seen from figure 31 that these modes fall into two groups. Uncontaminated granite, or granite not known from field evidence to be contaminated,

Fig. 31. Modes of the Granite

Specimen	Potash Felspar	Quartz	Plagioclase	Amphibole	Pyroxene	Ore.	
T 18	74·2	21·0	1·2	1·8		1·0	0·6% Allanite 0·2% Zircon
T 23	57·1	15·9	20·9	0·9	2·5	2·7	Xenolithic
T 25A	61	37·8	—			✓	1-2% Altered Mafic
T 60	62·6	29·8	4·2	3·2		0·2	
T 189	61·2	15·8	4·7	16·5	✓	1·9	Xenolithic
T 257	60·7	18·2	15·8	3·8		1·2	0·2 Allanite
T 21B	61	17·2	12·3	9·5	✓	✓	Xenolithic
T 21E	56·6	10·6	17·6	15·2	✓	0·8	Xenolithic
A 7	44·8	6·1	35·2	13·4		0·5	
T 44	68·7	28·8	—	4·3		✓	3·1% Biotite
T 6B	70·3	26·8	—	2·1		0·8	

Modes of the Microgranite

T 95A	43·3	23·8	23·5	5·3		✓	4·4% Biotite
T 183	40·7	29·4	23·5			✓	6·3% Mafic
T 184B	46·2	25·5	22·4	5·6		0·4	Biotite present
T 214	40·0	27·6	26·1	5·5		0·8	Biotite present.

and xenolithic granite. The modes of these two groups show that the mineralogy of the xenolithic granite has been affected by the presence of the xenoliths. The total content of mafics is higher, granular plagioclase is prominent as opposed to exsolved plagioclase, and the quartz content has been lowered.

The first four modes are taken to be representative of the original uncontaminated granite. Specimen T 257, although not obviously contaminated in the field, was collected from the margin of the granite adjacent to the gabbro, and its mode suggests that it may have been contaminated.

The remaining minerals of the uncontaminated granites occur in accessory quantities, and are plagioclase, amphibole, and ore. The plagioclase is almost entirely restricted to the perthite, very little granular plagioclase being found. The amphibole is hornblende with the pleochroic scheme X pale brown, Y dark greenish brown, Z dark olive green. The hornblende often occurs associated with ore and sometimes includes grains of ore.

A certain amount of biotite is usually present and is an alteration product of the amphibole. Zircon is present in all the granites and allanite occurs in several specimens.

The contaminated granite differs from the normal rock in being richer in mafic minerals and plagioclase, but poorer in quartz. The modes of four xenolithic samples are shown in the lower part of the

table figure 31.

Most of the amphibole is similar to that of the normal granite, but the pyroxene present shows alteration to amphibole and this is not the same, having distinctly blue pleochroic colours in some places.

The pyroxene shows much alteration to amphibole and also a yellow alteration product. When fresh, the pyroxene is a colourless or pale green clinopyroxene.

The plagioclase of the contaminated granites is typically oligoclase. In some specimens a core of sodic oligoclase is rimmed by albite. In one specimen, a much altered crystal of more calcic composition was present.

The common accessories are ore, biotite, zircon, and allanite.

The granitic rocks frequently show no flow texture but one or two bands were found to have a strong texture, and in xenolithic parts the xenoliths may be 'streaked out', parallel to the granitic bands. The few bands that do show a strong texture were found near the margin of the intrusion. In thin section these show extensive elongation of the perthite crystals, many being three millimetres long and half a millimetre wide. The mafics in the specimens collected were too weathered to be identified.

In general then, the granite is a hornblende leucogranite which shows banding in places. When xenolithic it is found to be richer in

mafic minerals and plagioclase and poorer in quartz.

The Microgranite

In the hand specimen, the microgranite is an even textured fine grained rock. It is leucocratic and of granitic aspect, and much more resistant to weathering than the coarse grained granitic rocks.

In thin section the rock is holocrystalline, with grain size ranging from half to one millimetre. The texture is granitic with perthitic potash felspar, plagioclase and quartz forming the bulk of the rock. Hornblende is the main mafic mineral, but in some slides shows extensive alteration to biotite. The accessory minerals are ore and zircon. Allanite and apatite are present in small quantities.

The modes of the microgranite are shown in figure 31. It will be seen from this that although called microgranite in the field, there is sufficient plagioclase present in some of the specimens for the rock to be classed as a micro-adamellite, but, since only a little over half the felspar is plagioclase in these, the name microgranite has been retained.

The White Quartz Syenite or Spotted White Syenite

In the hand specimen, this rock type is normally porphyritic, although it may be even grained. It is leucocratic with phenocrysts of potash felspar set in a groundmass of felspar, quartz and patchily distributed amphibole. Although called a quartz syenite, the quartz content is very variable, and the rock type actually ranges from an

orthosyenite to a granite. Pegmatitic patches are common.

In thin section, the rock is holocrystalline and medium to fine grained porphyritic. The texture ranges from hipidiomorphic to allotriomorphic granular, bordering on microgranophyric in places. The main rock forming minerals are potash felspar, frequently perthitic, plagioclase, amphibole, and quartz. Biotite and pyroxene are also found. The accessory minerals are ore, apatite, zircon; allanite was present in one or two specimens, and a small quantity of flourite was found in specimen T 143.

The modes of four specimens of spotted white syenite are shown in figure 30, and a typical specimen is shown in the photomicrograph Plate XVIIa.

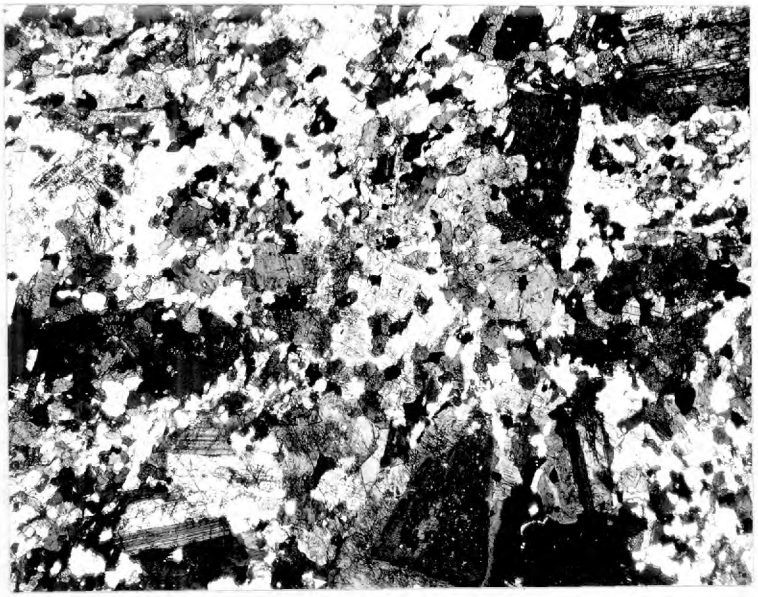
The potash felspar ranges in size from phenocrysts four or five millimetres or more across, down to crystals less than half a millimetre in size in the groundmass. It is usually perthitic (predominantly vein perthite) although some of the later crystals in the groundmass are homogenic. The plagioclase occurs as small grains in the groundmass and as large crystals often zoned and frequently fractured. These larger crystals also contain small inclusions of mafic minerals. The plagioclase of the groundmass is sodic plagioclase, usually within the albite oligoclase range, but the composition of the larger individuals lies in the andesine range, with overgrowths of sodic plagioclase or potash felspar. These crystals are not present in all

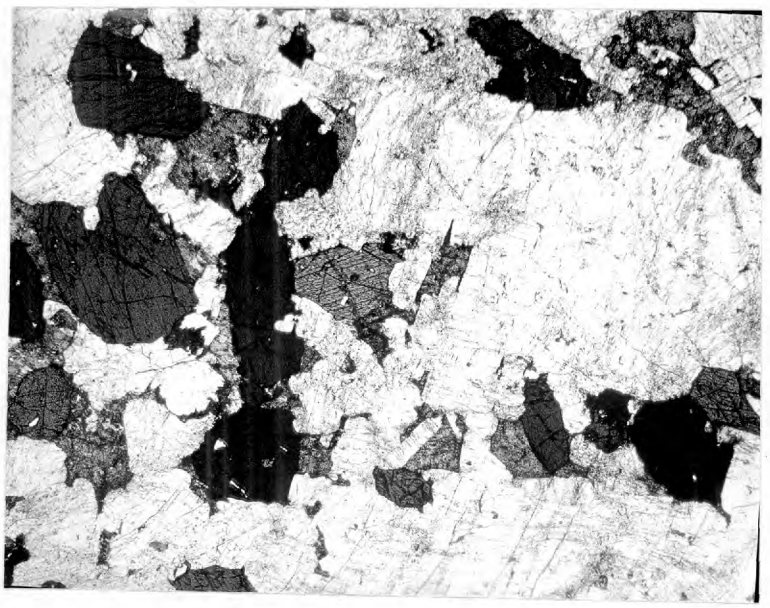
PLATE XVII

A. Photomicrograph (x15 crossed nicols). White quartz syenite. Showing large crystals of plagioclase (top right and bottom) and 'clots' of mafic minerals (left and right of centre) in a groundmass of potash felspar, plagioclase, quartz, and mafics.

B. Photomicrograph (x15 plane polarised light). Pulaskite. Potash felspar (white) amphibole (dark grey) and nepheline (stained - light grey).

(T 298 A)





specimens in which the large plagioclases are found.
The differences in composition, fracturing, and correlation with xenoliths indicate that these large plagioclases have been derived from the xenoliths. This is also supported by the presence of small inclusions in the plagioclase which probably grew during the early stages of inclusion and absorption of the xenoliths, which are believed to be of gabbroic origin.

The amphibole is hornblende with the pleochroic scheme X pale brown, Y greenish brown, Z dark green.

In the specimens known to be xenolithic, several of the hornblende crystals are seen to be overgrowths on an earlier mineral. In one or two cases this can be seen to be pyroxene, but usually the earlier mineral has been entirely altered, limonite stained alteration products remaining. Parts of the amphibole in these specimens show a different pleochroism with bluish green pleochroic colours. In some places, this can be seen as an alteration of pyroxene and would appear to be a more sodic type than the primary amphibole.

Only one specimen contains pyroxene in place of amphibole, and the pyroxene here is an ægirine-augite. This pyroxene shows a certain amount of alteration to bluish amphibole in places, and it seems probable that the altered pyroxene in the other specimens was somewhat sodic in composition. Compared with the amphibole which is generally anhedral and occurs in ragged crystals and aggregates,

giving the rock its spotted appearance, the pyroxene is subhedral to euhedral.

The quartz occurs as anhedral grains and patches between the crystals of the other minerals, and is one of the last minerals to have crystallized.

The Central Quartz Syenite

Owing to the deeply weathered condition of many of the exposures, only three specimens were collected, two of which have been sectioned.

In the hand specimen, the rock is medium grained with a grain size between two and five millimetres. The essential constituents are potash felspar, plagioclase and amphibole, with small quantities of quartz. The felspar is usually stained a reddish brown, due to weathering, but one exposure near a contact with the foyaites produced fresh specimens in which the felspar is white.

In thin section, the central quartz syenite is holocrystalline with a hipidiomorphic granular texture. The potash felspar, which is weakly perthitic, occurs as irregular grains up to five millimetres across and forms over sixty per cent of the rock in the specimens studied. The plagioclase is present as lath shaped crystals up to three millimetres long and as smaller grains. In parts of the intrusion, plagioclase forms the core of large perthitic potash felspar crystals. The plagioclase lies within the andesine range of composition and some crystals are weakly zoned. The amphibole is hornblende with

the pleochroic scheme X pale straw, Y brown, Z olive green, and extinction angle of twenty three degrees. The quantity of quartz is rather variable, but forms under ten per cent of the rock and may only be present in very small quantities. Biotite is present in places as an alteration product of hornblende and small quantities of epidote are also found. The common accessories are ore, apatite, and zircon.

In one part of the intrusion, the rock has been extensively altered and consists of sericitised felspar biotite and epidote.

The Xenoliths in the Acid Intrusion

a) Xenoliths occurring in trains

The most numerous xenoltihs in the acid rocks are those occurring in trains in the granite. Field evidence suggests that these may have been derived from intrusions of dolerite at one locality. Petrological evidence supports this suggestion in the case of one xenolith, which has retained a doleritic texture, but in the more altered xenoliths it is only possible to state that they were derived from a basic rock. However, it seems probable that many of the xenoliths in the trains were derived from dolerite intrusions.

From a study of the specimens of xenoliths collected it is possible to outline the changes which occur due to inclusion in the granitic magma, but for a more detailed study more specimens would be required.

The first effect is the alteration of the mafic minerals in

the dolerite to amphibole and biotite. In this first stage the alteration may be such that the ophitic texture of the dolerite is preserved. This is the case in one of the specimens collected, the pyroxene and olivine of the dolerite having been completely altered to amphibole and a small amount of biotite, but the unaltered laths of plagioclase, still with their original orientations, preserving the general appearance of the ophitic dolerite. Further alteration of the xenolith depends on the amount of reaction between the xenolith and the granite. If this is slight, little change in the mineralogy of the xenolith takes place, but the original texture is destroyed and the grain size of the xenolithic material is reduced. This produces an even grained granular rock, with a grain size below a tenth of a millimetre, formed almost exclusively of amphibole and plagioclase (cf. Joplin [1935]). If reaction does occur between the xenolith and the granite, potash felspar develops within the xenolith. Porphyroblastic crystals of potash felspar appear, and the xenolith becomes more leucocratic. With continued reaction the xenolith, with a considerably altered composition, develops a granoblastic texture which gradually becomes almost indistinguishable from that of the granite. The only evidence of the existence of xenoliths are patches richer in mafic minerals than is normal (cf. Nockolds.[1932]; H.H. Thomas and W.S. Smith [1932]).

Xenolith trains are also found in the green quartz syenite, but

are not as common as those in the granite. The two specimens of these xenoliths studied have features which suggest that they were derived from a gabbroic rock. The xenolithic material in these specimens is mostly fine grained, but a few large crystals of sericitised plagioclase are present and also a certain amount of olivine and pyroxene, which appear to be part of the original rock giving rise to the xenoliths. Olivine and pyroxene are stable in this rock, which is quartz poor in these xenolithic areas, probably because of reaction with xenoliths. Although there is a certain amount of amphibole present in the xenoliths, reduction in grain size does not appear to have been accompanied by extensive alterations of the mafic minerals, and the fine grained xenolithic material consists of a mixture of potash felspar and plagioclase, with pyroxene and olivine. Pyroxene and olivine are also present in the syenite surrounding the xenoliths, which is rich in mafic constituents compared with the non-xenolithic green quartz syenite. The syenite containing the xenoliths has therefore been considerably contaminated by the xenoliths. The xenoliths contain coarse grained patches with a granoblastic texture which are indistinguishable from the contaminated syenite surrounding them, and it is by increase of grain size following the introduction of felspathic material into xenolith that the contaminated syenite is produced.

b) Isolated xenoltihs in the granite

A number of isolated xenoliths were found in the granite such

as that shown in Plate V. These are of gabbroic origin and show little alteration due to inclusion in the granite, in many cases. Where alteration has occurred, it is similar to that described from the other basic xenoliths. Replacement of the mafic minerals by amphibole and development of potash felspar in the more altered specimens may occur.

Granitic Dykes

Closely associated with the major intrusion of granite in the field, are a number of acid dykes. These have been found to be fine grained equivalents of the granites, and in many cases show a microgranitic texture although one or two show a microgrnaophyric texture. They may be porphyritic with phenocrysts of potash felspar and/or plagioclase, or (more rarely) quartz. However, they are of similar composition to the major intrusives with which they are related, and it is not proposed to give a full petrological description of them.

The Composition of the Acid Intrusions

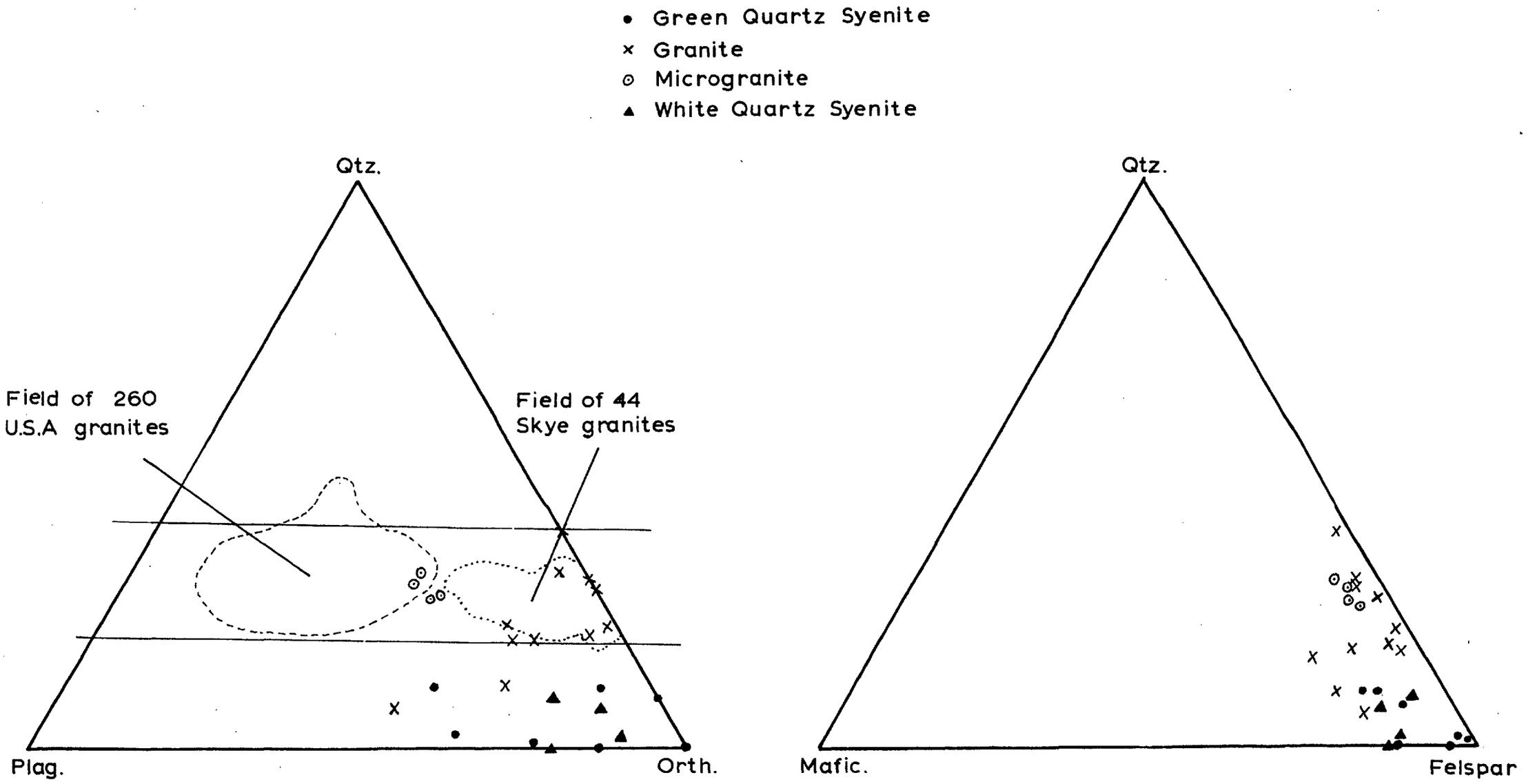
From figure 32, it will be seen that the compositions of the microgranite and of some of the granites fall in the zone of 'normal' granites, as represented by the Skye and U.S.A. granites (Tuttle and Bowen [1958]). However, excluding the microgranite, the compositions of the acid rocks show a considerable amount of variation. Nockolds (1935) demonstrates that contamination of granite by basic material

results in a lowering of the quartz content, and an increase of the plagioclase content. In several cases, those granites from Marangudzi which are poorer in quartz and richer in plagioclase than the normal types are found to be xenolithic (figure 31). This confirms the view that the variations in the modal compositions of the granites is partly the result of contamination, and that the uncontaminated granite has a composition approaching that of the Skye granites. Tuttle and Bowen regard granites with this composition, lying close to the quartz-potash felspar boundary of the triangular diagram figure 32, as high temperature types, and those whose compositions lie towards the centre of the diagram as having crystalized at lower temperatures. The compositions of the microgranite lie near the centre of the diagram, which therefore suggests that the microgranite crystallized at a lower temperature than granite. The finer grain size of the microgranite compared with that of the granite, and the small size of the intrusion, confirm a lower temperature of crystallization.

The green quartz syenite is known to be contaminated by xenolithic material in places, and the white quartz syenite is believed to have been extensively contaminated.

From the available evidence, the variations in the modal compositions of the acid intrusions may be attributed to three main factors:

Fig. 32. Compositions of the Acid Intrusives



1. Changing composition of the acid magma due to processes of differentiation.

2. Contamination of the magma by included material.

3. Variation in the proportion of plagioclase held in the perthitic potash felspar.

Petrology of the Undersaturated Rocks of the Marangudzi Centre

The Pulaskite

In the hand specimen, the pulaskite is light in colour with approximately three quarters of the rock made up of white felspar, mainly potash felspar, the remaining portion consisting of amphibole, felspathoid and accessory minerals. It is medium grained and usually structureless, although it does show banding in some parts. When banding is present it is shown up by variation in the proportions of mafic minerals and nepheline, as well as a degree of orientation of the minerals (Plate VIIb).

In thin section, the pulaskite is holocrystalline, medium grained, with a hypidiomorphic inequigranular texture. The essential minerals are potash felspar, amphibole, plagioclase, and felspathoid. The potash felspar is orthoclase which may or may not be perthitic. The perthitic orthoclase can be a fine vein perthite or contain scattered patches of plagioclase. The orthoclase crystals range up to four or five millimetres in length in the average specimen. They tend to have irregular boundaries between adjacent crystals and do not

generally show crystal forms against one another except in banded specimens where the orthoclase occurs as orientated prismatic crystals. In these specimens, the individuals are often twinned on the Carlsbad law, but twinning is less common in the more typical specimens. Plate XVIIb is a microphotograph of a typical specimen.

The plagioclase not occurring as exsolved perthite is present as rectangular grains up to a millimetre long. These frequently occur as aggregates of five or six grains, and show good crystal form against the potash felspar. Determination of the plagioclase, which is often present in fairly small quantities, is not specific on the flat stage microscope, but the majority of it lies in the oligoclase range.

The amphibole of the pulaskite has the pleochroic scheme X pale straw, Y blue green, Z dark green, and is a ferro-hastingsite. It occurs as anhedral to sub-hedral crystals and aggregates, and is frequently associated with small quantities of aegirine-augite. The aegirine-augite may occur within the amphibole individuals, which are up to five or six millimetres across in coarser grained samples, or occur separately. In many cases, the aegirine-augite is seen to have altered to amphibole which rims it and occurs in patches in it.

The felspathoid is nepheline, and occurs as interstitial patches between orthoclase and may include amphibole and plagioclase. Ad-

jacent patches frequently extinguish together. It may show alteration to muscovite, cancrinite or zeolites. The quantity of nepheline present is rather variable, ranging up to fifteen per cent, but typically reaches about five per cent. A pegmatite patch in the pulaskite was found to contain sodalite, as well as nepheline.

Modes of the pulaskite are shown in figure 33. Two of these modes show a higher proportion of nepheline than one would expect from the definition of a pulaskite. One of these specimens, T 135, was collected from the eastern part of the syenites originally mapped as pulaskite. This mode suggests that this section of the intrusion may be part of the foyaite ring, but insufficient samples were collected to warrant changing the boundaries mapped in the field, without further field study.

The other specimen, T 301, is from the south, and would appear to be a nepheline rich part of the pulaskite intrusion. It contains plagioclase which is present in most specimens of pulaskite, and also a certain amount of pyroxene. The specimen from the east contains neither plagioclase nor pyroxene, and this is a characteristic of the foyaites.

The Foyaites

In the hand specimen, these are seen to consist of potash felspar, nepheline, and amphibole. A variety of textures are present and variation in the proportions of nepheline and amphibole occur.

Fig. 33
Modes of the Pulaskite

Specimen	Potash Felspar	Plagioclase	Nepheline	Amphibole	Pyroxene	Ore	
T111	68·5	9·6	2·0	17·0	0·7	2·2	
T112	72·1	—	3·5	23·5	—	0·9	
T113	76·6	9·1	✓	8·6	2·1	2·6	1·0% Apatite
T135	52·8	—	12·8	33·9	—	0·2	Eastern Tongue Fojaite ?
T151	80·6	5·7	1·9	✓	✓	1·1	10·7% Amphibole + pyroxene
T152B	65·7	6·5	6·5	18·8	0·3°	0·6	
T301	48·0	14·4	12·6	22·1	0·8	1·4	0·7% Apatite

The textures vary from medium grained (grain size from one millimetre to five millimetres) granular and subporphyritic, to fine grained (grain size below one millimetre) porphyritic. In one case, field relations proved a fine grained porphyritic type to be later than a medium grained variety, but generally the age relations between the types remained obscure.

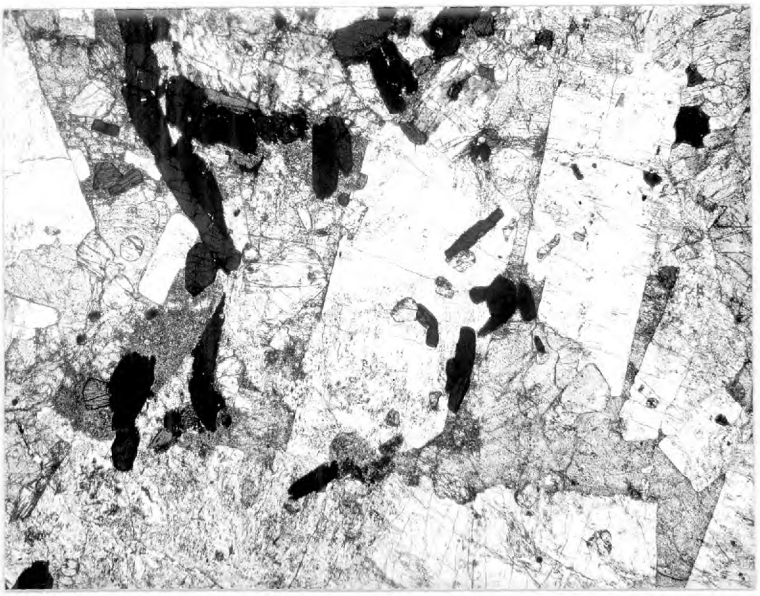
The texture of the groundmass varies from hypidiomorphic to allotriomorphic granular. The potash felspar tends to be lath shaped, with well formed laths in most specimens, but may be granular. When porphyritic, the foyaites contain porphyritic potash felspar up to five or six millimetres in length, and may also contain porphyritic amphibole up to three or four millimetres in length, but the nepheline is always restricted to the groundmass. The potash felspar forms two thirds of the rock and is orthoclase. It occurs as prismatic crystals in the groundmass and as porphyritic crystals. The orthoclase may be weakly perthitic or more commonly homogenious. In places, it includes small grains of amphibole and nepheline, and small laths of orthoclase are found inside nepheline crystals.

The nepheline occurs as grains and irregular patches interstitial to the felspar and amphibole. It rarely shows crystal form, but when it does, the nepheline has a square or rectangular cross-section. The grains of nepheline are typically about half a millimetre across, and rarely reach two millimetres in size.

PLATE XVIII

A. Photomicrograph (x15 plane polarised light). Foyaite. Medium grained with potash felspar (white) nepheline (stained - light grey) and amphibole (dark grey).
(T 304)

B. Photomicrograph (x15 plane polarised light). Foyaite. Fine grained porphyritic with potash felspar (white) nepheline (stained-light grey) and amphibole (dark grey).
(T 176)





The amphibole occurs as laths and grains and shows good form against the orthoclase and nepheline. It is a ferro-hastingsite and has the pleochroic scheme X pale brown, Y dark olive green, Z green. In the porphyritic foyaites, the amphibole occurs as two generations, as large porphyritic crystals, and as small laths, grains, and blebs in the groundmass.

The common accessory minerals are apatite and ore. A small quantity of aegirine is present in a few slides, but pyroxene is generally absent. When present, it is rimmed by amphibole to which much of it has been altered. In some places, the amphibole shows alteration to biotite, and nepheline has altered to concinite and muscovite, but generally the foyaites show little sign of alteration. The modes of the foyaites are shown in figure 34, and sections of two varieties are shown in Plate XVIII. From the modes it will be seen that the proportion of orthoclase remains reasonably constant with nepheline and amphibole making up the remaining portion of the rock. Specimens with a higher nepheline content tend to have a lower amphibole content, and vice versa. The finer grained porphyritic varieties are also found to be generally richer in nepheline and poorer in amphibole than the medium grained non-porphyritic foyaites.

At three localities, medium grained foyaite was found to contain scattered pseudo-leucites. These pseudo-leucites were between one and two inches across, and showed an irregular distribution, occurring

Fig. 34. Modes of the Foyaite

Specimen	Potash Felspar	Nepheline	Amphibole	Ore	
T148	62·7	26·0	10·6	✓	0·96% Acc.
T153	60·2	29·1	10·2	0·5%	
T176	52·7	23·8	23·2	✓	
T294	79·6	17·1	3·3	✓	
T304	64·7	28·6	6·7	✓	
T305	63·1	10·2	26·5	✓	0·2% Acc.
T318B	64·8	18·3	16·6	0·3	
T318c	59·6	7·0	32·5	✓	0·9% Acc.
T300B	74·7	13·6	11·0	0·8	

Modes of the Microfoyaite

T45	61·1	26·6	11·8	0·5	
T47	73·3	12·0	13·7	1·0	
T53	60·7	25·7	12·7	1·0	
T108	60·2	23·5	16·4	—	
T114A	53·3	32·2	13·3	1·3	

within six inches of each other (on a plane surface) in some places, but generally they are far less numerous. The pseudo-leucites (sketches of which are shown in figure 35) consist of fine grained leucocratic patches with a roughly circular form, out of which large potash felspar crystals extend into the enclosing rock. Smaller nepheline crystals occur along the margins of the altered leucites, which, with increasing alteration and recrystallization, become hard to distinguish from the surrounding rock.

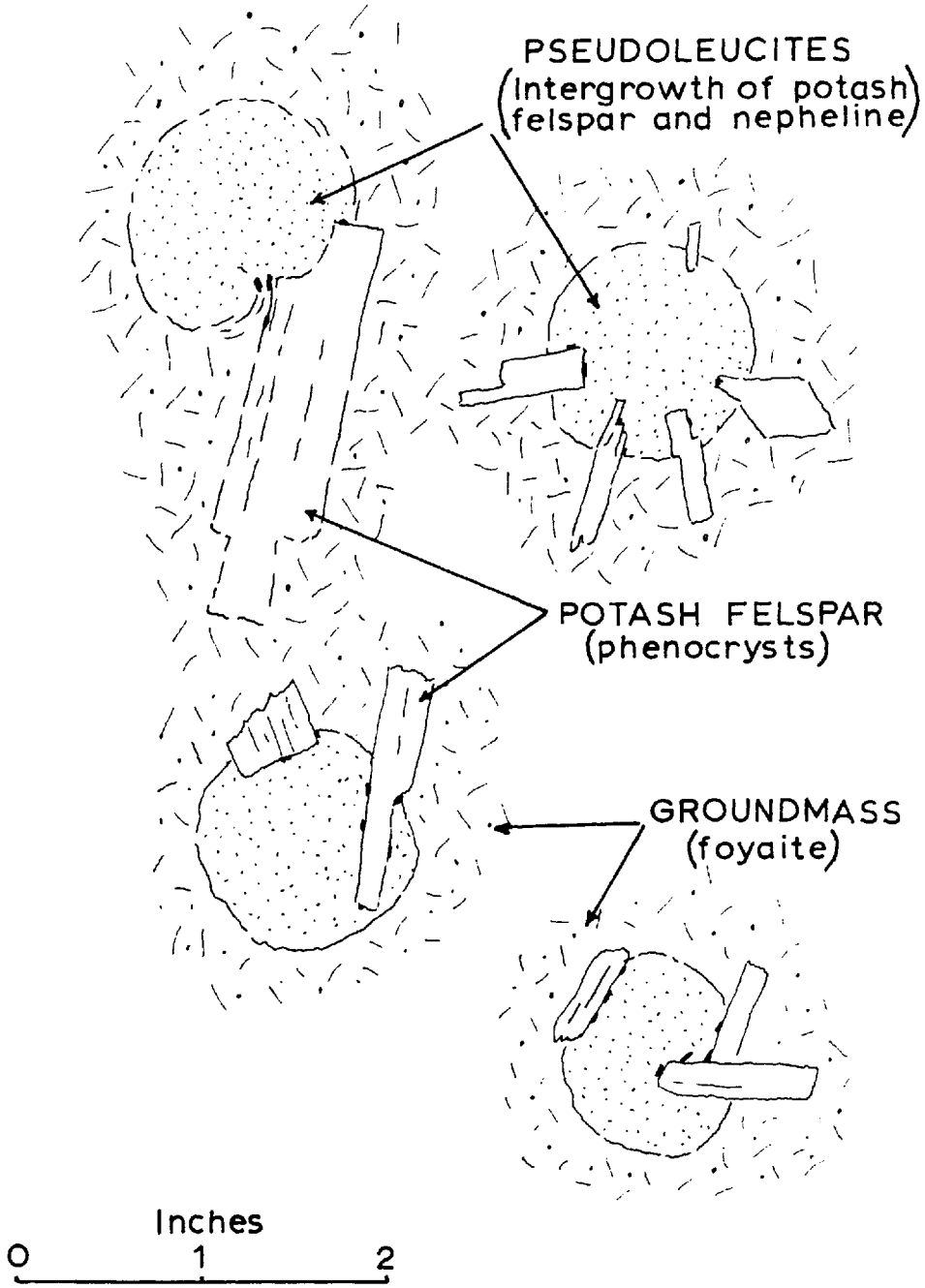
The Contaminated Foyaites and the altered Gabbroic material associated with them

The contaminated foyaites, which are found along the inner boundary of the foyaite ring, are a varied suite of rocks which from the field and petrological evidence are believed to be foyaites whose composition has been considerably altered by the absorption of basic xenoliths. Some of the specimens from this intrusion are true foyaites and are similar to the foyaites in the nearby intrusion, but many of the specimens are no longer of foyaitic composition.

In the hand specimen, the contaminated foyaites are variable in appearance and composition. They are usually medium grained with a colour index of about twenty. The felspar is mostly potash felspar in the majority of specimens, but there is a complete gradation from syehitic rocks to altered gabbros in which the dominant felspar is plagioclase. The mafic constituents are amphibole and/or monoclinic

Fig. 35.

Pseudoleucites in the Foyaites



pyroxene, and biotite is present in many of the specimens. Nepheline is present in small quantities in most samples, and only becomes a major constituent in those specimens which show little sign of contamination, and are truly foyaitic in composition. For the purposes of describing the rocks of this intrusion, they will be divided into three groups:

1. The Foyaites - consisting essentially of potash felspar, amphibole, and nepheline with small quantities of plagioclase and pyroxene.

2. The Contaminated Foyaites - in which potash felspar is commonly the most abundant felspar, but plagioclase is present as a major constituent and may be as abund- and as the potash felspar. The mafic minerals are amphibole, pyroxene and frequently biotite. Nepheline is present in small quantities and apatite is an important accessory.

3. Altered Gabbros - in which the major felspar is plagioclase, and the mafic minerals are pyroxene and ore showing alteration to biotite.

These three groups are not separated by clear cut divisions, but grade into one another. Of the sixteen specimens sectioned, four are classed as foyaites, nine as contaminated foyaites, and three as altered gabbros.

The Foyaites

These are similar to the foyaites in the main foyaitic ring, except that they contain small quantities of sodic plagioclase.

In thin section, they are seen to have medium grained (grain size two to three millimetres) hypidiomorphic granular or medium

to fine grained (grain size about one millimetre) porphyritic textures. Orthoclase makes up about sixty per cent of the rock, and sodic plagioclase and nepheline about ten per cent each, with twenty per cent of amphibole.

The orthoclase may be homogeneous or slightly perthitic, and occurs as phenocrysts in the porphyritic types. The sodic plagioclase is usually confined to the groundmass, but a phenocryst of sodic plagioclase occurs in one specimen. The nepheline occurs as irregular angular patches between the felspar and amphibole. The amphibole is commonly fairly well formed, and has the pleochroic scheme X straw brown, Y greenish brown, Z dark green. Small quantities of green diopside occur in association with the amphibole in places. Common accessories are ore and apatite. In one slide cancrinite is found to replace the plagioclase, occurring as finger-like extensions sometimes isolating parts of the plagioclase crystals.

The Conataminated Foyaites

In thin section, the contaminated foyaites are medium grained (grain size one to three millimetres) and show a variety of textures, both between specimens and between parts of a single specimen. Orthoclase, plagioclase, and nepheline, make up approximately seventy per cent of the rock in most specimens, with nepheline forming under five per cent, and a slightly higher proportion of orthoclase than plagioclase. The mafic minerals are amphibole, green monoclinic

pyroxene, and biotite.

The orthoclase normally occurs as subhedral laths up to three millimetres long, but may also be present as anhedral grains with irregular sutured boundaries. It frequenlty includes grains of plagioclase and pyroxene and in some slides has exsolved albite.

The plagioclase in most of the specimens is present as short prisms and grains about one millimetre in size often occurring in patches and usually showing good form against the orthoclase. The composition of this plagioclase lies within the oligoclase-andesine range, but in some of the slides calcic plagioclase is present as well, and may be as calcic as bytownite. This calcic plagioclase has a different mode of occurrence from the sodic plagioclase. It occurs as irregular grains and large prisms up to five millimetres long. Many of the crystals have been deformed as is shown by the curving of twin lamellae and the fracturing of some of the crystals themselves. Replacement by potash felspar is common, and produces complex textures which in some instances are reminiscent of myrmekitic intergrowths. Overgrowths of sodic plagioclase are also present.

Nepheline is present in all specimens, but only small quantities are found in those specimens containing calcic plagioclase, and it never forms more than ten per cent of the rock.

Monoclinic pyroxene and amphibole are the common mafic constituents but biotite is present in many specimens, and in one or two becomes

the most abundant mafic mineral.

The clinopyroxene is for the most part a green diopside, but aegirine-augite is also present in many of the specimens, sometimes rimming the diopside. Aegirine is generally not present, although small quantities are found. The clinopyroxene is frequently wholly or partly mantled by amphibole or biotite and shows evidence of alteration to these minerals.

The amphibole is mostly the brown or greenish brown amphibole found in the foyaites, with the pleochroic scheme X straw brown, Y greenish-brown or brown, Z dark greenish brown. It occurs as well formed crystals and as irregular patches surrounding clinopyroxene.

The biotite which is usually pleochroic from straw brown to dark brown occurs as discrete crystals and as irregular patches in an around amphibole and pyroxene. In one specimen, a small quantity of green biotite is also present. In several places, numerous small finger-like extensions of biotite invade the surrounding felspar.

The common accessory minerals are apatite, which is present in all specimens, and ore, which occurs in many.

Altered Gabbros

The three specimens classed as altered gabbros consist, essentially, of calcic plagioclase and clinopyroxene. However, potash felspar is found to replace the plagioclase along the crystal boundaries, and in irregular patches, and the plagioclase crystals show signs of

deformation and fracturing. The pyroxene shows alteration to amphibole and biotite, and the developemnt of pale green borders surrounding the cores of augite, in some cases.

The conclusions drawn from the above petrological evidence, together with the field relations, is that the rocks of the intrusion described as contaminated foyaite, although now essentially nepheline poor syenites, are the product of assimilation of gabbroic material by foyaitic magma.

The Microfoyaites

In the hand specimen, the microfoyaites are fine grained grey rocks with a grain size from a quarter to one millimetre. The colour ranges from pale grey in the coarser grained specimens, to dark grey in the finer grained varieties, and the rock is typically even grained with a trachitic texture. In several localities the microfoyaites contain pseudo-leucites, but they are not always present. Pseudo-leucites tend to be present in the finer grained microfoyaite. Microfoyaite bearing pseudo-leucites has been broken up and included in coarser grained microfoyaite. Examples of this are shown in Plate IX. The pseduo-leucites occurring in the microfoyaite are usually fairly large, up to four or five inches across, and frequently contain appreciable quantities of amphibole. They are typically in an advanced stage of alteration, and rarely show good crystal form.

Most of these pseudo-leucites have roughly circular cross-section and it is not possible to tell whether they were originally single crystals or aggregates. In a few cases, the crystal forms have been sufficiently well preserved to show that they have formed from a single leucite crystal, but in other cases the 'pseudo-leucite' is seen to have been formed by the alteration of several leucite crystals.

In thin section, the microfoyaites are holocrystalline fine grained rocks, and consist essentially of potash felspar, nepheline and amphibole. The modes of five specimens are shown in figure 34, and a microphotograph of a typical specimen appears as Plate XIX. The rocks commonly show a trachytic texture, although the minerals do not show a high degree of orientation and the texture is more obvious in the hand specimen than under the microscope.

The potash felspar is orthoclase or orthoclase perthite and occurs as prismatic crystals, which may be up to two millimetres long, and as grains. The longer prismatic crystals lie with their long axes subparallel (within 20°) to the general structure of the rock, but the shorter prismatic crystals and grains show no apparent orientation.

The nepheline which makes up approximately a quarter of the rock typically occurs as equidimensional grains with a tendency to show a square cross-section. However, idiomorphism is rarely obtained due to the moulding of the nepheline on the potash felspar, and in some slides the nepheline is interstitial to the potash felspar.

PLATE XIX

A. Photomicrograph (x15 plane polarised light). Microfoyaite (grey syenite) showing flow texture. Consisting of potash felspar, nepheline and amphibole. Weathering has taken place along cracks in the rock and shows up as grey bands.

(T 114A)

B. Photomicrograph (x120 plane polarised light). Dactylitic texture in basic xenolith in foyaite. Finger-like growth of amphibole on pyroxene extending into surrounding felspar.





Although nepheline is the most common felspathoid, sodalite and cancrinite may also occur - sodalite making up approximately half the total felspathoid in specimen T 47.

The amphibole is strongly pleochroic with the pleochroic scheme X pale brown, Y almost opaque greenish-brown, Z dark green. It occurs as laths and as smaller grains, and blebs, which are sometimes included in the potash felspar and nepheline. The laths of amphibole, which are up to a millimetre in length, lie subparallel to the structure of the rock. Small quantities of aegirine-augite and aegirine are associated with the amphibole in some specimens, but only in accessory amounts.

Ore is present as an accessory mineral in several specimens, but not all.

The Pseudo-leucite Syenite

In the field, the pseudo-leucite syenite is inhomogeneous. The rock typically contains pseudo-leucites in various stages of alteration, and re-absorption. In some localities, the crystal form of the leucite crystals is still discernible, but in much of the intrusion the rock has a patchy appearance, with circular areas free from mafic minerals, indicating the location of pre-existing leucites. These leucocratic patches now consist of potash felspar, nepheline, and, in some cases, a certain amount of muscovite. The proportion of the rock consisting of altered leucite varies considerably.

Parts of the intrusions consist almost entirely of pseudo-leucites, and yet in the northern part of the outcrop the rock contains none in some places, or occasional pseudo-leucites widely scattered. The matrix containing the pseudo-leucites and the pseudo-leucite free rock is a felspathoid rich syenite. The rock contains amphibole and pyroxene in varying amounts up to twenty-five per cent, and shows a range of grain size from fine grained (below one millimetre) to coarse grained (over ten millimetres). These changes in grain size and composition occur within a single hand specimen in some cases.

No modal analyses have been attempted owing to the difficulty of obtaining representative samples of these highly variable rocks.

The thin sections have been stained for felspathoid and show that felspathoids make up approximately fifty per cent of the rock. Nepheline is the most abundant felspathoid, but shows alteration to cancrinite in places, and a certain amount of primary cancrinite may be present. The nepheline also shows alteration to muscovite in some specimens, and one of the pseudo-leucites contains about twenty per cent of muscovite.

The felspar of the pseudo-leucite syenite is orthoclase and makes up approximately thirty per cent of the rock in most specimens. A certain amount of optical work carried out on the felspar suggests that it is rich in soda, but insufficient work has been done to enable the composition of the felspar to be determined.

The mafic minerals form from below ten per cent to about twenty-five per cent of the rock. They consist mainly of amphibole and pyroxene, the two minerals being present in equal proportions, or the amphibole being more abundant. A certain amount of biotite is present in some samples. The amphibole is ferro-hastingsite and occurs in well formed crystals with the pleochroic scheme X pale brown, Y dark brown, Z dark greenish-brown.

The pyroxene in the majority of specimens is a green diopside, but in two specimens a small quantity of aegirine-augite is also present. The crystals of diopside are normally well formed often showing the characteristic eight-sided cross-section of the pyroxene.

The leucocratic areas occupied by the alteration products of leucite are normally free from mafic minerals, but they may contain some isolated patches of amphibole or pyroxene. The pseudo-leucites usually consist of an intergrowth of nepheline and potash felspar. In many specimens this intergrowth produces a texture reminiscent of the micrographic intergrowth of quartz and felspar. An example of this intergrowth is shown in Plate XXIb. In this specimen, the nepheline shows no alteration, and besides the nepheline and potash felspar there is only a small quantity of amphibole and a little analcite. This example is not altogether typical since the nepheline has usually altered to cancrinite or muscovite which tends to destroy the texture to some extent.

When free from pseudo-leucites, the rock most closely resembles Nordsjoite of Johannsens classification, but no major intrusive bearing pseudo-leucites has been described. The rock has therefore been named pseudo-leucite syenite.

Xenoliths in the undersaturated intrusions

The petrology of the xenoliths occurring in the foyaites has been described with the petrology of the contaminated foyaites. Xenoliths also occur in the pulaskite and microfoyaites.

The xenoliths in the pulaskite are of gabbroic origin and may retain a gabbroic texture in the hand specimen which is lost with increasing alteration.

The two thin sections of xenoliths in the pulaskite whcih have been cut show extensive alteration of the plagioclase and patchy alteration of the potash felspar and sodic plagioclase throughout much of the xenoliths. Small quantities of nepheline are present and also sericite. The textures shown by the felspathic minerals are complex. The potash felspath occurs in irregular patches with sutured boundaries and may poikalitically enclose plagioclase. Intergrowths of potash felspar and plagioclase or nepheline are also found.

The unaltered pyroxene is monoclinic pyroxene of augitic composition, and in some parts of the xenoliths shows little sign of alteration. The first stage of alteration is the development of a

rim of amphibole around the pyroxene crystal. The amphibole frequently develops numerous small parallel finger-like processes which extend into the surrounding felspar and which are optically continuous with the amphibole rim. This texture has been termed dactylitic texture by Sederholme, and is shown in Plate XIX. The amphibole formed during the early stages of alteration shows pale brown to brown pleochroism, but as alteration becomes more intense, the amphibole shows green to brown pleochroism and finally blue to green. Biotite and clinopyroxene are also formed during the alteration. The biotite may be brown or green and the clinopyroxene is aegirine-augite. The augite crystals also show pleochroic outer zones, in some cases, which are not overgrowths but the alteration of augite to aegirine-augite without destruction of the original crystal lattice. This type of alteration is especially prominent in the region of a vein of perthite and nepheline which cuts the xenolithic material. The aegirine-augite which is developing in association with the amphibole also shows dactylitic texture. Although the finger-like extensions of pyroxene are associated with pyroxene crystals, they are also associated with crystals of amphibole, and conversely, dactylitic texture in amphibole is associated with crystals of pyroxene.

The development of the blue-green amphibole, the green pyroxene and the green biotite is believed to be the result of the introduction of sodic material from the enclosing pulaskite.

Small quantities of epidote occur and also clinozoisite. The epidote occurs associated with ore in patches surrounded by secondary mafic minerals and the clinozoisite occurs in smaller quantities in felspar. Apatite is a common accessory mineral and occurs in well formed crystals up to half a millimetre long. The apatite crystals are frequently enclosed by the mafic minerals or associated with them and are far less common in the felspar.

Xenoliths are found in many of the intrusions of microfoyaite but much of the xenolithic material is of earlier microfoyaite which has been broken up by later phases of intrusion. Xenoliths of pulaskite are found in the microfoyaite, cutting the pulaskite, and these show little or no alteration due to inclusion in the microfoyaite. The development of small quantities of aegirine-augite along the margins of some amphibole crystals being the only obvious result of inclusion.

In the intrusion of microfoyaite in the granite and white quartz syenite to the north of the pulaskite ring, two types of xenoliths are distinguishable. The most numerous xenoliths are of earlier microfoyaite and frequently contain pseudo-leucites, but there are also a number of xenoliths of a dark porphyritic rock. In the hand specimen the latter is a fine grained grey rock containing large well formed crystals of pyroxene and altered olivine up to three millimetres long and irregular leucocratic patches consisting mostly

of potash felspar.

In thin section the matrix of the rock consists of potash felspar, amphibole, and aegirine-augite, and has a grain size below one tenth of a millimetre. A certain amount of felspathoid is also believed to be present, although positive identification was not possible owing to the fine grain size. Porphyroblastic crystals of potash felspar and nepheline up to one millimetre across and patches of granular potash felspar with nepheline occur in the matrix. These include grains of amphibole from the groundmass and are also often rimmed by mafic minerals which have been excluded from the porphyroblasts. Set in the matrix are large euhedral crystals of monoclinic pyroxene up to one centimetre across, and olivine crystals which have been extensively altered. The clinopyroxene lies in the diopside-augite range, some crystals being zoned. The margins of the pyroxenes have been altered to aegirine-augite but the alteration has not penetrated far into the crystal and the original form of the crystal has not been destroyed, except in the smallest which have been entirely altered in some cases.

The olivine crystals have been extensively altered and olivine itself only remains as irregular patches in the centre of zoned areas of alteration products. In one example the alteration products formed a shell around the unaltered olivine one millimetre thick. Immediately adjacent to the unaltered olivine is a narrow zone of tremolite followed by diopside which gives way to phlogopite approximately

one third of a millimetre from the olivine. The outermost zone, one third of a millimetre thick, consists of green and brown biotite with grains of aegirine-augite.

The presence of these large well formed mafic minerals and the general appearance of the rock suggests that these xenoliths have been derived from a lampropyric intrusion, although no rocks of this type were found in this part of the complex.

Petrology of the Undersaturated Rocks of the Madawula Centre

The Nepheline Syenites

Owing to the varied nature of the nepheline syenites forming the major part of the Madawula centre, it has been decided to describe these rocks generally and discuss the varieties which occur.

In the hand specimen, the rocks are medium to fine grained and light to medium grey in colour. Some of the coarser grained varieties have a mottled appearance with well formed mafic minerals set in a whitish matrix, while the finer grained types have a dense greasy appearance. Porphyritic crystals of nepheline are present in many of the syenites and may be accompanied by porphyritic potash felspar. In places the rocks contain poorly defined leucocratic patches. These may be circular or oval in cross-section and are generally less than one inch across. They are pseudo-leucites and are present in varying concentrarions. When most abundant, they form the major part of the

rock, but this is unusual. In the most extreme case the rock consists of tightly packed pseudo-leucites up to an inch and a half across, which may or may not show the crystal form of leucite, together with nepheline phenocrysts up to half an inch across. The nepheline phenocrysts, which are subhedral in form, pack the areas between the pseudo-leucites and the interstices are occupied by altered mafic minerals.

In thin section the nepheline syenites of the Madawula centre are found to differ from those of the Marangudzi centre in that they have suffered alteration, causing the development of secondary minerals and, in many cases, complex textures.

The syenites consist of orthoclase, nepheline, and mafic minerals, and have colour indices ranging from below ten to over twenty five. The orthoclase may be present as prismatic crystals, but commonly occurs as irregular grains intergrown with nepheline and including grains of nepheline and mafic minerals. Nepheline, or its alteration products, form over ten per cent of the rock in most specimens, but rarely over thirty per cent. In the least altered specimens, augite, in some cases with an outer zone of aegirine-augite, is present as a primary mineral showing alteration to amphibole and biotite. A small quantity of olivine surrounded by alteration products is present in one specimen. However, in most of the specimens the mafic minerals appear to be almost entirely secondary, consisting for the most part of biotite and amphibole. Melanite garnet is present in several

specimens, forming angular patches. Granular melanite is found lining small cavities which are to be seen in several of the more leucocratic specimens. These cavities, which have been infilled with calcite, are rarely over two millimetres long, and are typically narrow and irregular. In one or two cases, prismatic crystals of orthoclase, also coated with melanite, extend into the cavities.

The pseudo-leucites are normally free from mafic minerals, but small quantities of biotite may be present. The orthoclase and nepheline tend to occur in an intergrowth similar to that found in pseudo-leucites from other parts of the complex.

The textures shown by the syenites of the Madawula centre are variable. In many of the more leucocratic types the mafic minerals show a patchy distribution in thin section, which is not apparent in the hand specimen. In some cases, the more leucocratic areas, consisting of orthoclase and nepheline, have a texture similar to that found in the pseudo-leucites. It seems probable that these rocks once contained pseudo-leucites, but reaction and alteration has been so extensive that little evidence of the existence of pseudo-leucite remains. In a few of the syenites having a high colour index, the mafic minerals are found to surround small circular patches of potash felspar, and nepheline, under one millimetre across in some cases. These also appear to be pseudo-leucites. The above evidence suggests that leucite may have been widely developed in the rocks of the Madawula centre.

The Malignite

In the hand specimen, these rocks are dark grey, medium grained, with a high specific gravity. In the majority of specimens well over fifty per cent of the rock is composed of mafic minerals, clinopyroxene being the most abundant.

In thin section, the rocks are found to have a colour index which ranges from fifty to seventy five. Clinopyroxene and biotite are the most prominent mafic minerals, and nepheline and potash felspar are the felsic minerals. Ore and apatite form important accessories.

The clinopyroxene may be aegirine-augite, but is usually titanferous augite with aegirine-augite rims. It is present as euhedral to subhedral grains two to three millimetres across, and frequently includes small flakes of biotite and apatite crystals. Biotite is also present as well formed crystals up to three millimetres long. Nepheline and potash felspar are present in approximately equal proportions and are usually unaltered. They form irregular crystals moulded on the mafic minerals and intergrown with each other. Grains of ore and apatite occur throughout the rock.

In one specimen nepheline is much more abundant than the potash felspar which is only present in small quantities. Thus in places the rock approaches ijolite in composition.

Petrology of the Minor Intrusions

In this section a brief description of the petrology of the minor intrusions associated with the complex is given.

Basic Dykes

Porphyritic Dolerites

Three specimens of dykes cutting the basement were collected which in the hand specimen appear to be coarse grained basic rocks. They are, however, porphyritic dolerites in which the large porphyritic plagioclase crystals are so numerous that they give a false impression of the grain size. In the hand specimen, the rock is dark, the plagioclase being a deep brown in colour.

In thin section, the groundmass is seen to be fine grained with a subophitic texture. The porphyritic plagioclase crystals are up to one centimetre long, and smaller phenocrysts of pyroxene are present and also olivine in one specimen. Two of the three specimens contain patches of quartz bearing material which appear to have been derived from the basement.

Altered Dolerites

The altered dolerites are fine grained grey rocks in the hand specimen, and contain porphyritic plagioclase and pyroxene.

In thin section the minerals are seen to be considerably altered. The grain size of the groundmass is between a half and one millimetre with phenocrysts of plagioclase up to five millimetres long and

pyroxene up to three millimetres across. The original texture of the groundmass was subophitic with lath shaped plagioclases partially enclosed by pyroxene. No olivine has been found in the slides, but a certain amount may have been present prior to alteration, and has been replaced by the patches of epidote and ore occurring in several of the slides.

The plagioclase has been extensively sericitised making determination impossible. The pyroxene has been altered to actinolite, chlorite and epidote, but a certain amount of unaltered pyroxene is present in most of the specimens and was found to be clinopyroxene.

The group is characterised by the porphyritic texture and extensive alteration found in all specimens.

Dolerites

The dolerites are medium to fine grained (grain size 1.5 millimetres to 0.5 millimetres) non-porphyritic. In thin section they are seen to consist of plagioclase and pyroxene and have a sub-ophitic texture. The plagioclase is labradorite (An 55-60) and occurs as lath shaped crystals with random orientation. The pyroxene is a clinopyroxene within the augite range. Small quantities of quartz are present in half the specimens, most of these being of dykes cutting basement rocks, and ore is present as an accessory in most specimens. The dolerites are not generally altered, although in one or two cases a certain amount of alteration has taken place.

Clouding of the plagioclase is found in several specimens, but sericitisation and alteration of the pyroxene may have taken place.

Basalts

In the hand specimen, the basalts are fine grained porphyritic rocks.

In thin section, the grain size is found to range from below one tenth of a millimetre in the finer grained types up to one third of a millimetre. When fresh, the rocks consist for the most part of plagioclase and clinopyroxene with a subophitic to granular texture, but many specimens have been altered, and in some the alteration has been such as to destroy the texture and make determination of the minerals impossible.

The plagioclase occurs as laths and grains in the groundmass, and is the most common mineral occurring as phenocrysts, which are typically short prismatic crystals or grains up to five millimetres across. The phenocrysts are of calcic bytownite and the groundmass of labradorite or sodic bytownite. Some of the phenocrysts show oscillatory zoning. In the altered specimens, the plagioclase becomes sericitised, the phenocrysts being completely replaced by felted patches of white mica in several cases.

The pyroxene is a monoclinic pyroxene and occurs as grains and irregular patches in the groundmass, and also as phenocrysts in half the specimens. The clinopyroxene phenocrysts are smaller than the

plagioclase phenocrysts, but may be up to three millimetres across and are well formed. Olivine is not generally present but is found as corroded phenocrysts in two specimens, and in the groundmass of one. Patches of serpentine minerals in some of the specimens may be alteration products of olivine.

Quartz is present in some of the more altered basalts, but none is found in any of the fresh samples. It occurs as small crystals in the groundmass, as aggregates and larger crystals associated with patches of alteration products, and as grains up to half a millimetre across. It has not been possible to demonstrate whether quartz is xenocrystic, primary, or secondary, owing to the altered condition of the specimens in which it is present.

The Trachytes

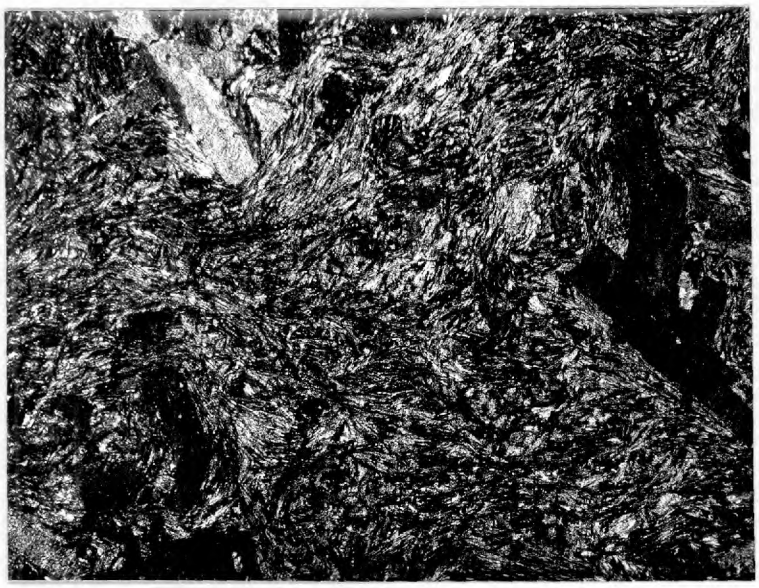
In the hand specimen, the trachytes are pink or grey, fine grained porphyritic rocks.

In thin section, the rocks are holocrystalline porphyritic with the groundmass formed of acicular felspars and mafics ranging from a tenth to a half a millimetre in length, and which may or may not show trachytic texture. A specimen showing well developed trachytic texture is shown in Plate XX. Many of the specimens have been considerably altered and only one of the five sectioned is fresh. This specimen will now be described.

PLATE XX

A. Photomicrograph (x15 crossed nicols). Trachyte. Showing well developed trachitic texture with porphyritic potash felspar set in a groundmass of altered felspar and mafic minerals.
(T 138)

B. Photomicrograph (x15 plane polarised light). Porphyritic phonolite. Phenocrysts of potash felspar and also amphibole set in a fine grained groundmass of potash felspar, amphibole, and nepheline.





This rock is grey in the hand specimen, and in thin section the groundmass is found to consist of potash felspar and sodic plagioclase with needle shaped crystals of riebeckite. The grain size is approximately a tenth of a millimetre and flow texture is present in places. The phenocrysts are lath shaped crystals of perthitic potash felspar and andesine (Ab67.An33) up to two millimetres long, with rare prismatic crystals of riebeckite up to one millimetre long. Quartz is present in the groundmass in accessory quantities and rare crystals of zircon occur. Secondary calcite and flourite form irregular patches throughout the rock, together with limonite which replaces riebeckite in places. Perthitic potash felspar forms over seventy per cent of the porphyritic material, but the proportion of potash felspar in the groundmass is impossible to estimate in the unstained slide. However, albite is a prominent constituent, and the rock is a soda rich member of the trachytes.

The other specimens of trachyte appear to be similar to the specimen just described, although considerably altered. Phenocrysts of biotite and diopside occur, and ore and apatite are present in some specimens.

Undersaturated Dykes of the Marangudzi Centre

The Phonolites

In the hand specimen, the phonolites are fine grained, dark grey rocks which break with a conchoidal fracture. They have a dense

texture and do not contain phenocrysts of felspar although they may contain small phenocrysts of amphibole or pyroxene.

In thin section, the phonolites are fine grained with potash felspar, amphibole, and nepheline forming the groundmass. The potash felspar is usually lath shaped, but is granular in some of the coarser grained specimens. The laths of felspar are under a quarter of a millimetre long, and may be randomly orientated or show flow texture. The amphibole occurs as fine acicular crystals often lying along the sides of laths of potash felspar. In the varieties with granular felspar, the amphibole may occur as needles which penetrate the felspar or may also be granular. The amphibole is strongly pleochroic with the pleochroic scheme X pale brown or straw, Y green, Z dark green. Small, well formed phenocrysts of amphibole up to two millimetres long are present in some specimens but have a different pleochroic scheme from those in the groundmass. (X pale straw, Y pale brown, Z greenish brown) but these have a narrow rim of green amphibole in many cases.

The nepheline occurs as grains between the laths of potash felspar. It is not present as phenocrysts. In addition to the nepheline other felspathoids and/or zeolites are present in some specimens, cancrinite, sodalite, and analcite being most common.

Phenocrysts of pale green diopside occur in several specimens. They are generally well formed with narrow rims of green amphibole.

In one specimen, rare phenocrysts of olivine are present. The common accessories are ore and apatite.

The phonolites generally show little alteration, but in some specimens the felspar has been weakly sericitised.

The Porphyritic Phonolites

In the hand specimen, they are fine grained grey rocks similar to the phonolites, but they differ from them in having porphyritic potash felspar. The phenocrysts of felspar are present as prismatic crystals up to six millimetres long, and are accompanied in most specimens by porphyritic mafic minerals.

In thin section the porphyritic phonolites are holocrystalline with the groundmass formed of potash felspar, amphibole and nepheline. The grain size of the groundmass is generally coarser than that of the non-porphyritic phonolites, the laths of felspar being up to half a millimetre long, in the coarser specimens. In these, the amphibole occurs as small prismatic crystals rather than as the acicular crystals found in the finer grained specimens. Both trachytic and tinguaitic textures are developed. A photomicrograph of a typical specimen is shown in Plate XX.

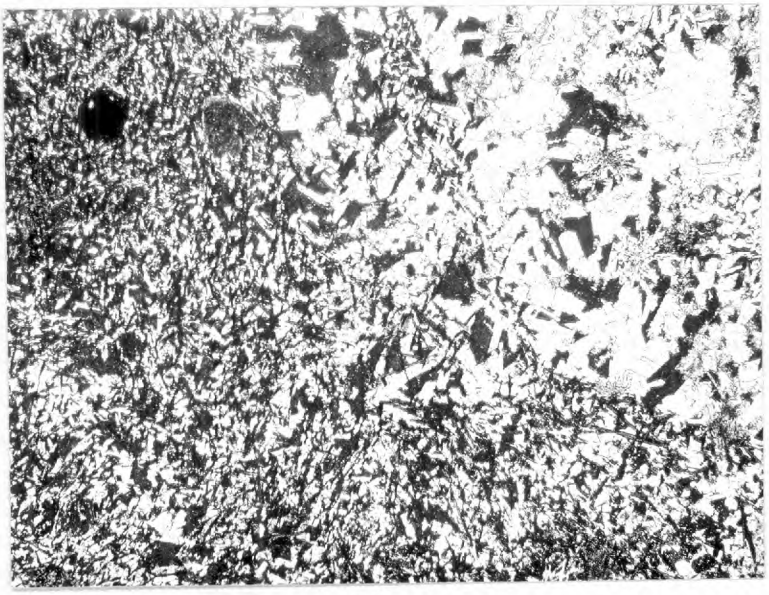
The felspar in most of the specimens is entirely potash felspar but in two of the specimens small quantities of sodic plagioclase are present as phenocrysts. In these specimens the place of nepheline has been taken, to a large extent, by an isotropic mineral, probably

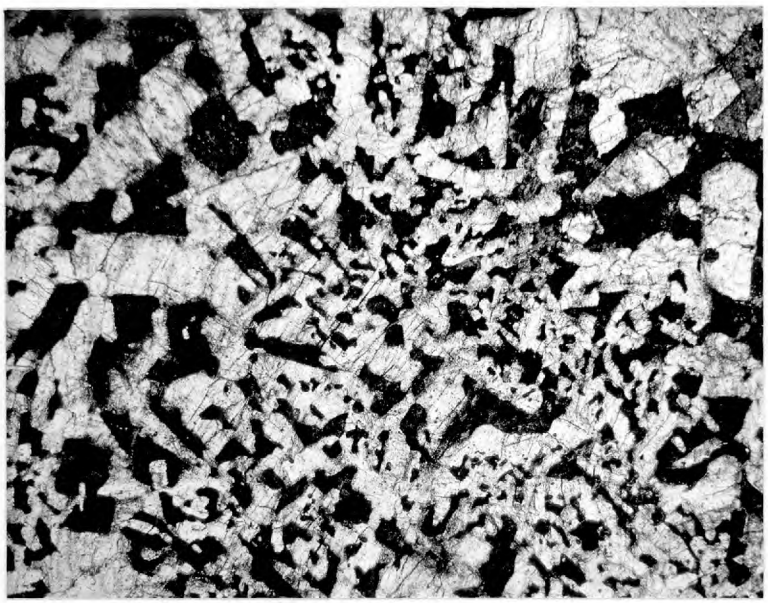
PLATE XXI

A. Photomicrograph (x15 plane polarised light). Pseudoleucite phonolite. Consisting of potash felspar (white) nepheline (stained-dark grey) and amphibole needles (medium grey). A pseudoleucite, consisting of an intergrowth of potash felspar and nepheline, occupies the top right hand portion of the plate.

(91)

B. Photomicrograph (x15 plane polarised light). Pseudoleucite from pseudoleucite syenite showing the intergrowth of potash felspar (white) nepheline (stained-dark) typical of many of the pseudoleucites.





mainly sodalite, but analcite is also present. In one specimen analcite is found filling small cavities, about two millimetres across, with earlier well formed crystals of andradite, showing sector twinning, which have grown into the cavities from the walls.

The amphibole in the groundmass is similar to that in the phonolites although in those specimens which are richer in nepheline the amphibole has blueish green pleochroic colours, reflecting the soda rich nature of these rocks.

The phenocrysts are for the most part orthoclase and amphibole but phenocrysts of diopside are also common. Other minerals found as phenocrysts are biotite, olivine, and nepheline.

The Pseudo-leucite Phonolites

This rock type is the most distinctive dyke rock associated with the Marangudzi complex. In the hand specimen it is a dark grey phonolite containing large, prophyritic, altered leucites. The original leucite crystals have altered to a mixture of potash felspar and nepheline, while retaining the original form of leucite in many cases. The size of the pseudo-leucites varies considerably and they may have diametres of up to four inches. Examples of pseudo-leucite phonolite are shown in Plates XII and XXII.

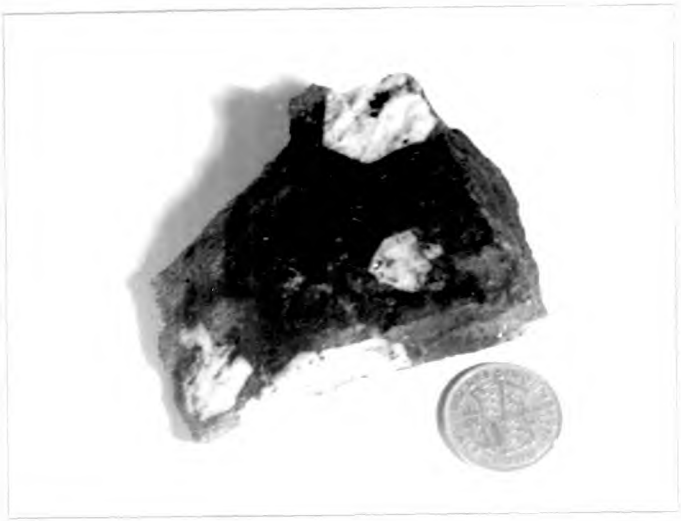
In thin section, the rock is fine grained with a grain size below half a millimetre. The groundamss consists of potash felspar, amphibole, and felspathoid, with phenocrysts of pseuod-leucite, mafic

PLATE XXII

A. Hand specimen of pseudoleucite phonolite containing pseudoleucites, porphyritic potash felspar and xenoliths of nepheline syenite. The specimen was collected from a dyke in the gabbro near the contact of the gabbro and the foyaite ring.

B. Hand specimen of pseudoleucite phonolite containing well formed pseudoleucites.





minerals and potash felspar. Although several porphyritic minerals are normally present, the rock may only contain porphyritic pseudo-leucite.

The texture of the groundmass is trachytic or tinguaitic to allotriomorphic granular in the coorser grained varieties. The groundmass is similar to that of the other phonolites except for an increase in the proportion of nepheline. A photomicrograph of a typical specimen is shown in Plate XXIa. This plate shows the groundmass and part of a pseudo-leucite. The typical texture developed by the nepheline and potash felspar forming the pseudo-leucites is shown more clearly in Plate XXIb, although the pseudo-leucite illustrated here is actually one from a plutonic rock. The compositions of the pseudo-leucites are discussed at the end of this chapter.

Nepheline Vogesite

Only three specimens of this rock type have been studied, all of which have been altered to some extent.

In the hand specimen, the rock is dark grey and fine grained, with porphyritic mafic minerals.

In thin section, the rock is seen to consist of porphyritic clinopyroxene set in a groundmass of clinopyroxene and felspar. The presence of nepheline can be established, but it is impossible to estimate the proportions of the minerals in the groundmass due to the altered condition of the minerals.

Undersaturated Dykes of the Madawula Centre

The dykes associated with the Madawula centre are all nepheline bearing, and fall into two broad groups, the syenitic dykes and the lamprophyric dykes.

The Syenitic Dykes

In the hand specimen, these dyke rocks are medium to dark grey, fine grained, porphyritic rocks. The common phenocrysts are of potash felspar, nepheline, pseudo-leucite or mafic minerals, and all may be present in one rock. The phenocrysts of potash felspar are usually prismatic and may be up to one centimetre long. Nepheline forms equidimensional grains up to five millimetres across and the pseudo-leucites appear as round or oval leucocratic patches on the surface of the specimens, and are rarely as well formed as those occuring in the phonolites. They range in size from one or two millimetres up to four centimetres across, and when present tend to be much more abundant than those in the pseudo-leucite bearing dykes associated with the Marangudzi centre. The mafic minerals form small phenocrysts up to three millimetres in size.

In thin section, the rocks are holocrystalline with a grain size below a quarter of a millimetre. The groundmass may show a trachytic or granular texture and is composed of potash felspar, nepheline, and mafic minerals. The potash felspar usually shows little sign of alteration, but the nepheline may be replaced by alteration products.

Amphibole is the most common mafic mineral, but aegirine-augite also occurs. However, the amphibole frequently shows alteration to biotite and the aegirine-augite to amphibole, and biotite. Granular melanite garnet is present in the groundmass of several specimens, and secondary epidote and calcite are frequently found.

Amphibole (pleochroic from pale straw to deep green) and aegirine-augite are the most common porphyritic mafic minerals, but diopside, biotite, and olivine, also occur.

Owing to the nature of these rocks, modal analyses have not been carried out on them, but compared to the phonolites they are richer in nepheline and poorer in mafic minerals.

The Lamprophyric Dykes

In the hand specimen, these rocks are dark grey and typically strongly porphyritic. The weathered surfaces are irregular and pitted, and the fresh surfaces are studded with lustrous phenocrysts of biotite and/or pyroxene up to five millimetres across.

In thin section, the groundmass of the lamprophyric dykes is found to have been altered. The texture of the groundmass is usually granular but may show flow structure, and the grain size is below a quarter of a millimetre. Amphibole is a prominent constituent of the groundmass in many specimnes, but most of it appears to be secondary after clinpyroxene, although a certain amount of primary amphibole is present. The amphibole is typically strongly pleochroic: X pale

brown, Y green, Z dark green, and occurs as irregular crystals and grains. Clinopyroxene, biotite, or melanite may also be major constituents of the groundmass, and are often present in small quantities. Potash felspar and felspathoids occur in granular patches with, or between, the mafic minerals. Calcite is present in many of the specimens and occurs as blebs, grains, and small irregular patches.

The biotite phenocrysts are well formed and are pleochroic from dark brown to pale straw. In a few cases, the crystals are seen to be zoned, the outer zones being paler in colour than the core of the crystal. The clinopyroxene occurring as phenocrysts is a weakly pleochroic augite which in some cases has an outer zone of aegirine-augite, and which is rimmed by alteration products. Altered olivine phenocrysts are present in some specimens, and crystals or grains, up to a half a millimetre in size, of ore, apatite, nepheline, and zoned melanite may be present. Some of these are phenocrysts but others, such as the melanite, are porphyroblastic crystals.

The lamprophyric rocks are therefore of rather variable mineralogy, but are characterised by a high colour index and the presence of mafic phenocrysts, usually biotite or pyroxene, in a groundmass which has typically suffered re-crystallisation.

The Ore Minerals

A comprehensive study of the ore minerals has not been possible, but a number of polished sections have been made and the ore minerals present have been identified.

The Gabbroic Rocks

Titaniferous magnetite is the most abundant opaque mineral in the gabbroic rocks, and occurs as subhedral to anhedral grains. Exsolution lamellae of ilmenite parallel to (111) are present and also fine lamellae of ulvöspinel parallel to (100). The lamellae of ulvöspinel form a fine network in the magnetite similar to that described by Ramadohr (1953). In some of the specimens the magnetite shows alteration to martite.

Small quantities of pyrrhotite, pyrite, and chalcopyrite may be present, but are not found in all specimens.

The Acid Rocks

Titaniferous magnetite and ilmenite are the common opaque minerals in the acid rocks. The ilmenite occurs as exsolution lamellae in the magnetite, in intergrowths with magnetite, and as discrete grains. The titaniferous magnetite is usually the most abundant opaque mineral, but ilmenite predominates in one or two specimens. Ulvöspinel is not found in the titaniferous magnetite occurring in the acid rocks. In all the specimens studied, the magnetite has been partially altered to martite. Sulphides were not found in the acid rocks.

The Undersaturated Rocks

Little opaque material is present in many of the undersaturated rocks, but titaniferous magnetite is again the most common ore mineral.. It usually contains exsolution lamellae of ilmenite and may show alteration to martite. Small quantities of pyrite, pyrrhotite, and clal opyrite are present in some specimens.

The Pseudo-leucites

Pseudo-leucites occur in the phonolites and nepheline syenites. Those occurring in the phonolite dykes are frequently very well formed, while those in the plutonic rocks often lack crystal form altogether.

In most cases, it was not found possible to remove the pseudo-leucites from the rocks in which they occur. However, one dyke to the north-west of Marangudzi did yield one or two pseudo-leucites, or parts of pseudo-leucites, bounded by crystal faces, and differential weathering of a dyke to the south of the complex produced the specimens shown in Plate XXIII. Where possible, the interfacial angles have been measured with a simple goniometer. These measurements are plotted below, together with the calculated interfacial angles for the form (211) of an isometric crystal.

PLATE XXIII

A. Two pseudoleucites which have weathered out of a pseudoleucite bearing phonolite. The pseudoleucites show good crystal form and scale is given by a match.

B. Specimen of pseudoleucite phonolite with well formed pseudoleucites standing out on surface.





INTERFACIAL ANGLES

33°)	
33 1/2°)	
34°)	33° 33 1/2'
34°)	
38°)	
47°)	
46°)	
47 1/2°)	48° 11 1/2'
46°)	
50°)	
51 1/2°)	

Considering the irregular nature of the surfaces measured and limit of accuracy of this type of goniometer, the results agree well with calculated interfacial angles shown on the right. These crystals were therefore originally isometric with the form of leucite or analcite.

Before thin sections of the pseudo-leucites were studied, it was erroneously supposed that pseudo-leucites showing good form had suffered little alteration and a few specimens from pseudo-leucite phonolites were sent to R.F. Fudali in the United States who has been studying pseudo-leucites. Unfortunately, these specimens have been found to contain large quantities of secondary analcite and were therefore unsuitable for the experimental work being carried out by R.F. Fudali.

Modal analyses have been carried out on a number of pseudo-leucites, the slides being stained for felspathoid. However, analcite

also takes the stain, and therefore is not distinguished from the felspathoid in the modes which are given in figure 36. It will be seen from this figure that the three pseudo-leucites from phonolite dykes have suffered secondary mineralisation and also contain appreciable quantities of mafic minerals. Two of the pseudo-leucites from the pseudo-leucite syenite have been found to consist of a well developed intergrowth of nepheline and potash felspar, and show little sign of alteration (Plate XXI). The modes of these two pseudo-leucites are comparable to the modes of two pseudo-leucites from the Bearpaw Mountains, Montana, (Zeis and Chayes [1960]), which are also given in figure 36. The third pseudo-leucite from the pseudo-leucite syenite contains euhedral crystals of nepheline which would appear to have been included in the original leucite crystal.

It appears from the above that some of the pseudo-leucites at Marangudzi have escaped secondary mineralisation, but that these are not the well formed pseudo-leucites in the phonolites but the poorly formed individuals in the pseudo-leucite syenite. The well developed intergrowth may also make it possible to decide whether phenocrysts of potash felspar or nepheline were included in the original leucite, a phenomenum which may obviously occur, as is shown by the pseudo-leucites in the foyaites (figure 35). Marangudzi may therefore provide some important material in connection with the study of pseudo-leucites, of which study a major problem is the obtaining of samples

Fig. 36. Modal Compositions of the Pseudoleucites.

	Specimen	Potash Felspar	Felspathoid + Analcite	Mafics.	Remarks.
Pseudoleucite Phonolite	P.L. 4	46·5	46·5	7·0	Much secondary analcite
	P.L. 6	33·5	24·0	42·5	High proportion of included material.
	P.L. 7	56·2	37·3	6·5	Secondary analcite present
Pseudoleucite Syenite	P.L. 3 .	62·3	33·2	4·2	Well developed intergrowth of Ne + Kf.
	P.L. 9	64·3	33·4	2·2	Nepheline altered.
	P.L. 10.	47·0	52·5	0·5	Included nepheline phenocrysts ?
Pseudoleucite Tinguaite	A	66·9	29·0	4·1	From Bearpaw Mts. Montana (Zeis + Chayes 1960)
	B	65·4	30·7	3·8	

that have not suffered secondary mineralisation.

The modes show that the compositions of some of the pseudo-leucites from the pseudo-leucite syenite are similar to those occurring in the pseudo-leucite tinguaite from the Bearpaw Mountains which have been studied by Fudali. Fudali concludes (Fudali [1960]) that these pseudo-leucites are the result of subsolidus breakdown of soda-rich leucite and that the formation of 'pseudo-leucite' from potash-rich analcite is highly improbable.

The presence of pseudo-leucite in a rock is a reflection of its composition and also the cooling history of the rock. Fudali (1960) states:

> The final nepheline-sanidine assemblage in plutonic alkaline rocks, whose compositions lie in the primary field of leucite, is, in most cases, the result of the subsolidus breakdown of leuicte solid solutions, and these rocks must, at one time, have carried recognisable pseudoleucite, the evidence of which may or may not be obliterated by the subsequent history of the rock.

It follows from the above that the composition or cooling history of the pseudo-leucite syenite, or a combination of the two, differs sufficiently from other alkaline plutonic rocks to have caused the development and preservation of pseudo-leucite so rare in rocks of this nature.

C H A P T E R 4

CONCLUSIONS

General

The Marandugizi ring complex is a plutonic igneous complex, together with an early irregular gabbro mass. Minor intrusions in the form of dykes are associated with the major intrusives, and also intrude the rocks of the basement complex in which the igneous bodies have been emplaced. The total area of the complex is thirty square miles, and the areas of outcrop of the various major intrusions are given in the table figure 37. The geology of the whole complex is shown in figure 38.

The gabbro is elongated along a north-west south-east axis and has been divided into two parts by the main acid ring dyke which encircles the north-westerly portion (see figure 38). Within the acid ring, the gabbro has been intruded by a number of undersaturated intrusions and another group of undersaturated intrusions, believed to be later than the gabbro, form the neighbouring Madawula centre, east of Madawula Hill. Gabbro xenoliths are found in many of the major intrusions and screens of gabbro occur in the ring dykes. Although the age relationship of the gabbro and the undersaturated intrusions of the Madawula centre has not been demonstrated, it is

Fig.37 Areas of Outcrop of the Plutonic Rocks

	ROCK TYPES	AREAS (square miles)
BASIC	Gabbro	13·4
	estimated original area	c.20
ACID	Total	12·0
	Green Qtz. Syenite	5·9
	Granite	5·4
	Microgranite	0·2
	White Qtz Syenite	0·5
ALKALINE	Total	4·4
	Marangudzi Centre	3·8
	Pulaskite	1·6
	Foyaite	1·55
	Pseudoleucite Syenite	0·5
	Screens	0·15
	Madawula Centre	0·6
	Unexposed	1·0
TOTAL AREA OF COMPLEX		30 sq.miles.

believed to be the earliest of the major intrusions.

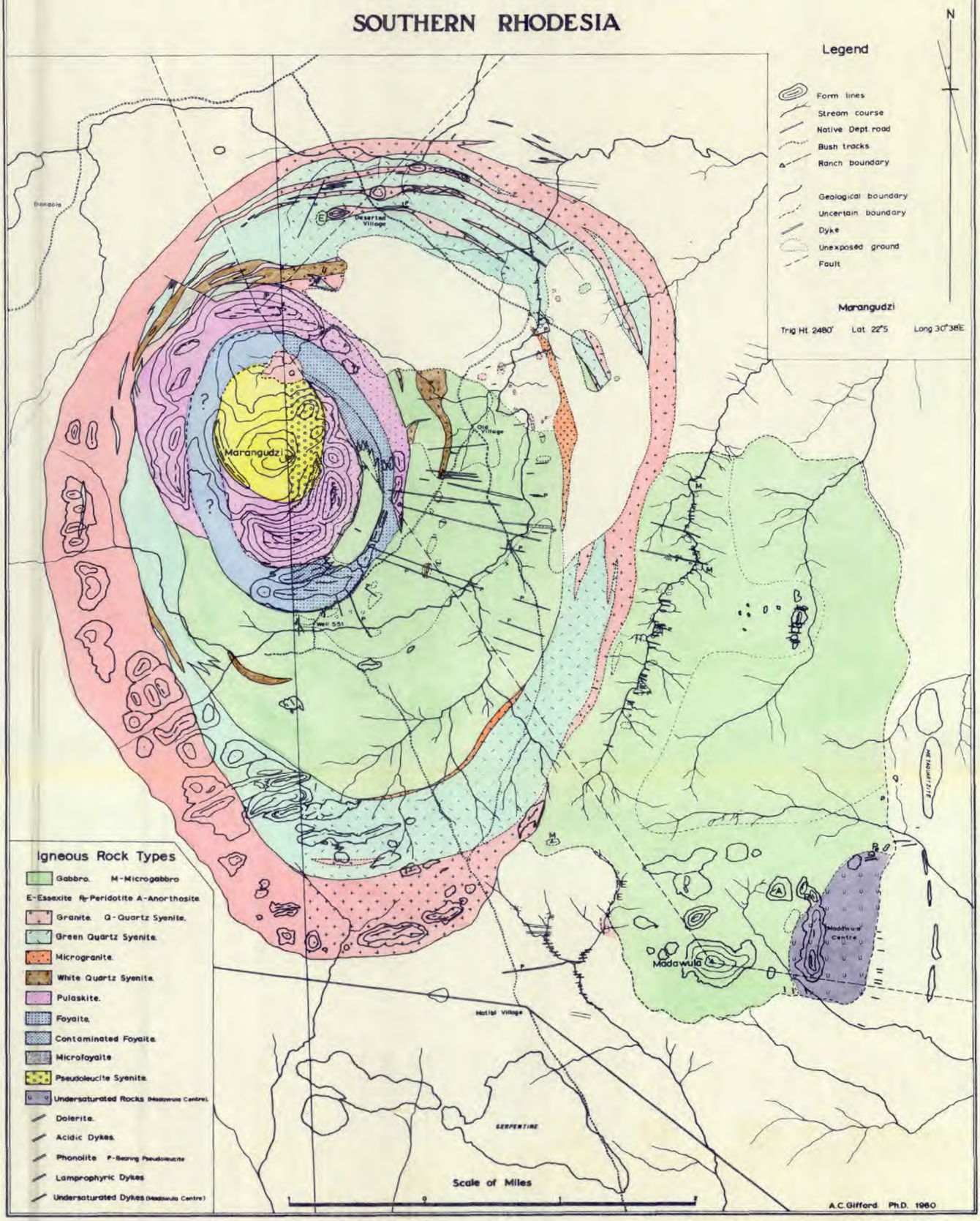
The gabbro is an olivine gabbro and frequently contains a certain amount of biotite. Small quantities of potash felspar are present in places. No layering was seen in the field, but petrological evidence suggests cryptic layering may be present (see page 82) and to the north-east of Madawula Hill the gabbro has undergone differentiation to form anorthosite and peridotite. Flow banding was observed at a few localities, but is not generally present. Steeply inclined flow banding is not confined to the margins of the gabbro which may indicate that the gabbro is not a single intrusion, but is composed of several intrusions the margins of which were banded in this manner.

Dolerite dykes cut the gabbro and a phase of dyke intrusion clearly followed the emplacement of the gabbro and continued until after the emplacement of the main acid ring dyke. It is possible that certain dolerite dykes found in the basement, but which are not seen to cut the gabbro, indicate an earlier pre-gabbro phase of dolerite intrusion. From figure 1 it can be seen that most of the dolerite dykes mapped in the field occur in the gabbro to the east of the acid ring and in the acid rocks themselves. Only two dolerite dykes were discovered in the gabbro within the acid ring. Although this might be a reflection of the quality of the exposure in these areas, the difference in the concentrations of the dolerite dykes

Fig. 38

THE GEOLOGY OF MARANGUDZI

SOUTHERN RHODESIA



inside and outside the main acid ring are such that they are believed to have a greater significance. Since the main acid ring dyke was emplaced within the period of dolerite intrusion (see Field Relations of the Minor Intrusions) the paucity of dolerite dykes within this ring might be a result of the isolation of the rock within the ring faulting (which facilitated the emplacement of the acid ring) from the stresses which produced the east-west fractures along which the majority of dolerite dykes have been intruded.

The multiple intrusion forming the main acid ring dates from the second phase of major intrusion. Three intrusions have been recognised: the green quartz syenite; the granite; the microgranite. The green quartz syenite was the earliest and was followed by the granite, the major part of which lies to the outside of the ring of green quartz syenite (see figure 38). This is unusual since in most ring dyke intrusions the later intrusions lie to the inside of the earlier, (Richey [1932] and Anderson [1936]). The narrow discontinuous intrusion of microgranite which lies to the inside of the green quartz syenite is believed to be the latest intrusion of the three.

The third phase of intrusion is notable for the white quartz syenite which forms a discontinuous ring intrusion with a centre offset to the north-west from that of the main acid ring. The quartz syenite cuts the rocks of the main acid ring in the north and west (figures 38 and 39) and is therefore later than the in-

trusions of the main acid ring, and is the last of the acid ring dykes.

Field and petrological evidence indicate that the acid intrusions have suffered contamination in places. Basic xenoliths are known to be present, but xenoliths of the basement gneisses have not been discovered, although they might reasonably be expected to occur. It may be that xenoliths of the basement, much of which is acid in character, were included in the acid intrusions but have been completly absorbed.

Following the acid intrusions are the alkaline intrusions of the Marangudzi centre. Three main phases of intrusion are distinguished. The earliest of these is the pulaskite which forms a ring intrusion with a centre to the north-west of the centre of the white quartz syenite ring. The foyaite ring dyke was emplaced during the second phase of intrusion, with which phase the intrusions of microfoyaite are also correlated. The foyaite ring has a centre which lies to the south-east of the centre of the pulaskite ring, and intruded about a point lying between these two centres is the intrusion of pseudo-leucite syenite. These three intrusions show increasing undersaturation indicated by an increasing proportion of nepheline and by the presence of pseudo-leucites in the last of the intrusions, and also in parts of the foyaite ring.

Associated with the major undersaturated intrusions are minor

intrusions of phonolite. Phonolite dykes were being intruded before the last of the acid intrusions was emplaced, and until after the pulaskite and foyaites were intruded.

The undersaturated intrusions of the Madawula centre are similar to those of the Marangudzi centre, but show a greater variety of rock types. Like the Marangudzi intrusions, they contain pseudo-leucites in places, and have associated dykes which also contain pseudo-leucites. Ultramafic rocks are found along the margins of the centre in the east and north, and nepheline bearing lamprophyres occur with the syenitic dykes. The age of the undersaturated intrusions of the Madawula centre has not been ascertained.

The two small intrusions of essexite (page 27) one in the main acid ring and one in the gabbro, are both seen to have been brecciated and are possibly volcanic pipes. One of them at least is later than the main acid ring intrusions, but no other evidence as to their age was discovered. However, these two small intrusions may have been the forerunners of the alkaline phase of intrusion. They are also the only intrusions which suggest that extrusives may have been associated with the complex.

From a study of the petrology of the Marangudzi intrusions, it seems probably that future work (especially on the gabbroic rocks) will establish the presence of two series of intrusions, a tholeiitic series and an alkaline series, similar to those recognised in the

Okonjeje complex (Simpson [1954]).

The Structure of the Complex

A THE MAJOR INTRUSIONS

Little evidence as to the structure of the gabbro was discovered during the field work. The few examples of flow banding which were found were all vertical, but the strikes of the banding do not show any obvious relationship with the form of the intrusion as a whole. The gabbro in its original form must have extended as far north-west as the later ring complex, for gabbro relics are seen in the north-western parts of the main acid ring (Rees [1960]). The gabbro is, in fact, the largest component of the complex, and at the level at which it is now exposed occupies an area of 13·5 square miles. However, it probably occupied an area of over 20 square miles (at this level) before it was disrupted by the later intrusions. The strikes of the flow banding suggest that the gabbro consists of several intrusions, or possibly a single intrusion emplaced in several stages. The vertical nature of the flow banding makes it probable that the gabbro is not a sheet-like body such as the gabbro of the Okonjeje complex (Simpson [1954]) to which the Marangudzi complex is petrologically similar.

The acid intrusions form two ring dykes. The largest of these is a complete ring dyke elongated north to south, having external diameters of six miles north to south, and four and a half miles

east-west. The thickness of this ring varies from half a mile to one and a quarter miles, and it is formed by three intrusions. The smaller ring dyke is a discontinuous ring intrusion three miles north-south by two and a quarter miles east-west of quartz syenite, and it is offset to the north-west with respect to the centre of the main acid ring. Field evidence indicates that these ring intrusions have vertical or almost vertical walls, and thus conform in structure to the ring dykes described from other complexes (c.f. Billings [1943], Richey [1932], Stevens [1958], King and Sutherland [1960]). Jointing in the acid ring intrusions was found to be essentially radial and concentric, with a weakly developed cross jointing. As has been pointed out, the focus of the joint system was found to be a point near the Marangudzi trig. beacon and not the geometric centre of the acid ring. This strongly suggests that the jointing in the acid ring developed in response to stresses set up during the emplacement of the undersaturated intrusions of the Marangudzi centre.

The undersaturated intrusions of the Marangudzi centre form three structural units. The earliest and largest of these is the pulaskite ring intrusion. This intrusion has an external diameter of about two miles, being slighlty elongated north-south, and is six to seven hundred yards in width. Cutting the pulaskite in the east and lying to the inside of this ring in the north and to the outside of it in the south, is the ring intrusion of foyaites. The foyaite

ring probably cuts the pulaskite again in the west and thus may form a complete ring, but this relationship was not certainly established in the field, although it is suggested by petrological evidence, and also by a certain amount of field data. However, before this can be finally ascertained, more field work will be necessary. The size of the foyaite ring is two miles north-south by approximately one and three quarter miles east-west, showing the north to south elongation characteristic of the ring dykes. The width of the ring is approximately five hundred yards. The geometric centres of the pulaskite and foyaite rings are approximately half a mile apart, the centre of the foyaite ring lying to the south-east of the centre of the pulaskite ring.

Radial and concentric jointing is present in the pulaskite ring, and also a certain amount of banding dipping steeply towards the centre of the intrusion. The banding is brought out by the orientation of the minerals and by the concentration of amphibole along certain bands. In parts of the intrusion, gravitational settling structures are present (G. Rees [1960]) showing similar concentration of mafic minerals in bands. This suggests that the steeply dipping banding must be regarded not purely as flow banding, but as the result of flow and gravitational settling. For this reason, the banding cannot be assumed to parallel the walls of the ring structure, although it seems probable that these ring dykes have steeply inclined or

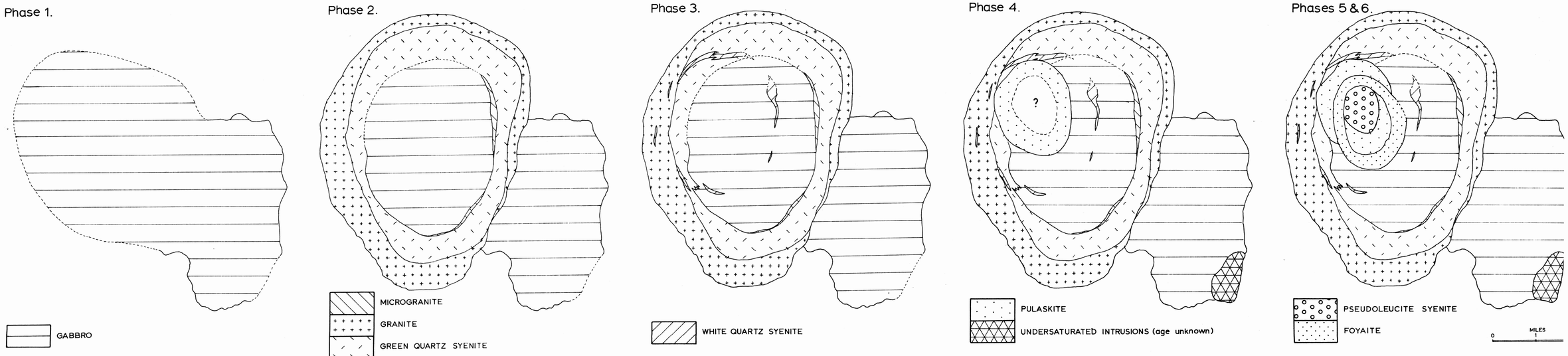
vertical walls.

The last of the major intrusions of the Marangudzi centre is the pseudo-leucite syenite. It forms an oval mass in the centre of the earlier undersaturated intrusions measuring one mile north to south by three quarters of a mile east to west. The geometrical centre of the intrusion lies a little to the south-east of the centre of the pulaskite ring. For the most part the pseudo-leucite syenite is structureless, but in one locality banding, dipping towards the centre at forty degrees, is present. With little evidence it is not possible to arrive at any definite conclusions regarding the structure of this central mass, but the possibility of it being a funnel intrusion (Wager and Deer [1939]) may be mentioned.

The small intrusions of microfoyaite found in the pulaskite are generally irregular, but in places occur as narrow bands with a concentric strike and inward dip. Although these intrusions lack the continuity of the cone sheets occurring in the majority of Scottish tertiary ring complexes (Richey [1932]) some, at least, of the microfoyaite intrusions may be regarded as cone sheets, although in general this form of intrusion is not found at Marangudzi.

The undersaturated intrusions of the Madawula centre form an elongated mass, one mile north to south by a half a mile east to west. The centre occurs at the south-easterly extremity of the gabbro and is believed to be later than the gabbro. Field investigation

Fig. 39. Phases of Intrusion Illustrated Diagrammatically



revealed no evidence as to the form of the intrusions, and well formed ring structures do not appear to have been developed.

The phases of intrusion just discussed are illustrated diagrammatically in figure 39, and the centres of the ring dykes are marked. These centres are plotted together in figure 40, and it will be clearly seen from this that the centres lie along a straight line trending north-west south-east. The centres are numbered according to their relative ages, the mid-point of the gabbro being termed the first centre, although it can not be considered as a centre strictly comparable to the foci of the ring dykes. It will be seen from this diagram (figure 40) that successive centre do not show a constant direction of movement along the line on which they developed. Although the first four centres show a steady migration to the north-west, centres 5 and 6 lie to the south-east of centre 4, and the Madawula centre, whose age is not known, lies well to the south-east.

The possibility of cauldron subsidence at Marangudzi has not been discussed up till now. In many ring complexes cauldron subsidence has been recognised, but ring intrusions are not always accompanied by cauldron subsidence (Billings [1943]). In those complexes in which volcanics are present, cauldron subsidence can usually be readily recognised by the attitudes of the volcanics which have been modified by the subsidence. However, in complexes which have been deeply eroded, such as Marangudzi, evidence regarding relative movement

between the walls of the ring dykes may be hard to obtain.

At the level at which Marangudzi is now exposed, gabbro is present both outside and inside the main acid ring, and also the discontinuous ring of white quartz syenite. Screens of gabbro are found in the acid ring dykes, and also between the foyaite and pulaskite rings, and probably between the pulaskite and pseudo-leucite syenite. The presence of gabbro within succeeding rings only proves that if cauldron subsidence did occur, the total subsidence was not sufficient to displace the rocks which once overlay the gabbro to the present level at which the complex is exposed. Future work may establish whether cauldron subsidence has taken place or not, but no decision can be made at this stage, owing to the lack of any evidence regarding the relationship of the gabbro within the ring faulting to that outside it.

The Minor Intrusions

The dykes occurring within the acid ring intrusion radiate from the Marangudzi centre. However, they do not radiate from a single point but from the region occupied by the undersaturated intrusions themselves. As a result of the oval nature of these intrusions the dykes, which are normal to their contacts, converge at two points. The dykes to the east of the centre converge on a point to the west, and those to the west on a point to the east. The dykes outside the main acid ring, on the other hand, have dominantly east-west strikes.

Those to the east, although fanning out slightly away from the complex, are concentrated in a swarm, the general trend of which is five degrees north of east. This swarm is most dense in the vicinity of the Bubye river (figure 2) but has been traced on aerial photographs to a point sixteen miles east of the eastern contact of the gabbro. The dykes to the west of the complex are not nearly so numerous and show a tendency to to be normal to the main acid ring.

Structural Control of the Marangudzi Intrusions

The Marangudzi intrusions show several well defined structural features. Of these three are considered to be the result of stresses in the basement which controlled the emplacement of the intrusions, as opposed to the other features which are the result of stresses set up during the emplacement of the intrusions.

These three structural features, which are plotted on the diagram figure 42, are as follows:

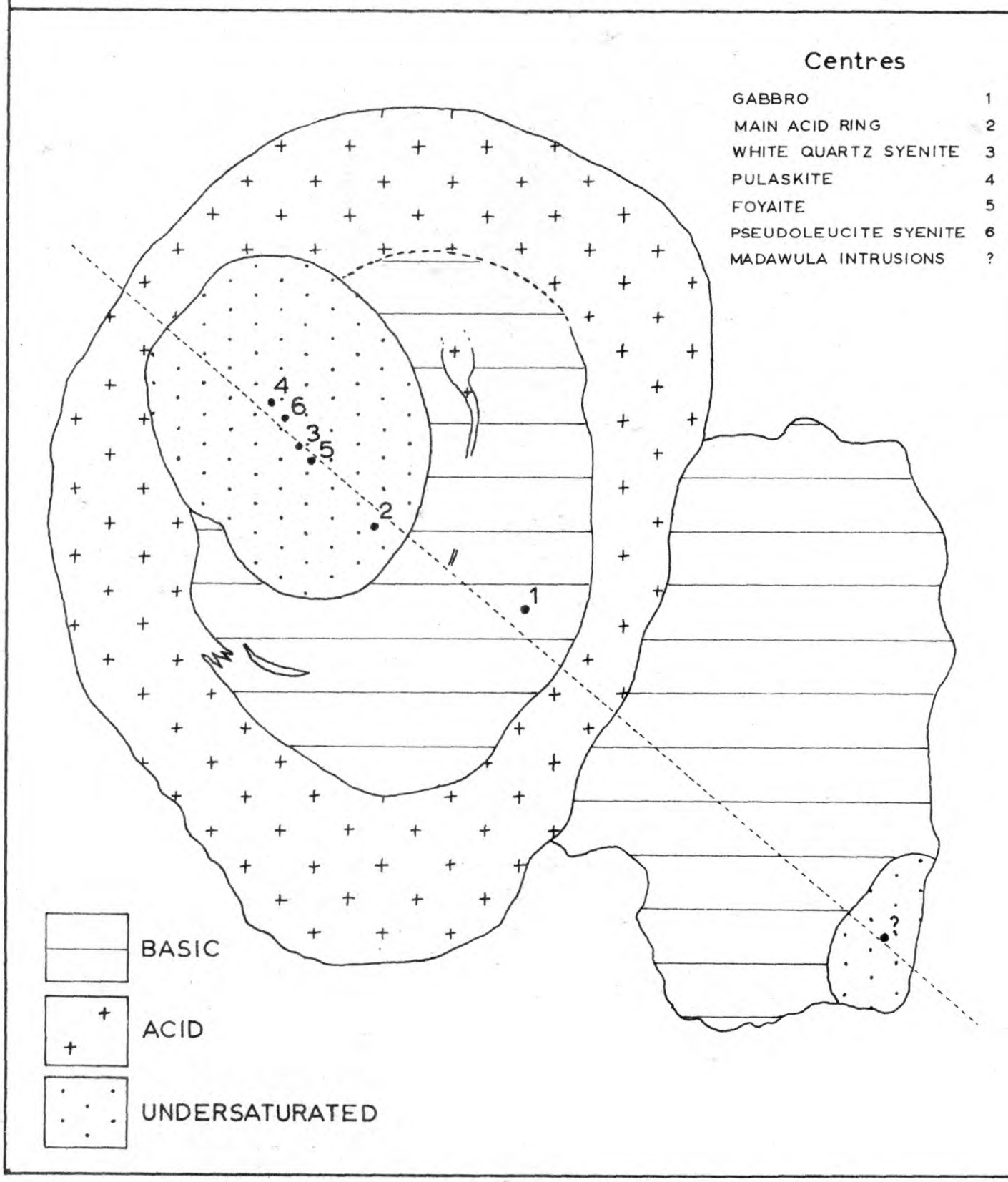
1. Alignment of the centres of intrusion along an axis striking at 140°.

2. Concentration of dykes in a well defined swarm striking at 85°.

3. Persistent oval form of the ring dykes with the longer axis of symmetry lying north-south.

It is now proposed to correlate these features with the known tectonic history of the region.

Fig. 40. Centres of Intrusion.



Although the rocks of the basement have obviously had a complex tectonic history, the tectonic episode during which the Marangudzi ring complex was emplaced must have been later than the formation of the basement complex. The only tectonic episode known in the region is that which occurred during Karroo or late Karroo times and which resulted in faulting of the basement and Karroo sediments.

To the south-east of the Marangudzi complex, Karroo faults have downthrown Karroo sediments to the south (figure 2). These faults strike at 65° and it is not known if they have a tear component or not. To the south-south-west of the complex, the trace of a fault is marked by the western tributary of the Chabili river (figure 2). This fault has displaced the large Karroo dyke in the south, indicating that movement took place along this fault in Karroo times.

Although little is known about the Karroo faulting in the immediate vicinity of Marangudzi, at Messina, in the Transvaal, copper mineralisation has been localised in Karroo faults and the faulting had been studied in detail (Söhnge [1946]). The faulting is of two types: normal faulting and tear faulting. The normal faulting at Messina strikes at 80° with a downthrow on the south side. The tear faulting strikes in two directions, the major fault at 85° with several branch faults at 60°. The major fault is known as the Dowe-Tokwe fault and the branch fault in which the mineralisation

Fig. 41. Pattern of Faulting in the Region.

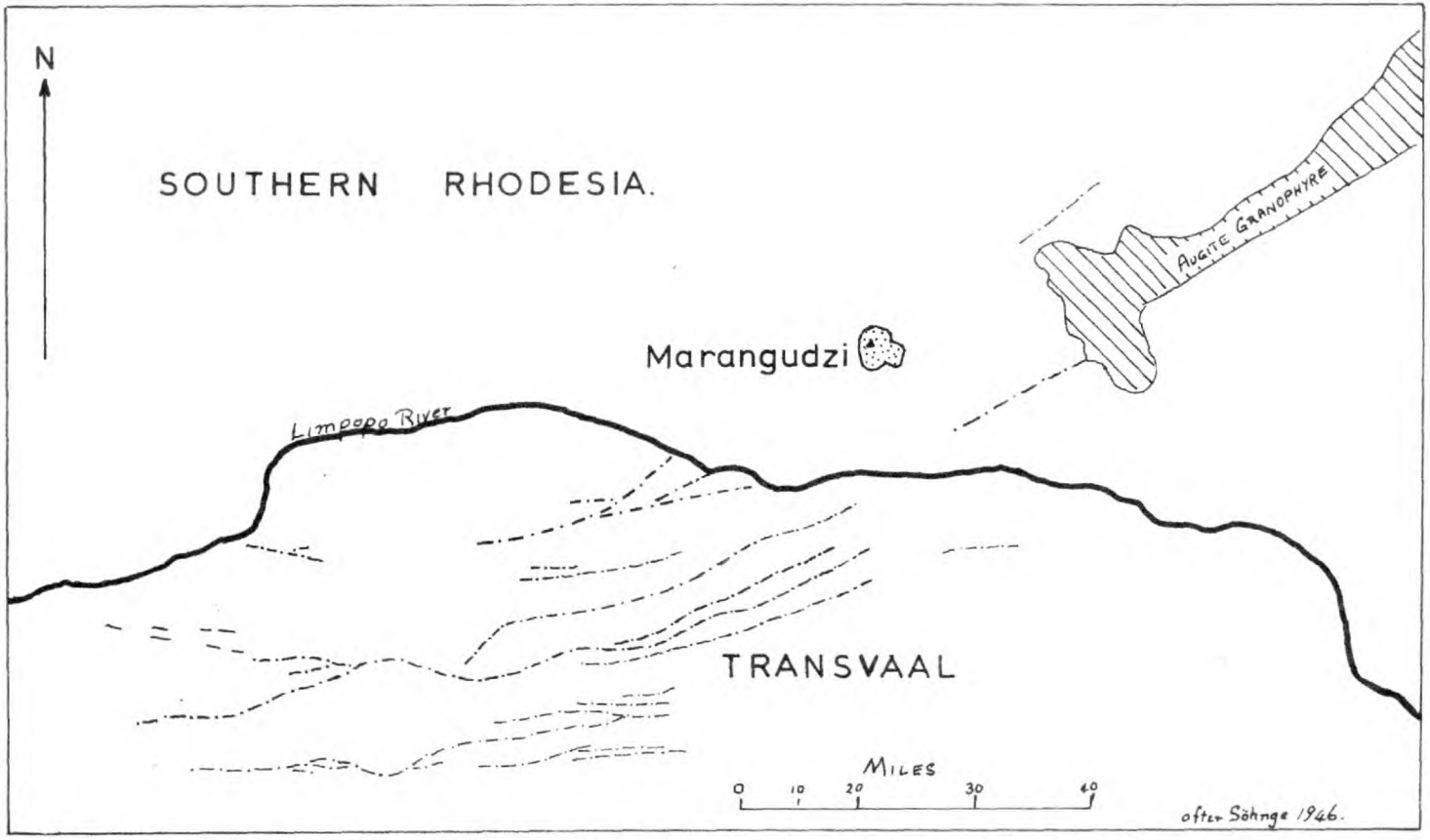
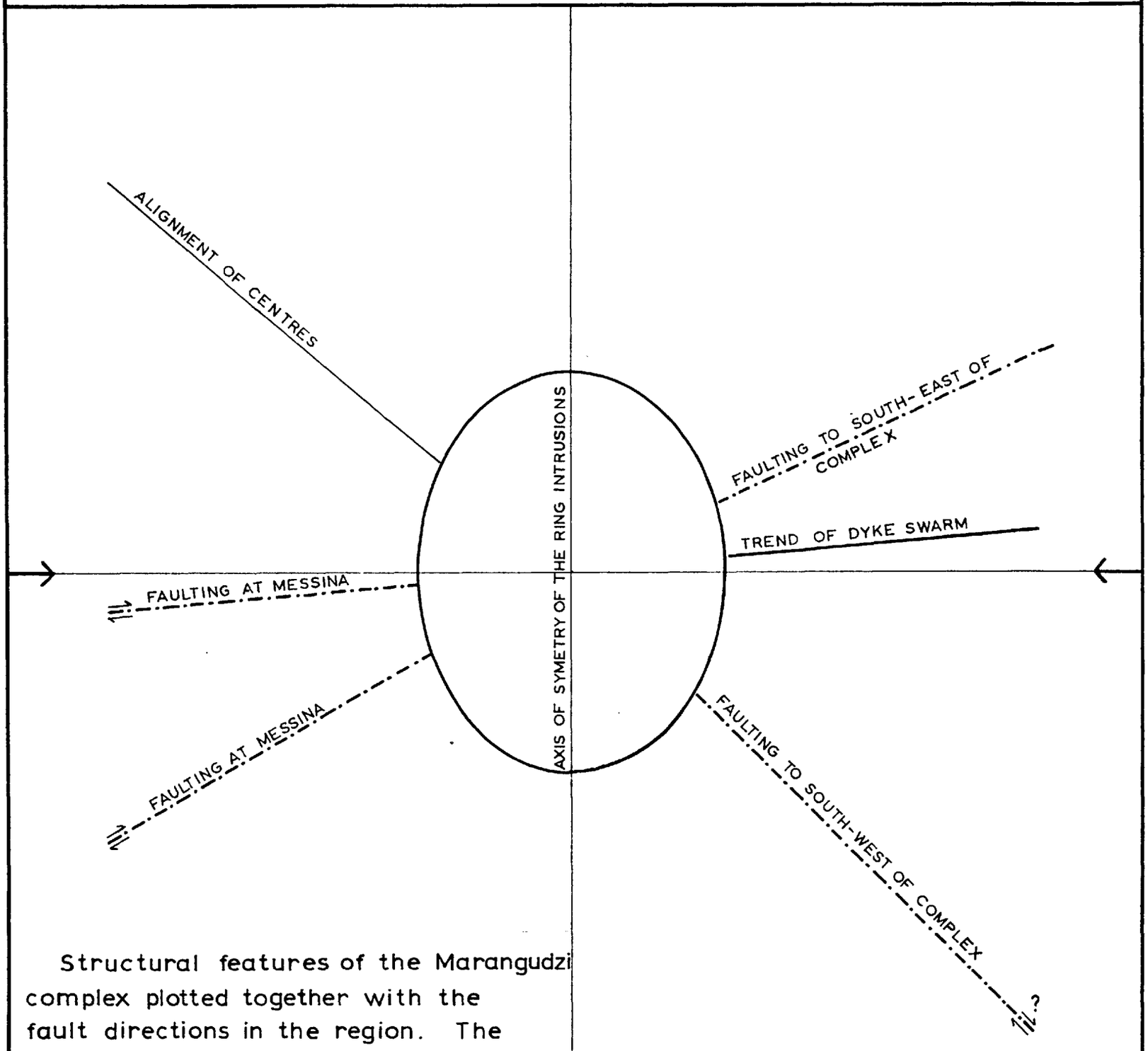


Fig.42. Structural Control of the Complex



Structural features of the Marangudzi complex plotted together with the fault directions in the region. The pattern suggests these features may be the result of an E-W compression.

has been localised as the Messina-Campbell fault. The movement in both cases has been dextral. P.G. Söhnge sums up the Karroo faulting in the Messina area as follows:

> Although the Messina-Campbell fault seems to cut through the Dowe-Tokwe fault, they both indicate a relative shift of the north side to the east, and may on this ground be considered to belong to one extended period of fracturing during which the dominant stress components acted as a shearing couple in an east-west direction. Movement along the Messina fault probably continued for a longer time than along the Dowe-Tokwe fault, and metallisation by copper sulphides occurred at this late stage of deformation. The age of the strike-slip faults, due to the absence of Waterberg or Marroo formations along them, could not be determined any further than that they are post-Bulai granite. For reasons more fully detailed in the section on the genesis of the copper deposits, the deformation is thought to be of late Karroo age, being coeval with the intrusion of a 100 mile long 'augite granophyre' batholith in Southern Rhodesia, as described by B. Lightfoot (1938). Pre-Karroo fracturing is nevertheless not necessarily excluded.

The major faulting in the Messina area is shown in figure 41, which is based on a map in the Messina Memoir (Söhnge [1946]). It will be seen from this that Marangudzi lies along the strike of the Messina-Campbell fault and is now the nearest known igneous intrusion. The pattern of tear faulting in the Messina area is also plotted on the diagram figure 42.

From figure 42 it will be seen that the tectonic pattern is a regular one and on the whole consistent with an east-west compression. Although the faulting in the vicinity of Marangudzi will have to be further investigated before this analysis can be accepted, the

following features support this hypothesis:

1. The principle directions of faulting form acute angles with the postulated maximum pressure P acting east-west.

2. Analysis of faulting at Messina, 30 miles to the south west, indicates a maximum compression along an east-west axis.

3. The strikes of dykes associated with the complex are approximately parallel to the direction of maximum compression.
   This is consistent with the dynamics of dyke emplacement (Anderson [1951], De Sitter [1956]).

4. The centres of intrusion lie along a line which parallels a fault to the south-west of the complex.

5. The symmetry of the ring dykes matches the symmetry of the postulated regional stresses. (Anderson [1936] does not consider the form of ring dykes intruded into a medium in which there are lateral pressures or tensions. However, the presence of such pressures or tensions must obviously control the form of the ring intrusions, causing them to deviate from the ideal circular section. Such deviation must also reflect the symmetry of the forces producing it. It also appears from a study of the stress diagrams in Anderson's paper that an increase in lateral pressure would cause a reduction in the diameter of a ring fracture. An oval intrusion thus indicates a maximum pressure along the shorter diameter of the ring).

Features which do not support this analysis of the structures are as follows:

1. The sense of movement on the fault to the south-east of Marangudzi (as suggested by the displacement of the large Karroo dyke) is opposite to that which would be expected. However, this displacement may represent late movement along an earlier tear fault in which the major displacement was in the opposite direction. Late movement

opposite in sense to the major movement has been reported on normal faults in the Transvaal.

2. The fault to the south east of Marangudzi has a normal component of movement and although it may also have a tear component, such faults have not been reported in the region to the south.

The structural control of the Marangudzi intrusions cannot be considered to have been defined, but available evidence suggests that Karroo deformation may have been the major influence.

Comparison with other ring complexes

Tertiary Ring Complexes of Great Britain

The well documented tertiary ring intrusions of Great Britain (Richey [1932]) are an ideal starting point in any discussion of the structure of ring intrusions. Although all the main structural features of Marangudzi are not matched by any of the complexes, several of the Scottish complexes have features in common with Marangudzi. Thus many show the development of more than one centre. In the case of the Ardnamurchen complex (Richey and others [1930]) three centres are recognised and at Mull (Clough and others [1924]) two centres. The ring intrusions of Mull and those associated with the third centre, and possibly the second centre, at Ardnamurchen show elongation along an axis trending approximately north-east south-west. The dyke swarms associated with these complexes trend north-west south-east. This relationship of the dyke swarms to the

symmetry to the ring intrusions is also present at Marangudzi, where the ring dykes show elongation along a north-south axies and the dyke swarm trends east-west. Marangudzi differs from the intrusions of Mull and Ardnamurchen in that, although showing well developed ring dykes, it virtually lacks cone sheets which are so prominent in both these Scottish complexes. Radial dyke swarms are associated with some of the Scottish complexes and are especially well developed on Rum. Unlike the Marangudzi dykes, the radial dykes of the Rum complex extend into the country rocks, whereas at Marangudzi the dykes only show radial trends within the ring intrusions.

Vent agglomerates and breccias which are prominent in many of the tertiary complexes in Great Britain are not present at Marangudzi, although the two small intrusions of essexite showed brecciation in places and may be connected with an extensive phase. The character of the intrusions at Marangudzi is plutonic and the lack of phenomena associated with volcanic activity should not be interpreted as suggesting that such activity did not occur, but rather that evidence of it, which may have been present in the higher levels of the complex, has been removed during the erosion of the complex to its present level.

Finally, the dimensions of the acid ring dykes of Marangudzi are comparable to the dimensions of the tertiary ring structures in Britain, as tabulated by J.E. Richey (Richey [1932]) though the undersaturated intrusions are smaller.

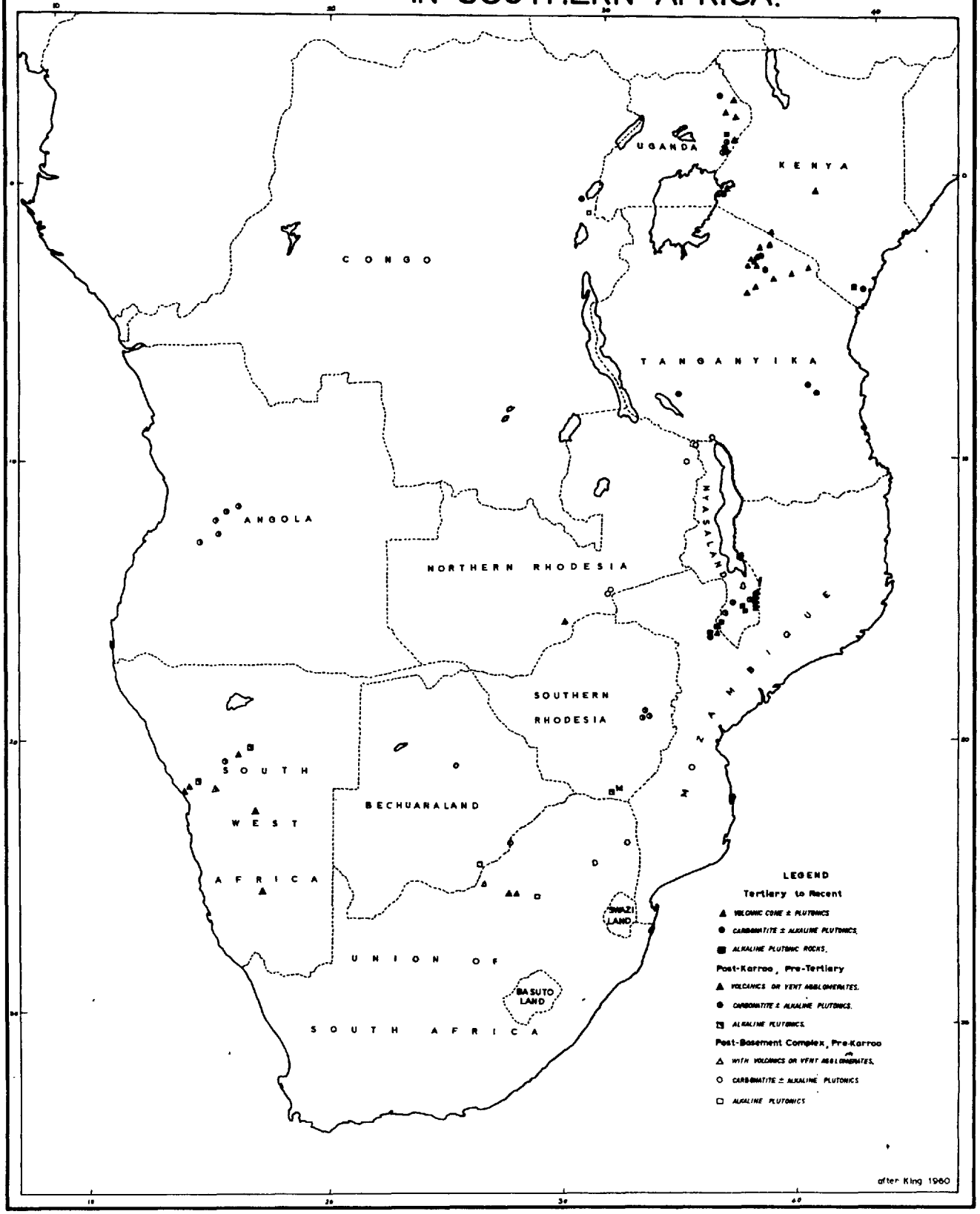
The Alkaline Complexes of Africa

The alkaline complexes of Africa as exposed at the present time are believed to represent essentially similar or closely allied intrusions of varying ages and in varying states of erosion (Williams [1956], King and Sutherland [1960]). However, these complexes are diverse in character and it is proposed to consider them generally, with specific reference to one or two which have features in common with Marangudzi.

The distribution of known alkaline complexes is shown in figure 43. Garson and Campbell Smith suggest that carbonatites (and hence the alkaline complexes which contain them) are distributed along zones which follow lines of weakness (Garson and Campbell Smith [1958]). As more complexes are discovered, these zones become less well defined, but the associations of alkaline complexes with major tectonic features is a constant feature of African igneous geology. Marangudzi fits into the general pattern very well, linking the complexes to the north in Rhodesia and Nyasaland with those to the south in the Union of South Africa. It is also situated in a belt of faulting which was active in Karroo times and possibly much earlier (Söhnge [1946]).

The alkaline complexes of Africa are practically all central intrusions and frequently form ring structures. These are usually intrusive structures, but may be formed by the process of fenitisation.

Fig. 43. DISTRIBUTION OF ALKALINE COMPLEXES IN SOUTHERN AFRICA.



Like the intrusions of Marangudzi, these are normally ring dykes as opposed to cone sheets, but they may also be produced from horizontal sheets by cauldron subsidence (Messum, Korn and Martin [1954]). Garson (1956)) suggests that the presence of cone sheets in the British tertiary ring structures is connected with strong updoming of the overlying rocks, whereas in the Chilwa structures, studied by him, there has been little updoming and shearing has been predominant.

The intrusions of the Marangudzi complex have little in common with those to the north in Rhodesia and Nyasaland, or those to the south in the Union, but are most closely matched by certain of the complexes of Damaraland, South West Africa (Martin, Mathias, and Simpson [1960]). Of these Okonjeje (Simpson [1954]) shows a striking similarity to Marangudzi with regard to the rock types present.

Marangudzi thus belongs to that group of African alkaline complexes which is notable for the association of alkaline and gabbroic intrusions. As a ring complex, it is outstanding in the perfection of the ring dyke intrusions and the multiplicity of the centres of the intrusion. The variety of rock types, ranging from ultrabasic to undersaturated alkaline intrusives bearing pseudo-leucites, obviously poses interesting petrogenetic questions which are beyond the scope of the present investigation. However, the sequence of intrusion which has been established shows that two trends of differentiation operated during the formation of the Marangudzi complex. One trend was

towards oversaturation, leading ultimately to a granitic magma, and the other towards undersaturation resulting in the formation of the series of nepheline syenites and culminating, as far as is known, with the pseudo-leucite syenite. Minor intrusions in the form of dykes are associated with the major intrusions, and extensive phases almost certainly accompanied plutonic intrusion.

-oOo-

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THE GEOLOGY OF MARANGUDZI

SOUTHERN RHODESIA

N

Legend

- Form lines
- Stream course
- Native Dept road
- Bush tracks
- Ranch boundary
- Geological boundary
- Uncertain boundary
- Dyke
- Unexposed ground
- Fault

Marangudzi

Trig Ht. 2480′ Lat. 22°S. Long 30°38′E

Dondola

Deserted Village

Old Village

Marangudzi

Well 551

METAQUARTZITE

Madawula

Madawula Centre

Matibi Village

SERPENTINE

Igneous Rock Types

- Gabbro. M-Microgabbro
- E-Essexite P-Peridotite A-Anorthosite.
- Granite. Q-Quartz Syenite.
- Green Quartz Syenite.
- Microgranite.
- White Quartz Syenite.
- Pulaskite.
- Foyaite.
- Contaminated Foyaite.
- Microfoyaite
- Pseudoleucite Syenite.
- U U Undersaturated Rocks (Madawula Centre).
- Dolerite.
- Acidic Dykes.
- Phonolite P-Bearing Pseudoleucite
- Lamprophyric Dykes
- Undersaturated Dykes (Madawula Centre)

Scale of Miles

1 0 1 2

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THE REGIONAL GEOLOGY OF MARANGUDZI

Legend

Water Courses.

Watershed.

Roads and Tracks.

N

Scale of Miles.

0 1 2 3

Dondola

Mafungabwe R.

MARANGUDZI

Bubye R.

← Beitbridge

MADAWULA

Matibi

Cherera R.

Guvini

NYALANGUNDI

MUCUMBWE

Chabili

Malapi R.

Chabili R.

Tshiturapadsi

Shashashi

Chamsunga

ROCK TYPES

Basement.	Karroo.	Igneous (Marangudzi)
Undifferentiated Basement.	Sandstone.	Alkaline Rocks.
Serpentine.	Shale.	Acid Rocks.
Marble.	Sandy Shale.	Gabbro.
Quartzite.	Dyke.	Dykes.
Trend Lines.	Fault.	
Foliation (measured).	Dip (interpreted).	

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