Report No. 38

COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
MWINGI AREA, NORTH KITUI

DEGREE SHEET 45, SOUTH-WEST QUARTER
(with coloured geological map)

by

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FOREWORD

The geological survey of the Mwingi area was carried out by Mr. Crowther as part of the primary mapping of Kenya, with the assistance of funds provided under the Colonial Development and Welfare Act. Before he could bring his report to its final stages he was called up for military training and subsequently was retained in the Kenya Regiment. He served with the Regiment in Kenya from the beginning of 1953, but unfortunately lost his life in February, 1954, in a skirmish with terrorists. To prevent undue delay in publication, the first draft of his report had been completed and amended on his behalf in 1953, but he had not had the opportunity to read the proposed final draft before his death. In preparing the final draft every attempt was made where possible to preserve the original outline and the trend of the author's thoughts.

The area east of Mwingi, a village on the road from Nairobi through Garissa to the Northern Province of Kenya and Italian Somaliland, became known to people in Kenya on account of a prospector's camp and factory at Nguni where chalks, whitening powders and mineral pigments were prepared. Unfortunately little else of mineral value has been found in the area. Mr. Crowther's report gives a brief account of the general geology of the district, special emphasis being laid on small ultra-basic intrusions in its eastern part. The intrusions are of a kind that in numerous parts of the world contain valuable metallic or non-metallic minerals, and though their prospects are not hopeful in view of the results of the present survey, it is not impossible that more intensive prospecting might reveal small deposits of such minerals as magnesite and asbestos.

For some years rumours have persisted of the occurrence of coal in the northern parts of the Kitui district. Mr. Crowther made a special investigation of the reported finds but, as was expected from the geology of the area, was unable to find any trace of coal or possibly coal-bearing beds. There can be no doubt that coal found in such areas is the relics of war-time dumps.

WILLIAM PULFREY,
Chief Geologist.

Nairobi,
15th November, 1954.

CONTENTS

ILLUSTRATIONS

MAP

ABSTRACT

The report describes an area in the northern part of the Kamba Native Reserve in central Kenya. It is approximately 1,200 square miles in extent and is bounded by latitudes 0° 30′ S. and 1° 00′ S. and by meridians 38° 00′ E. and 38° 30′ E. Physiographically it can be divided into three units: (1) the Mumoni mountains in the north-west, (2) relatively high ground in the west that is considered to be a remnant of the sub-Miocene peneplain, which is also represented by the tops of scattered monadnocks in the southern half of the area, and (3) a low-lying peneplain of presumed end-Tertiary age in the north and east.

The area is made up mainly of highly metamorphosed and granitized sedimentary rocks of the Basement System of East Africa. It includes calcareous, semi-calcareous, pelitic, semi-pelitic and psammitic types. In the east the metamorphic rocks have been invaded by small ultra-basic plugs. Details are given of the petrology, petrography, and economic minerals of the rocks and of the water-supply of the area.

GEOLOGY OF THE MWINGI AREA

I—INTRODUCTION

The country described in this report is quarter-degree sheet 45 S.W. (Kenya), bounded by latitudes 1° 00′ S. and 0° 30′ S. and by longitudes 38° 00′ E. and 38° 30′ E. It has an area of about 1,200 square miles and lies in the northern portion of the Kitui district of the Southern Province of Kenya, forming part of the Kamba native reserve.

It is inhabited by about 30,000 Wakamba who subsist by the cultivation of maize, beans and millet, and by herding cattle and goats. At Nguni on the Garissa road there is a camp founded by E. G. Powell but subsequently acquired by Tula Products Ltd., a subsidiary of Diaclem Products Ltd., where gypsum from the Tula valley, near Garissa, is processed for the manufacture of plaster of paris, chalks and whitening blocks. Powell also collected from the roots of certain thorn trees a vegetable fibre which he baled and sold under the name "flotite" as an insulator, and originally as a substitute for kapok in life belts.

Mwingi is the main village and has a post office, a market and Indian-owned shops, and is the scene of cattle auctions. It lies on the Garissa–Nairobi road, which runs across the southern portion of the area and forms the main line of communication to the railway at Thika, 80 miles away. A railway was planned during the 1939–1945 war to run through Gai to the Northern Province but the project was abandoned when only the surveying and grading of the rail-bed has been carried out as far as the Mwingi–Katze road. Besides the Nairobi–Garissa road, which is maintained by the Public Works Department, there is a good system of Local Native Council roads that are usable during the dry weather, but become difficult during the rains.

Rain falls in the area in two distinct seasons, from March to May, and during November and December. The rain, which falls mainly in the evening, is of the heavy convectional type and the amount at any place is conditioned by its proximity to high ground. Thus at Mwingi there is an average of about 25 inches per year, at Katze about 23 inches, and at Ngomeni less than 15 inches. Details of rainfall records are given in the table below.

RAINFALL STATISTICS FOR THE MWINGI AREA

(Taken from the 1952 summary report of the East African Meteorological Department)

Station	Altitude (feet)	Rainfall 1952 in inches	No. of rainy days, 1952	Heaviest monthly rainfall, 1952 (inches)	No. of years recorded	Average annual rainfall
Nzui Dispensary ..	2,500	22·61*	Not recorded	Apr. 15·48	10	21·48
Katze Dispensary ..	2,500	20·22	43	Nov. 7·34	10	23·19
Ngomeni Dispensary ..	2,350	11·58	16	Nov. 4·35	1	—

*Not complete, November not included.

Owing to the comparatively low rainfall and to the indigenous practice of overgrazing with both cattle and goats the vegetation is mainly of the thick thorn-bush type with little grass. The lack of a good cover of vegetation, as is especially noticeable in abandoned cultivated patches, has led to serious gullying and soil-wash, and some areas in the north-west are severely eroded. The soil now covering most of the area is a red-brown sandy type and very deep in parts, but of poor fertility. It consists mainly of quartz and iron oxides, with a darker biotitic facies near biotite-rich rocks. The tops of Mumoni and Kyaikuyu (Gakuyu) have been gazetted as forest reserves and the tops of Muvaroa, Imba and Mai are forested; the natural virility of growth coupled with a slightly higher rainfall due to relief has covered these hills with thick bush and in some places with trees.

The only recent map of the area is that published in 1940 by the army on a scale of 1:500,000 (E.A.F. No. 680, Garissa, 1945). The map accompanying this report was compiled from aerial photos, controlled by a skeleton of trigonometrical points surveyed by the

Survey Department, augmented by further points fixed by plane-table. The area was mapped between December 1950 and August 1951 as part of the systematic reconnaissance geological survey of the Colony. Mapping was made difficult by the heavy bush and soil cover which effectively conceals exposures in many parts of the area. In the higher and more densely populated parts in the west, paths and more varied relief enable the geology to be seen more easily, but in the low ground in the east exposures are poor.

II—PREVIOUS WORK

So far as is known the first geological reconnaissance of the Mwingi area was made by E. E. Walker on behalf of the Colonial Office in 1902 (Walker, 1903)*. At Kibui (south-west of Kiormo ?) he found a hill of crystalline limestones, some of which he observed contained crystals of blue spinel, while other parts contained phlogopite and a yellow mineral suspected to be chondrodite. Associated with the limestones he found metacalcareous rocks rich in pyroxene and garnet. In the Pia (Tyaa ?) river he noted a cliff formed by another limestone, in which there were patches of milky opal and veins of quartz. Walker climbed Mumoni and described it as composed of gneisses cut by common coarse-grained pegmatites containing magnetite crystals up to two inches across. He was unable to find any valuable minerals in his traverses. Brown in 1904 travelled northwards from the region of Mwingi to Mumoni, and thence north-east to the Tseikuru district and the River Tana. He concerned himself mainly with geography, meteorology and ethnology and made little mention of rocks or minerals beyond stating that prospectors of the East Africa Syndicate had passed through the district, but had found no minerals there (Brown, 1906, p. 38)

A rapid reconnaissance of the roads in the area was made by W. D. Harverson in 1934 (Mining and Geological Department, 1935) and short visits were paid by Dr. W. Pulfrey in 1942 and 1946. The latter noted the presence of ultra-basic rocks at Kamuthengi and the occurrence of recrystallized limestones at Nzui and in the north and west. He also examined the ochres formerly worked by E. G. Powell south-west of Nziu and south-west of Mutuangombe.

III—PHYSIOGRAPHY

The area can be divided into three physiographic units; the mountain masses of Mumoni and Muvaroa in the north-west, moderately high ground with residuals in the west, and a low peneplain in the north and east with scattered residuals (Fig. 1).

The country on the west has marked relief, the pattern of which is based partly on the predominant N–S strike and partly on the north-westerly trend of many of the rivers. It is a relic of a peneplain over 4,000 ft. high which now is most closely represented by the ground in the south-west corner of the area and by the summit levels of Kiormo, Ithumbi, Endui and Etinda, the remainder having been eroded considerably below its original level. The erosion surface is an extension of the bevel that passes under the base of the lavas of the Yatta plateau and which Schoeman (1948, p. 3) has suggested is the sub-Miocene peneplain. In the north-west corner of the area Mumoni and Muvaroa attain a height of nearly 6,000 ft. and their summits are considered to be relics of the end-Cretaceous peneplain of Shackleton (1946, p. 2).

From the base of Endui at 2,500 ft. approximately, the ground slopes away eastwards as a pediment with a gradient of about 50 ft. per mile, but in the eastern half of the area the lowlands slope eastwards at about 20 ft. per mile. The plain continues eastwards and north-eastwards to Garissa and Wajir and has been referred to by Dixey (1948, p. 3) as the end-Tertiary peneplain. From this peneplain isolated monadnocks project as relics of the sub-Miocene peneplain. It is belived that the peneplains and their residuals developed by a process of scarp retreat and pedimentation. In the course of time the residuals on the end-Tertiary peneplain will be gradually removed by erosion, ultimately leaving a perfect plain. At the same time erosion will eat back into denuded remains of the sub-Miocene surface, gradually extending the end-Tertiary plain further west. The oldest surface in the area mapped can be traced only on the tops of the highest hills. Subsequent to its maturity, presumably towards the end of the Cretaceous period, there was a general rise of the land and another cycle of erosion began leading to the formation of a lower plain with residuals of the earlier surface standing up from it. This plain attained maturity in mid-Tertiary times. At the end of the Tertiary renewed uplift took place, when the older surfaces were tilted gently seawards and a new cycle of erosion and planation was initiated. The end-Tertiary peneplain resulted.

*References are quoted on p. 21.

There are almost no permanent rivers, the drainage consisting predominantly of water courses that only carry surface water during the rains or for a short time afterwards. The only exceptions to this are the headwaters of the Mwengo and Ndatha rivers which rise on Mumoni and have a small permanent flow, and a solitary spring in the bed of the river Katze near Etinda. There is a main watershed in the west of the area that is followed by the Mwingi-Mivukoni road, east of which the rivers run generally south-east across the lower peneplain to the lower reaches of the Tana river. West of the watershed the rivers run north-west to north, with divergences round Mumoni, to join the upper reaches of the Tana River.

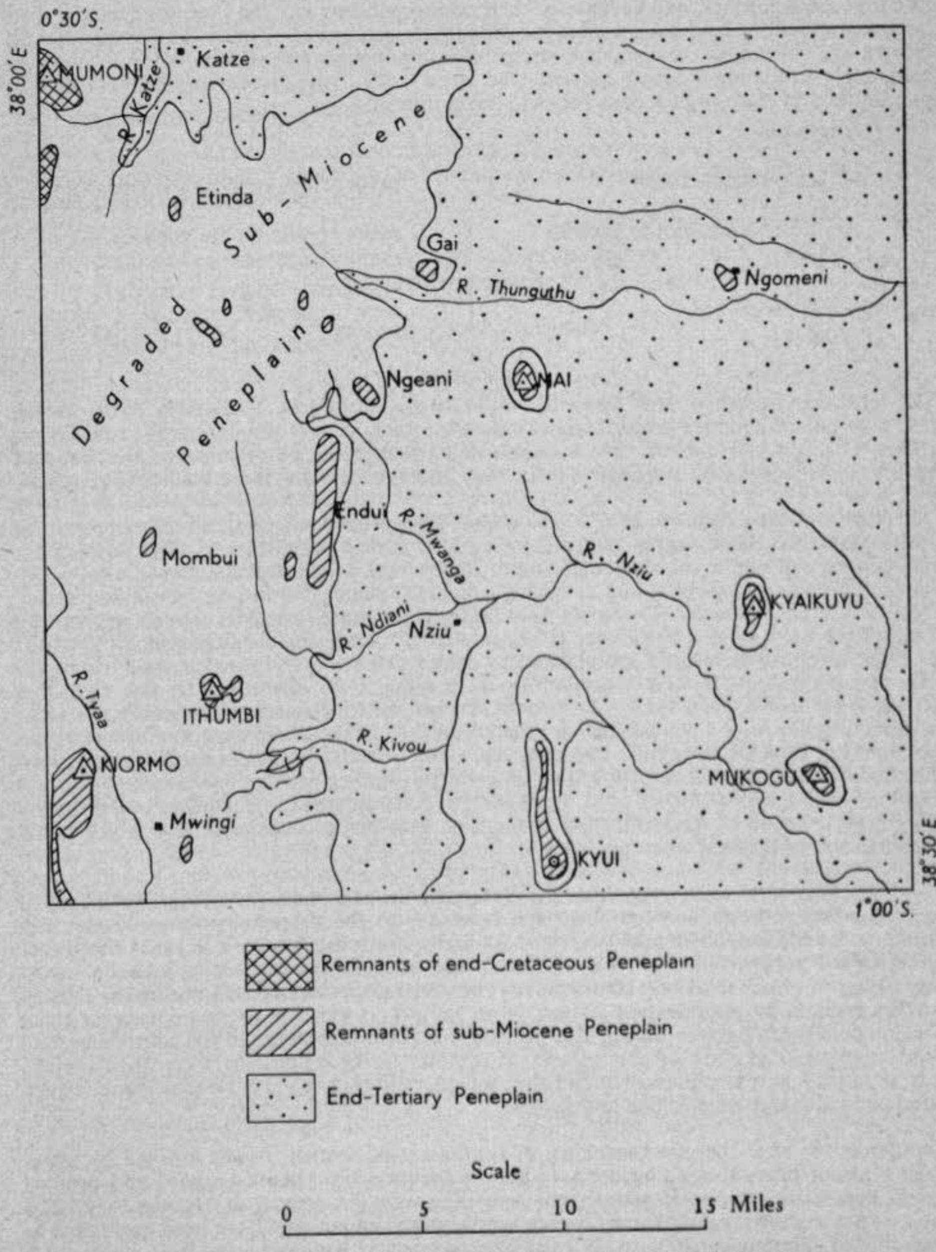


Fig. 1.—Sketch map of the chief physiographic units in the Mwingi area.

IV—SUMMARY OF GEOLOGY

The rocks of the area fall into three main groups: (1) metamorphic rocks belonging to the Basement System of East Africa and presumed to be of Archæan age, (2) post-Archæan ultra-basic intrusive rocks in a plug at Kamuthengi, composed of dunites, anorthosites and serpentine, associated with anthophyllite and magnesite rocks, and large xenoliths of plagioclase amphibolite, and (3) superficial deposits consisting mainly of red-brown sandy soils.

The Basement System (*see* Stockley, 1943, p. 161) is a metamorphosed series that is considered to be of sedimentary origin because of the composition and texture of most of its component gneisses, and because of their conformability with the limestone bands, their large-scale banding and their typically sedimentary structures. The rocks comprising the System are calcareous, semi-calcareous, pelitic, semi-pelitic and psammitic, and there are completely gradational series between the main rock types, from calcareous rocks to psammites and from argillaceous rocks to psammites, viz.:—

limestones
calc-sillicate rocks
hornblende-biotite gneisses
garnet-sillimanite-biotite gneisses
melanocratic biotite gneisses
biotite gneisses
leucocratic biotite gneisses
granulites

The left-hand branch of this series is similar to that found by Holmes in Mozambique (1918, p. 58) i.e., biotite gneisses—hornblende-biotite gneisses—amphibolites—calc-silicate rocks. Owing to the limited time available and the high degree of inherent and imposed variability it was found possible to map only the broader and more well-defined bands.

All the rocks except the marbles contain a high proportion of alkali felspar, much of which probably originated as material introduced during granitization. The felspars are microcline, orthoclase, perthite and sodic plagioclase, which are sometimes evenly disseminated through the rocks and at others irregularly segregated in porphyroblasts, augen, clots, schlieren or bands. The rocks containing them might often be termed migmatites, which have been defined by Turner (1949, p. 11) as "composite rocks in which the effects of metamorphism have been complicated by soaking of rocks in migmatic fluid, or by the development of lenticles and sheets of liquid magma . . .". According to this definition all the Basement System rocks of the area, except the limestones and possibly the other calcareous rocks, could be classified as migmatites but, as the interpretation of the term has been subject to some variability in recent years, the word has not been used in this report. The use of terms indicative of specific classes of migmatites such as "*permeation gneisses*" and "*injection gneisses*" (Read 1931, pp. 118–120) is considered more suitable but, owing to the irregular mode of felspathization in the area now being considered, it was not found practical to utilize them when mapping.

Sometime after their deposition the Basement System rocks were folded and faulted and intensely plane-foliated parallel, it is believed, to the original bedding-planes. The strike of the foliation is regular and runs generally north-south with a gradual north-east swing in the north. The dips of the foliation are variable, due to folding and the superimposition of minor folds and contortions. The metamorphism imposed during the folding was augmented by granitization. There is no indication that the rocks or parts of them became completely molten during this process, but there is evidence in the contortions and flow structures that they became plastic. It appears to the writer that when they were in that state they were compressed round the melanocratic calcareo-argillaceous bands, which remained solid and were folded and broken.

Sometime after the metamorphism of the Basement System, it was injected by ultrabasic plugs at Kamuthengi. Since that time the area has been heavily eroded and levelled during successive periods of peneplanation, ending with the present day topography. The area is now covered mainly by red-brown sandy soils: similar soils have been correlated at Malindi (c.f. Thompson, 1956, p. 30) with Pleistocene and Recent coastal deposits.

V—DETAILS OF GEOLOGY

1. Basement System

The rocks of the Basement System can be petrographically divided into numerous types which are described below under the following groups:—

(1) crystalline limestones

(2) calc-silicate rocks

(3) pelitic rocks

(4) semi-pelitic rocks

(5) psammitic rocks

The mapping was insufficiently detailed to enable the working out of a complete stratigraphical succession, but it appears from the sequence established in the south-west part of the area that it is broadly as follows:—

	Feet
Interbanded psammitic granulites and semi-pelitic gneisses . .	8,500
Semi-pelitic gneisses, probably with part passing into pelitic gneisses in the north-west	24,000
Crystalline limestones and semi-pelitic gneisses	10,000 (?)

(1) *Crystalline limestones* occur as isolated lenses or lines of lenses mainly in the south-western and northern parts of the area. Most of the lenses are 50 to 100 yards wide and they vary in length from a quarter of a mile to two miles. The lens at Gahie, in the centre of the area, is both solitary and exceptional in size, as it is 500 yards wide and nearly three miles long. The soil overlying the limestone bands is much whiter than that resting on the gneisses of the remainder of the area and contains superficial limestone nodules, while the bush cover is greener but more stunted and open. The limestones vary from fine-grained saccharoidal marbles to coarse-grained rocks, though most have a grain size of about a quarter of an inch. They consist of granular mosaics of grains of carbonate with prominent rhombohedral cleavages and twinning, with pink and white calcite and dolomite in proportions varying from nearly pure calcite (in specimen 45/180, Galui hill) to nearly pure dolomite (in specimen 45/143, from the lens near the south-west corner of the area), as estimated from the reaction of crushed material in cold dilute hydrochloric acid. By using Lemberg's test (Hatch and Rastall, 1950, p. 322) it was proved that in marbles of intermediate composition grains of dolomite and calcite are evenly intermixed. Scattered sparsely in this mosaic are variable amounts of lime-bearing alkali-aluminous minerals represented by calcic plagioclase or scapolite, muscovite, epidote, and ferromagnesian minerals represented by diopside, hornblende, forsterite, and serpentine and chlorite, the magnesium having been provided by dedolomitization of the limestone. The limestone lenses are also sheathed by and sometimes intercalated with rocks composed of calc-silicate minerals formed by the dedolomitization of the limestone by reaction with silica-bearing minerals in surrounding or included sediments. In some instances, however, recrystallized calcite is in passive contact with quartz, as in specimen 45/148 from the limestone band on the road just east of the River Tyaa, where a recrystallized limestone encloses unaltered quartz grains, and where some of the limestones have not been completely surrounded by a protective sheath of calc-silicate minerals. Lack of exposures prevented a determination of the widths of the calc-silicate sheaths and their passage into granitized rocks.

(2) *The calc-silicate rocks* are usually mesotype and foliated, and in addition to their occurrence round the borders of the limestone lenses, or as bands within them, they sometimes form extensions to the limestone lenses, interdigitating with the surrounding sediments. Calc-silicate rocks not associated with limestones are also seen in small isolated bands and lenses in other parts of the area, the largest being on Muvaroa and north-east of Gai.

The most common minerals in the calc-silicate rocks are pale-green to green faintly pleochroic diopside, deep-green to brown hornblende that appears to be secondary after diopside, pale-coloured epidote and clinozoisite, plagioclase of labradorite-bytownite composition, scapolite, often quite large crystals of sphene, and small sub-hedral crystals of brown garnet. Quartz, orthoclase, microcline, apatite and zircon appear in less calcareous examples, which have probably suffered some granitization.

Some idea of the variation of the calc-silicate rocks is obtained from the following estimated volumetric modes.

	45/122	45/124	45/141	45/161	45/167	45/171	45/176
	%	%	%	%	%	%	%
Plagioclase	30	30	30	5	10	15	20
Diopside	30	—	40	65	25	8	—
Hornblende	12	35	30	7	—	—	+
Clinozoisite-epidote ..	6	35	—	3	40	12	35
Scapolite	—	—	—	15	15	20	10
Quartz..	20	—	—	2	—	30	30
Sphene	2	—	—	3	10	+	2
Garnet	—	—	—	—	—	15	3

45/122 On path to Imba, just north of the Nziu river. Borders a limestone lens.

45/124 As 44/122.

45/141 From the valley south of the Garissa road near the bench-mark, south of Kiormo. A calcareous gneiss.

45/161 Mutui hill.

45/167 Kandaoni Ridge near Katze. Float block.

45/171 From limestone band on road about three miles south of Katze.

45/176 On road, one mile north of Gai.

Specimen 45/140, from the Garissa road south of Kiormo, contains abundant crystals of brown biotite associated with large poikiloblastic grains of pale-green pyroxene, green hornblende, sphene, large grains of apatite, a perthitic felspar and quartz. Specimen 45/164, from the amphibolite lens near Kyando, is a lime-rich rock composed of nearly equal proportions of diopside and hornblende with less than five per cent of interstitial plagioclase. The rock is similar to one described by Bear (1952, p. 11) from the western side of Mumoni south of Muguthu, and forms part of one of a number of isolated, usually concordant, lenses occurring between Muvaroa on Mumoni and a point south of Kyando. Similar lenses occur further south at Mukuni and Kitumbi. The lenses are not here associated with any other calc-silicate rocks but in central Kitui similar rocks have been mapped as melanocratic facies of more normal calc-silicate rocks (Sanders, 1954, p. 10).

(3) *Pelitic rocks* are represented in the area by small bands, schlieren, clots and lenses in the semi-pelitic biotite gneisses, and locally by rocks with garnet and sillimanite. The sillimanite always occurs as fibrous crystals which are often aggregated in sheaves or bands. During crystallization the aggregates were greatly affected by stress and now they are well foliated and possess a well-defined "flow structure" around the weakly foliated felsic minerals and the pink to red garnets which are sometimes present. The garnets occur as round subhedral cracked crystals, usually distributed irregularly through the rocks, but sometimes lie in poorly defined impersistent bands.

The presence of sillimanite and garnet leads to a range of rock types including: sillimanite-quartz-felspar gneiss (specimen 45/7, two miles north of Waita) sillimanite-quartz schist (specimen 45/160, below Mutanda rocks), sillimanite-biotite gneiss (specimen 45/174, foot of Mumoni), and sillimanite-garnet-biotite gneiss (specimen 45/166B, Kyando-Gai road near Katze turn-off), garnet-quartz-felspar granulite (specimen 45/69, near Uumaa), garnet-biotite gneiss (specimen 45/166A, Kyando-Gai road near Katze turn-off).

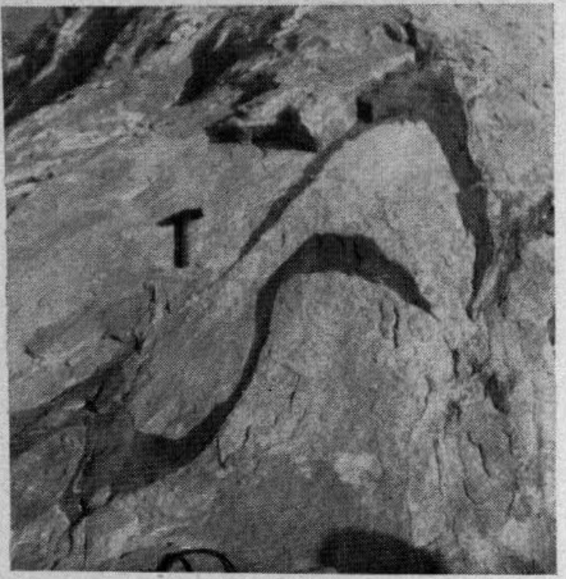
The rocks of Mumoni are exceptionally pelitic, sillimanite-biotite gneisses being the most common among them. They are locally spotted by small garnets, forming rocks similar to those described as sillimanite-garnet-biotite gneisses by Shackleton (1946, p. 9) from the Maralal area and by Bear (1952, p. 15) from the western side of Mumoni. In addition to foliated sheaves and bands of fibrous sillimanite they contain flakes of biotite and scattered garnets, quartz, oligoclase and microcline, with accessory zircon, apatite, sphene and iron ore. They can be regarded as biotite gneisses containing sillimanite in proportions varying from a trace up to about 50 per cent.

Plate 1

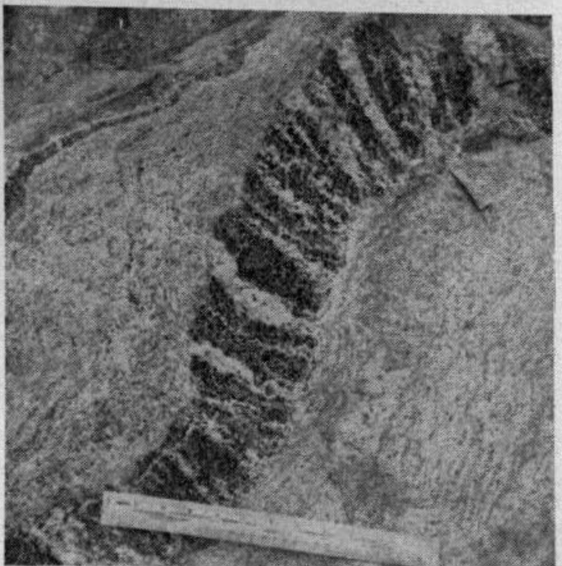
(a) View south from Gai showing peneplains.

(b) Leucocratic biotite gneiss enclosing melanocratic masses.

Plate II



(a) Leucocratic biotite gneiss enclosing folded melanocratic bands.



(b) Melanocratic biotite-rich band, bent and injected by quartzo-felspathic material.

Specimen 45/7 is composed mainly of gneissic quartz and a little orthoclase, with the foliation planes marked by many easily-weathered fibres and thin bands of sillimanite. The quartz-sillimanite rock represented by specimen 45/160 was found only as a float block. It is a white and schistose rock that in thin section is seen to be composed of quartz, sheaves of sillimanite, and secondary sphene.

(4) *The semi-pelitic gneisses* form a variable granitized and metamorphosed series and in places have nearly flat foliation planes, while in others the foliation is highly contorted and cut by numerous minor cross-fractures. The country formed by the semi-pelitic rocks is usually low-lying and soil-covered, but there are occasional hills and low whale-backs. The whale-backs usually occur where the rocks are well banded, when they are also often highly contorted and ptygmatically folded. The rocks can be divided into several types on their colour index, amount and type of granitization and on their mineral compositions, but the series is so variable that several such rock-types may be seen in one exposure. Due to this and to the limited time available for the survey it was impossible to map divisions in the group. The main rock types are: biotite gneisses and hornblende-plagioclase gneisses, with transitionary hornblende-biotite gneisses.

Biotite gneisses in the Embu-Meru area have been well described by Schoeman (1951, pp. 13–16) under the heading of migmatites, and from south-east Embu by Bear (1952, p. 12). They are composed of quartz, plagioclase, potash felspar and biotite with accessory apatite, sphene, zircon and iron ore with rarer, more sporadic, rutile and muscovite. In some exposures garnet was found. The quartz and felspar (which have developed partly as products of granitization) form a granulose groundmass in the rocks, as in specimen 45/133 from the north part of the central rib of Ithumbi, but the felspars also form porphyroblasts (as in specimen 45/23 from the summit ridge of Ithumbi), augen, schlieren, bands or pegmatite-like veins (as in specimen 45/3 from near Waita dam). The veins follow the foliation planes and the minor cross-fractures. In the larger veins the crystal size is much coarser and magnetite and biotite are sometimes present in crystals up to three centimetres across.

A common feature in the leucocratic or mesotype gneisses is the inclusion of irregular but sharply defined melanocratic portions round which the host-rock has flowed and become highly contorted. The dark inclusions are sometimes composed entirely of dark-brown biotite in interweaving flakes or of biotite and hornblende or of hornblende alone, but they usually contain plagioclase and potash felspar in addition. They are arranged parallel to and along planes whose traces in outcrops follow and indicate the general structure. In the banded types the bands sometimes taper laterally, but are often displaced by small faults or even sharply terminated. Their characteristics suggest that they represent more calcareous or argillaceous bands that were metamorphosed, distorted and broken during folding and sometimes partly digested during granitization.

Hornblende-biotite gneisses and hornblende-plagioclase gneisses representing more calcareous members of the semi-pelitic group have been described by Schoeman (1948, p. 14, Kitui, and 1951, p. 10, Embu-Meru) and by Bear (1952, p. 13, south-east Embu). In addition to the presence or predominance of hornblende among the dark minerals such rocks are characterized by a marked sparsity of potash felspar, especially microcline, which suggests that they have not been granitized as much as the other types.

Muscovite occurs sporadically in various rocks throughout the area, but is present in quantity in a quartz-muscovite schist at Kaikuyu hill. Specimen 45/78 from that locality is composed entirely of well-foliated coarse-grained quartz with occasional felspars and muscovite in flakes, thin folia, bands and lenses. On the flanks of the hill the muscovite is associated with biotite and farther away the rock passes into a biotite gneiss.

(5) *Psammitic gneisses* occur as bands or lenses at numerous places throughout the area, where they sometimes form high ridges such as Endui, Mai and Mukogu, but more usually form low but prominent craggy features.

The predominant rock type is a quartz-felspar granulite which weathers into rounded boulders with a characteristic fawn colour spotted by scattered, sub-hedral, black magnetite grains. They are similar to granulites described by Shackleton (1946, p. 12) from the Matthews range and by Bear (1952, p. 18) from south-east Embu, being composed of quartz, microcline, and oligoclase, with subhedral titaniferous-magnetite, and occasional flakes of muscovite and biotite lying parallel to the faint foliation. As already mentioned some are spotted by a few garnets.

2. Pleistocene and Recent

Over most of the area and especially on the end-Tertiary peneplain, there are red-brown quartzose soils such as cover large areas of East Africa and are similar to soils that have been correlated with Pleistocene sands near Malindi (Thompson, 1956, p. 30). There are occasional developments of surface limestone and lateritic ironstone, while where drainage has been hindered or confined there are black cotton soils, below which there are sometimes restricted deposits of gypsum and ochreous clays. Some bands in the valley soils that apparently have a high content of soluble salts are used by cattle as salt-licks when they are exposed in the river banks.

3. Intrusives

The intrusive rocks consist of pegmatites which vein the Basement System and ultra-basic plugs in the eastern part of the area.

(1) Pegmatites

The pegmatites of the Basement System occur as numerous small concordant and discordant veins. They are composed of a coarse-grained mosaic of quartz and potash felspars with occasional crystals of biotite, muscovite, amphibole and titaniferous magnetite. The veins often follow fracture planes and were probably formed at a late stage in the metamorphism. An exceptional graphic pegmatite composed only of quartz graphically intergrown with microcline was found west of Kyaikuyu. It has a large extent and appears to have a cross-cutting relationship to the country-rocks.

(2) Ultra-Basic Intrusions

The ultra-basic intrusions lie close together in the eastern part of the area and consist of:—

(*a*) the hill Kamuthengi;
(*b*) a low unnamed hill, south of Kamuthengi and just north of the Garissa road;
(*c*) a low ridge south-east of the hill Twamagua.

The three occurrences are roughly equally spaced on a north-south line about twelve miles long, Kamuthengi being central. The total area covered by the intrusions at the three localities is about five and three-quarters square miles, but the actual exposure is extremely small. Near Twamagau particularly, little more than loose boulders which gave little indication of the underlying geology were seen.

The soils at the three localities are very dark coloured due to a high content of amphibole and iron ore. On ground between the three localities where there are no rock exposures the soils are light brown and sandy, supporting a thick cover of bush, which is typical of the metamorphic rocks rather than of the ultra-basic plugs, as was also found at Kipiponi (C. S. Hitchen, unpublished departmental report). The few surface pebbles that are to be observed in such soil-covered areas are indicative of underlying gneissic rocks rather than intrusive ultra-basic rocks.

(*a*) *Kamuthengi Hill*.—The hill rises steeply from the surrounding low-lying flat plain. At its western end it is thickly bush-covered and has a loose surface cover composed mainly of quartz fragments. This is sharply demarcated from the rest of the hill which has dark coloured soil with grass and occasional bushes. There are many loose boulders embedded in, or lying on, the soil which confuse the geology. A tentative indication of the distribution of rock types is given in Fig. 2, for which the topography was drawn partly in the field and partly by enlargement from aerial photographs. The form-lines are based on spot-heights obtained by barometer.

The structure is that of a complex plug or stock built of several types of rock, which has later been veined by pegmatites and quartz veins. The main rock types are:—

(i) Dunites.
(ii) Plagioclase-bearing Dunites.
(iii) Anorthosites.
(iv) Actinolite-anthophyllite rocks.
(v) Serpentine rocks.
(vi) Pegmatites and Quartz veins.

Amphibolitic xenoliths are enclosed by the dunite at various places on the hill.

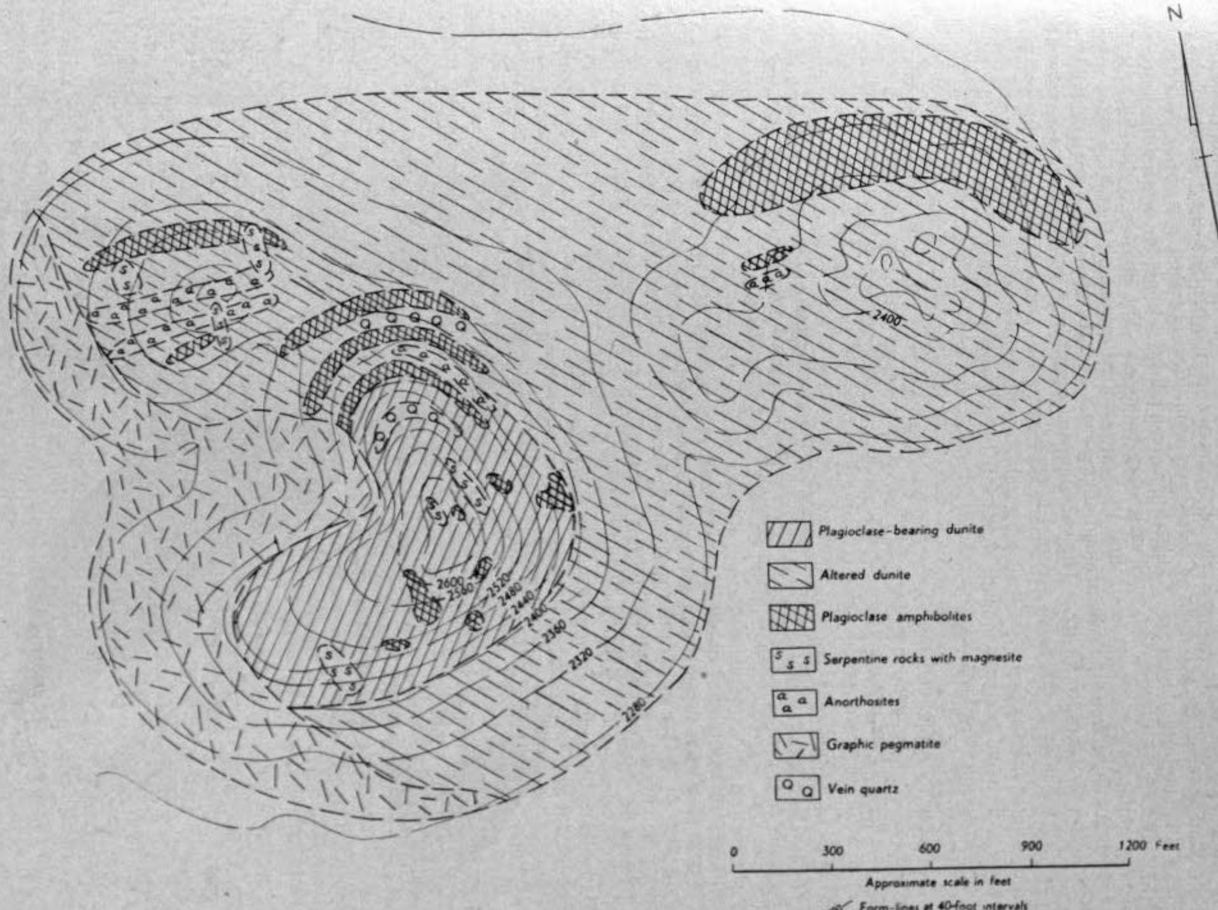


Fig. 2.—Geological sketch map of Kamuthengi hill.

(i) *Dunites.*—These rocks are now mainly composed of actinolite and chlorite with variably serpentinized and oxidized remnants of olivine. They are typified by specimen 45/101, which in the hand-specimen is green and finely micaceous with scattered, sub-angular brown spots of serpentinized olivine (Fig. 3a). Specimens 45/118 and 45/39 are similar. In a thin section of specimen 45/101 the brown areas are seen to be composed of limonite-stained serpentine, honeycombed by small veins of chlorite. Remnants of olivine are present in the pseudomorphs and vary greatly in number and size. Between the ser-pentinized grains there is a mass of pale-green actinolite and pale-green clinochlore crystals with a small amount of iron ore. The actinolite is in bladed crystals of variable size associated with plates of the chlorite set with various orientations. The actinolite-chlorite aggregate in part simulates flow structures round the serpentinized masses so that it appears to have penetrated and broken apart the original olivine mass, rather than to have been derived from the olivine by alteration *in situ*. The variation in composition of the dunites is shown by the following table of estimated volumetric modes:—

	45/101 %	45/39 %	45/118 %
Olivine and olivine pseudomorphs ..	35	25	60
Chlorite	34	{ 73 }	29
Actinolite	30		10
Iron Ore	1	2	1

The chlorite-actinolite dunite predominates in the lower slopes of Kamuthengi and in the north and east spurs, where it is apparently vertically jointed along bearings of 110° and 80°. It appears to form the outer or lower portion of the complex.

A completely altered dunite is represented by specimen 45/111, which consists largely of masses of fibrous crystals that are probably amphibole, interspersed with limonite grains. Aggregates of plates of chlorite and small masses of carbonate lie interstitially to the amphibole clusters. Another variation, of which only a small amount was found, consists of chlorite in which lie scattered small prismatic crystals of hornblende.

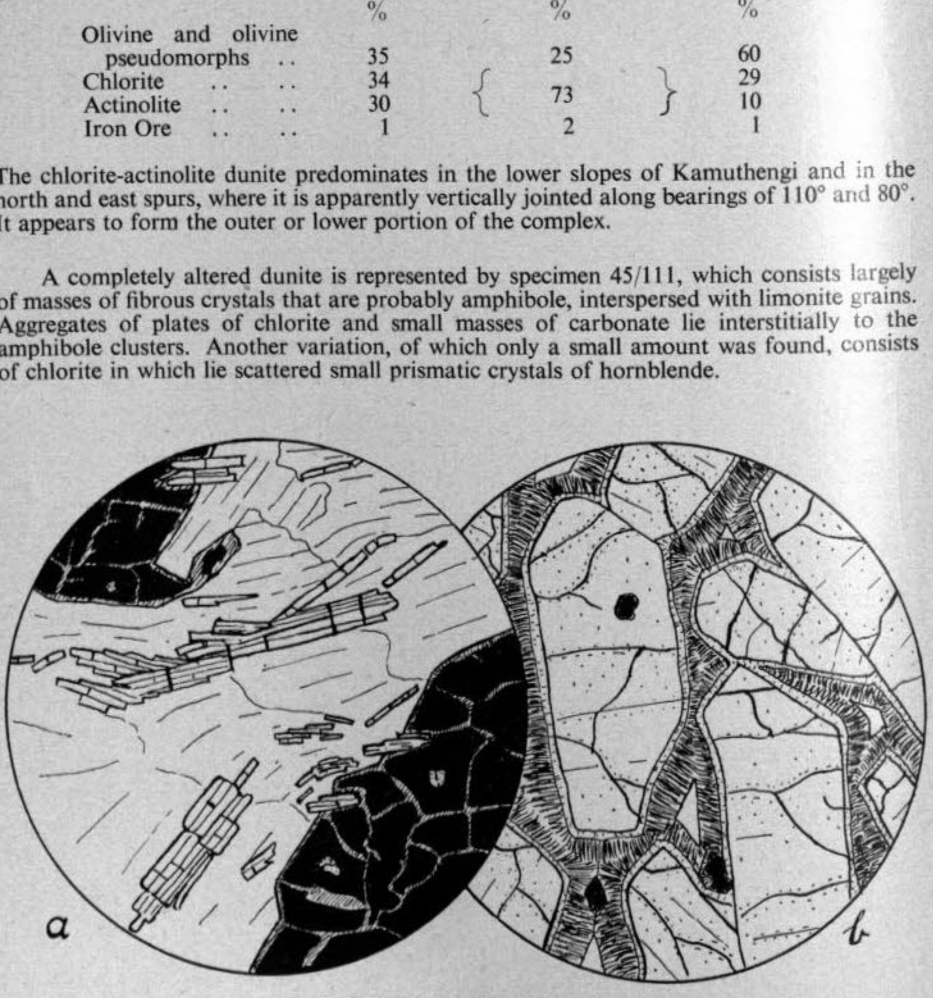


Fig. 3.—Diagrammatic microscope drawings of thin sections of rocks from Kamuthengi.

(a) Altered dunite, specimen 45/101, x18, ordinary light. Heavy lines = actinolite; fine lines = chlorite; black represents brown serpentine which is veined by chlorite.

(b) Plagioclase-bearing dunite, specimen 45/102, x20, ordinary light. Crystals of olivine are surrounded by zones of orthopyroxene and actinolite. Plagioclase occurs in interstitial pools.

There is a certain amount of segregation and orientation of the dark minerals in the dunites. This is seen in the parallelism of larger melanocratic lenses and bands, in the strong foliation of the dark minerals in such bands and in the feeble alignment of dark flakes and spots in the more felspathic portions.

(ii) *Plagioclase-bearing Dunites* were seen only in the central, higher, parts of Kamuthengi. They are similar to the melanocratic portions of the Belhelvie troctolites as described by Stewart (1946, p. 472) and in hand-specimen are dark, compact, waxy-looking rocks, that weather with a brown and pitted surface, the colour being mainly due to iron-staining. They consist of olivine, a small amount of interstitial plagioclase and an accessory dark mineral, probably picotite. They are typified by specimen 45/102 (Fig. 3b). In thin slice it is seen that the olivine is in fairly large grains that have suffered little serpentinization, but are surrounded by two-zone reaction rims. The inner zone consists of a colourless mineral with a fibro-lamellar habit, refractive index close to that of olivine, moderately high birefringence, and positive elongation, that is probably an orthopyroxene. The outer and wider rim consists of a colourless amphibole in which green spinel is intergrown as an extremely fine symplektite. The outer rims are often narrow where the olivine crystals are closely spaced. Scattered indiscriminately through the rock are small subhedral grains and octahedra of a partly opaque mineral which transmits light in patches, when it is brown. This is probably picotite and where it occurs in the amphibole coronas it is rimmed by a brown zone. A pale bluish-green spinel is also present interstitially, in relatively large irregular grains and occasionally as octahedra associated with stout crystals of a colourless amphibole (tremolite ?). The amphibole rarely traverses the olivines as long narrow allotriomorphic crystals. Sometimes it is associated with a phlogopitic mica. There is little plagioclase—about five per cent—interstitial to the olivines; it is optically positive with a fairly high refractive index and is probably labradorite. It is considered that the coronas round the olivines are due to reaction with the felspar in the presence of late-stage liquors (c.f. Stewart, Belhelvie, 1946, p. 472). Corona structures around olivines are well known from numerous basic intrusives throughout the world—Belhelvie (Stewart, *op. cit.*) and Risor (Hatch, Wells and Wells, 1949, p. 286) may be quoted as examples. In both cases the inner rims are composed of orthopyroxene, while the outer rims are formed of a cummingtonite-spinel symplektite. The Kamuthengi coronas are similar. As at Belhelvie, there are dark brown spinels in the rocks.

A variety of the plagioclase-bearing dunite is represented by specimen 45/100, which is generally similar to the specimen described above but contains more plagioclase and a few grains of augite and hypersthene, and might well be called gabbro. In hand-specimen the rock is generally similar to the normal plagioclase dunites but when fresh has brown spots in it which are due to aggregates of hypersthene and augite between the olivines. Round the cracked olivines there are corona structures of orthopyroxene and amphibole-spinel symplektite. In some cases the inner rim consists of individualized grains of light purplish-brown pleochroic hypersthene. Grains and crystals of picotite are scattered sporadically through the rock.

A second saxonitic variety of the plagioclase-bearing dunites is represented by specimen 45/109, which consists mainly of olivine and hypersthene. The faintly pleochroic hypersthene occurs in large striated crystals with iron ore inclusions along the cleavages, among fairly coarse allotriomorphic grains of olivine which are serpentinized along cracks. The olivine is a magnesia-rich variety. There are in addition small amounts of interstitial pargasitic amphibole that is faintly pleochroic in green, and scattered grains of an opaque ore mineral.

A hypersthenite (45/105) is associated with the plagioclase-bearing dunite at the top of Kamuthengi hill. The rock consists largely of different-sized grains of pleochroic hypersthene, heavily dusted with iron ore along the cleavages. Interstitially in parts there is a light green slightly pleochroic chlorite enclosing small prisms of a colourless amphibole, which however, in some places has grown into large prisms and occasionally forms aggregates. Green hornblende also occurs massive, interstitially, and often penetrates between crystals of hypersthene.

(iii) *Anorthosites.*—These occur as infrequent bands in the dunite. Specimen 45/107, which in hand-specimen is white with a blue tinge, is typical and made up of labradorite crystals of varying sizes, with small amounts of chlorite and scapolite and small flakes of muscovite. Specimen 45/110 is composed of a pale-blue labradorite with sharply defined sub-circular spots of hornblende, while scattered through the rock are a few crystals of biotite and chlorite. The hornblende spots sometimes coalesce into bands and lenses as is seen in specimen 45/112, in which the felspar is bytownite and the dark bands are composed either of hornblende and dark green spinel or of hornblende alone. The spinel is probably pleonaste.

These rocks may have arisen by the segregation of felspars during crystallization of the dunites, with subsequent intrusion as anorthosites, in which the compact amphibole-spinel lenses may represent segregations or inclusions. The foliation may have been imparted to the rocks during their formation and emplacement in their present position.

(iv) *Actinolite-Anthophyllite Rocks.*—In the eastern part of the hill actinolite occurs with anthophyllite in a 15-inch thick lens. The anthophyllite, which is fawn coloured and has a silky lustre, occurs in long straight fibres which form columnar aggregates with prominent cross-fractures (45/115). In the central part of the lens the fibrous aggregates of hard brittle anthophyllite up to twelve inches in length are transverse to its length. At the margin the columnar aggregate gives way to a two to three inches wide felt of green pleochroic actinolite needles and prisms interspersed irregularly among short crystals of anthophyllite, as seen in specimen 45/116. In some marginal parts of the lens there is little anthophyllite and the actinolite forms a foliated mass of larger anhedral to euhedral crystals, as seen in specimen 45/117. The lens lies horizontally along the strike length of about five yards, beyond which it grades laterally into a band of actinolite and then into serpentine and magnesite. These progressive changes agree closely with Hitchen's observations at Kinyiki hill (Parkinson, 1947, p. 33), where cross-fibre veins are composed of anthophyllite and alter at surface to magnesite. By analogy some of the many anastomosing magnesite veins at Kamuthengi may be replacements of asbestos veins, though no evidence was seen to indicate that such is the case. The country-rock surrounding the dunite at Kinyiki is hornblende gneiss and Hitchen concluded that the asbestos was formed by the metamorphism of rafts of the gneiss in the intrusion. The country-rock is mainly biotite gneiss around Kamuthengi so far as can be seen, and there is no evidence whether or not the asbestos was derived from hornblende.

(v) *Serpentine and Magnesite Rocks* occur in apparently vertical lenses with a thickness of about ten ft. which run north-south and, being more resistant to weathering than the surrounding rocks, they stand up as low ribs that are presumably *in situ*. The ribs are composed mainly of brown-red serpentine which weathers with a dark brown, irregular, earthy-looking surface and is honeycombed with variably narrow ramifying veins of bone magnesite. Set in the serpentinous mass there are crystals of a green micaceous mineral. The serpentine is represented by specimen 45/108, the bulk of which consists of a massive brown alteration product showing weak pleochroism and moderate birefringence that is probably iddingsite. It is finely veined by chlorite and on a larger scale by magnesite which in part is margined by chalcedonic silica, and encloses crystals of a positive colourless amphibole and more rarely antigorite crystals. A few pools of chlorite are also present. Chlorite (45/46) was also found in the soil as large green flexible subhedral plates measuring up to six inches across. Its optical properties suggest that it is penninite.

The magnesite veins are mainly narrow, varying from microscopical veinlets up to veins half an inch wide. In parts of the hill pieces were found that must have come from veins three inches wide, but no such veins were seen *in situ*.

(vi) *Pegmatites and Quartz Veins.*—In the western part of Kamuthengi hill, and demarcated from the ultra-basic rocks by the edge of the thick scrub, there is an area of graphic pegmatite consisting of coarsely intergrown quartz and microcline. The pegmatite extends from the edge of the scrub to the base of the hill where the surface suddenly becomes undulating and slopes gently away to the nearest water-course. Although float material from it occurs in this undulating country, there is no evidence for extending the boundary of the ultra-basic complex beyond the base of the hill.

The central part of the pegmatite mass is mainly composed of massive cloudy quartz, though small grains of clear quartz and small scattered flakes of muscovite were seen. Lying in the soil at the base of the hill below the pegmatite, there are scattered flakes of vermiculite which may be derived from the pegmatite or may possibly be contact alteration products of the biotite of the gneissic country-rock, developed in a manner similar to the vermiculite found at Kinyiki (Parkinson, 1947, p. 35).

In several parts of the hill, massive quartz fragments were seen which presumably come from quartz veins, but their relation to the massive graphic pegmatite could not be determined.

(vii) *Plagioclase-amphibolites* occur as xenoliths in the dunites and form a variable but distinctive group of rocks in the field. One type is represented by specimen 45/103, which is a blue-black fine-grained rock, speckled by small felspar crystals and weathering with a thin dark brown crust. It consists of about three parts green hornblende and about one part andesine-labradorite plagioclase, with small grains of magnetite scattered throughout. The hornblende and felspar form an even-grained mosaic, the felspar being interstitial or enclosed in the amphibole. Clinozoisite occurs sporadically in some of the felspars, some of which are completely replaced by a pale brown isotropic material studded with clinozoisite grains.

A second variety is represented by specimen 45/41 which has a melanocratic portion sharply demarcated from a portion that has less than 50 per cent hornblende. Specimen 45/41B, which includes the junction between the plagioclase amphibolite and the dunite shows gradational variation from more leucocratic to more melanocratic portions. The dunite appears to be altered and mixed with the plagioclase amphibolite but only at the contact. Specimen 45/48 illustrates another mode of occurrence of the amphibolite, in which there are patches and streaks of the dark minerals and sometimes hornblende porphyroblasts, giving a mottled appearance.

(*b*) *The low hill south of Kamuthengi* is composed of rocks similar to those on Kamuthengi. Topographically it is a narrow ridge 200 yards long and about 50 yards wide that rises steeply 50 ft. from the plain and is heavily bush covered, with few exposures. The hill appears to be composed mainly of plagioclase-bearing dunite (45/119) with a few masses of plagioclase-amphibolite, as well as scattered occurrences of serpentine and magnesite, represented by float blocks. The plagioclase-bearing dunite is seen *in situ* on the crest of the ridge. It has parting planes which run on a bearing of 110° and dip N. 70°.

There is a small band of actinolite-anthophyllite rock (45/120) on the southern slopes of the ridge. The rock is green in the hand-specimen and has a silky lustre. It is mottled by small brown and fawn patches which contain anthophyllite fibres as well as actinolite, the brown colour being due to iron-staining of the anthophyllite. The actinolitic rock strikes on a bearing of 110° and dips N.N.E. at 20°, which suggests that the partings in the plagioclase-bearing dunite are joint planes.

(*c*) *The ridge south-east of Twamagau* is a low, gently-sloping ridge running on a bearing of 25°, which is also composed of ultra-basic rocks. The detailed structure of the intrusion is completely masked by the soil cover, but the trends of the intrusion and of the rocks appear to be the same as that of the ridge. The surface consists mainly of dark-coloured soil in which are numerous boulders of types similar to those of Kamuthengi. The rocks are mainly dunites and plagioclase-amphibolites with sparser serpentine, magnesite and chlorite and a blue-grey, waxy rock that is composed almost entirely of small interwoven crystals and fibres of anthophyllite (45/96).

One of the serpentine rocks (45/54A) has a blue, waxy appearance in the hand-specimen and weathers with a white surface with etched-out banding, resulting from the occurrence of parallel fibres of antigorite arranged along strings of magnetite grains and lenses at right-angles to them, giving a repeated comb-structure.

Specimen 45/57 is a foliated green rock composed of flakes of chlorite obliquely cross-hatched by long bladed prisms of actinolite, pleochroic from straw to blue-green, which measures in the hand-specimen up to three inches in length.

Origin of the ultra-basic intrusions.—The intrusions are essentially related dunite stocks that are unconnected at surface. They are intrusive into Archæan metamorphic rocks belonging to the Basement System of Kenya, but it is difficult to decide whether they were emplaced before or after the metamorphism, though the consensus of evidence suggests that they are post-metamorphism intrusions. They are little foliated, though the lack of foliation might be due to the resistance of such rocks to dynamo-thermal metamorphism. The dunite has, however, been serpentinized and the plagioclase-bearing dunite has been affected by solutions, causing reaction between the felspar and olivine to give reaction rims of enstatite and amphibole with spinel. The latter is, however, purely an end-stage reaction as is seen elsewhere, for example in the post-metamorphic intrusion of Belhelvie (Stewart, 1946). The formation of serpentine lenses with magnesite veins and chlorite crystals and the formation of occasional veins of anthophyllite must also be considered. Hitchen at Kinyiki (Parkinson, 1947, p. 33) considered that such veins originated from reconstituted hornblende rocks and that a passage could be traced through anthophyllite to magnesite at the surface. The serpentinization at Kamuthengi can be attributed to the action of late stage liquors and recrystallization under slight stress.

The intrusion of Kamuthengi appears to be so similar to those of Kipiponi (Kapuponi) in south Kitui and Kinyiki that tentative conclusions in connexion with its age and origin can be drawn from them. The Kinyiki intrusion is post-metamorphism as is shown by the presence of nests at the margin of large corundum crystals which have not been broken, as they would have been had they been pre-metamorphism.

The plagioclase-amphibolites can be reasonably mapped at Kamuthengi and the field relations do not suggest that they are sheet intrusions but rather xenolithic inclusions. Plagioclase-amphibolites similar to the Kamuthengi xenoliths but also containing garnets and scapolite have been mapped near Mpwapwa in Tanganyika Territory by B. N. Temperley (1938). These rocks are in sill-like bodies, the centres of which have ophitic structure, showing their doleritic origin, and have been injected into the country-rocks with which they were partly metamorphosed. At Kamuthengi there are in the plagioclase-amphibolites no signs of ophitic structures nor of pyroxene which would have been protected and preserved had the amphibolites been intrusions in the resistant dunite stock. Moreover because of the strong and clean-cut difference between the plagioclase amphibolites and the dunite it is virtually impossible for one to have come from the other by differentiation *in situ*. The remaining alternative is that the plagioclase amphibolites represents rafts or xenoliths of incorporated hornblende gneiss. If the intrusion had taken place before metamorphism the xenoliths would have remained as thermally altered sediments and would not have become foliated amphibolites. Because of the foliation and the banding, which is so typical of the metamorphic rocks, it is likely that intrusion occurred some time after metamorphism of the country-rock and that the plagioclase-amphibolites do, in fact, represent incorporated gneiss.

Other ultra-basic intrusions in Kenya have been mapped as later in age than the metamorphism of the Basement System. That at Kinyiki, near Mtito Andei, has already been mentioned. Other similar dunite plugs occur in the south Kitui district at Kipiponi, Magongo and Kenzi (Saggerson, 1957). At Dobell in the Northern Province there are other ultra-basic intrusions (Parkinson, 1920, p. 28; Hamilton, unpublished report, 1951) consisting of variously serpentized peridotites and pyroxenites. They differ from those already mentioned in containing chromite veins and segregations and in being cut by shear-zones along which they have been converted into talc or talc-carbonate rocks. Other ultra-basic intrusions in Uganda (Groves, 1935) and Kenya (Embu-Meru area, Schoeman, 1951, p. 17) often contain enough hypersthene to be classified as charnockitic rocks. The Kamuthengi rocks contain little orthopyroxene.

At Selukwe, Mashaba and Shabani in Southern Rhodesia (MacGregor, 1947, p. 10) there are ultra-basic intrusions which are considered to be pre-metamorphism in age. The rocks types are similar to those at Kamuthengi, but in Southern Rhodesia there are more serpentine, magnesite, and asbestos bodies. Also, at Shabani the serpentine has been silicified and is a blue and green colour while at Selukwe and Mashaba there are chromite and talc schists.

In north-western Scotland there are many small ultra-basic bosses of pre-metamorphic age emplaced in the Lewisian and Moinian rocks. They consist of olivine, tremolite, talc, chlorite, biotite and serpentine rocks, and include eclogites and epidiorites and are not similar to the ultra-basic rocks found at Kamuthengi. At Loch Torridon (Sutton and Watson, 1951, p. 248) in Sutherland the metamorphism of ultra-basic rocks intrusive into the Lewisian has produced zoned bodies, in some of which cores of unaltered original minerals remain. There is usually an outer zone of actinolite, which is sometimes rimmed by a thin sheath of biotite. At Scourie (*op. cit.* p. 269) ultra-basic rocks have been broken up, shredded, and converted into anthophyllite-chlorite-actinolite knots.

VI—METAMORPHISM

The bulk of the rocks of the area represent an originally sedimentary series that has been subjected to intense pressure, heat and granitization. The metamorphosed sediments are often banded, partly due to the preservation of original interbanding of argillaceous and arenaceous components and partly to preferential granitization along certain planes, giving quartzo-felspathic bands. As sillimanite has developed in pelitic beds it is obvious that the metamorphism was of a high grade, corresponding with the sillimanite zone of

Barrow (1912, p. 274). The temperature was probably high enough to cause recrystallization and to allow flow in the gneisses, although these phenomena probably occurred while the rocks were in a solid though plastic state.

On the metamorphic facies classification (e.g. Turner, 1949, p. 76) most of the rocks fall into the potash-sufficient section of the staurolite-kyanite sub-facies of the amphibolite facies, with the assemblage—

biotite-hornblende-plagioclase-microcline-quartz

and when more calcareous—

diopside-hornblende-plagioclase-microcline-quartz.

The sillimanite-almandine sub-facies of the amphibolite facies is also represented by the assemblage—

sillimanite-almandine-plagioclase-quartz-orthoclase.

All the gneisses now contain more felspar than is found in most sedimentary rocks, and it is considered that much of it must have been introduced, probably by granitization, but what form this process took is doubtful. From the even distribution of most of the felspar, it is judged that it was probably effected by quiet permeation, the formation of bands being due to segregation or preferential permeation along certain planes. Evidence for quiet introduction of material is found in the granitization series—

(*a*) homogeneous biotite gneiss;

(*b*) porphyroblastic gneiss;

(*c*) augen gneiss;

(*d*) banded gneiss;

the members of which represent stages of increasing intensity of granitization. The permeation may have been by aqueous liquors or by ionic diffusion through the solid rock, reaction with the host minerals leading to the formation of alkali felspars. During the process recrystallization in some cases removed the effects of earlier shearing stress imposing granitoid, textures on the rocks. Granitization did not effect the calcareous rocks except marginally and along impure bands, probably because on the whole they remained compact, which suggests that granitization was more probably the action of liquors rather than of solid diffusion.

VII—STRUCTURES

The area has in parts complex structures due to the superimposition of minor folds and contortions on the major folds. The dips of foliation are high, averaging about 60°, and strikes are in general essentially conformable with the regional roughly north-south strike.

Faults.—In the south-west there is a fairly regular north-south strike with a prevalent easterly dip which changes abruptly in the north to a north-east-south-west strike with north-westerly dip (Fig. 4). Because of this abrupt change it is considered that there is probably a fault between the two blocks of country with differing strikes. No fault was seen on the ground but a line has been inserted on the map just north of Tia and Myethani as the most probable site of a fracture. The rocks on the high ground between Uumaa and Endui and between Kyui and Wemanzi have opposing dips, which suggests the presence of a broad syncline or fault. Because of the sudden change of attitude of the rocks between Endui, where they are well-banded and regular with a north-south strike and Wamwathi where the rocks are more closely folded with north-east—south-west strike, it appears likely that the structure is, in fact, a fault. It will probably run along the eastern foot of the ridges between Uumaa and Endui, which form a remarkably straight and sharp feature. The nature and throw of the postulated fault are unknown though it must have a throw of less than 1,500 ft., as can be deduced from the relation of the peneplains on either side of it.

Along the Mwanya valley, south of Ngeani, the Endui ridge and the Mutuangombe-Endui fault have been displaced by a tranverse fault-zone in which there is a series of minor faults.

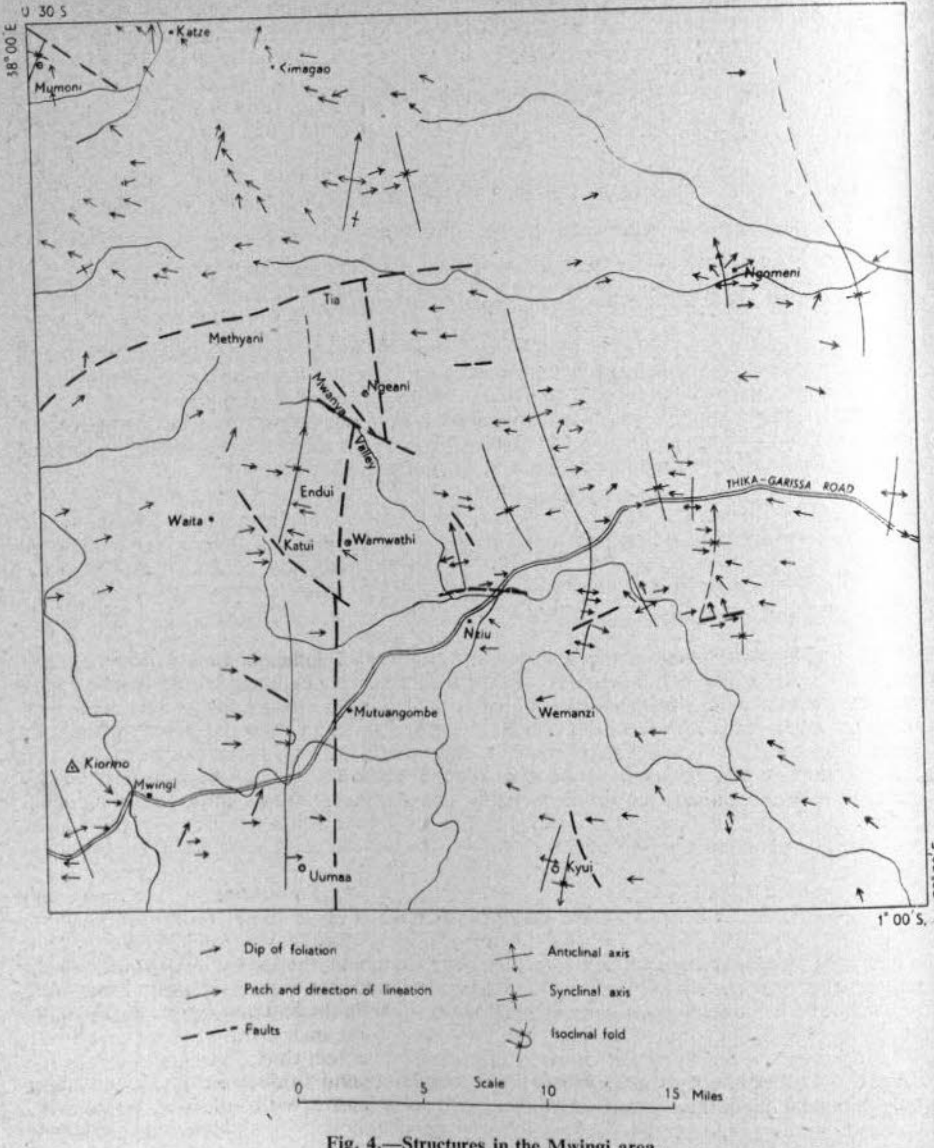


Fig. 4.—Structures in the Mwingi area.

Dip faults are common in all parts of the area and run north-west to south-east with dextral displacement, i.e. the blocks of country north of the faults have moved south-eastwards. One exception to this is in the Mumoni hills where the northern block has moved westwards. A conjectural fault north of Nzui has been inserted on the map because of the sudden reversal of dip along the strike. No evidence was found to indicate the nature of the faults or their throws or displacements.

Folds.—South-west of Kiormo there is an anticline with a north-north-west trend. West of Endui converging bands and opposed dips outline a northward-pitching syncline. After converging closely near Katui the marker bands continue parallel, with an easterly dip which is considered to mark overturning of the easterly limb, forming an isoclinal fold. Lack of symmetry in the beds on either side of the axis may be due to lensing out of the bands across the axis of the fold or to a strike fault in the axial region. From comparison with this fold and the general steepness of the dips, with some reversals, it appears probable that the area is composed of many successive isoclinal folds (c.f. Shackleton, 1946, pp. 26–27). The rocks of the Kyui-Wemanzi ridge dip generally west, but east of Kyui there is a tight southward-pitching syncline. It is well displayed by the convergence of hard ridges and is immediately succeeded westwards by an anticline. The axis of a large syncline lies just outside the western boundary of the area, and probably passes through Mumoni as shown on Fig. 4. The western flank of the fold has been demonstrated by Bear (1952, Fig. 1, p. 5).

Several other folds were detected in the area, but often they are only of short determinable strike length. They have dominant roughly north-south trends and pitch north at low angles.

Lineation was observed in the western portion of the area and, with one exception, had a pitch of about 25° along bearings of 20°. It was found in banded contorted biotite gneisses with linear segregation of the dark minerals on the foliation planes. The exception is near Kiormo in the south-west corner of the area, where the lineation pitches at 25° to the south-east.

VIII—ECONOMIC GEOLOGY

1. Basement System

The Basement System rocks in the area yielded no evidence of the presence of economically valuable minerals. Neither graphite nor kyanite were found, and the pegmatites proved to be little mineralized, containing in addition to quartz and felspar only sparse crystals of biotite, muscovite and titaniferous magnetite. Brief notes are given below on minerals found in the area.

(1) *Garnet* and *sillimanite* were found, but nowhere in sufficient quantity to warrant working. Search among the Mumoni hills may reveal bands of sillimanite-rich rock, but it is doubtful if they would be workable. Local concentrations of alluvial garnets may also be found in the same region.

(2) In the *limestone* bands there is often a large proportion of fairly pure marble, which appears, however, to have a variable magnesia content. The marble could be easily quarried and calcined to produce lime but there is no local demand and lime can be more profitably produced elsewhere nearer to railways and towns.

(3) Common minerals are more important in the area. E. Powell has worked ochre for *pigment* from a river basin infilled by Pleistocene ochreous clays south-west of Nziu. The ochre is limonitic (yellow ochre) but, on calcining, red and purple ochre and umber can be produced from it. Green pigments were obtained by using the green gypsiferous clays associated with the ochre. In 1945, the only year for which figures are available, the production of pigments was 1½ tons, valued at £375. *Gypsum* is disseminated through the clay and also irregularly distributed in thin veins about half an inch wide, which sometimes swell to several inches in thickness or even into lenses a few feet thick, but it would not be economical to work. Pulfrey (unpublished report, 1946) found similar deposits south-west of Mutuangombe, and many more of the shallow valley basins with black soils probably contain gypsum and ochre.

2. Ultra-basic Intrusions

Economic minerals are commonly found in ultra-basic intrusions similar to those of Kamuthengi, and include magnesite, asbestos, corundum, vermiculite, chromite, talc, serpentine, mica and in some cases nickel, copper and the platinum minerals. The dunite of Kamuthengi and the neighbouring intrusions apparently does not contain these minerals in sufficient quantities to be commercially interesting. Further prospecting by pitting and trenching might, however, reveal economic quantities of magnesite or asbestos.

(1) *Magnesite* veins the dunites but as estimated from surface exposures the amount available is small and not sufficient to warrant working. Associated with the magnesite there are segregations of an earthy valueless serpentine.

(2) A horizontal lens of *anthophyllite asbestos* was found in the eastern part of Kamuthengi, but is only about fifteen inches in thickness and five yards in strike length. No indication of other asbestos veins was seen.

3. Superficial Deposits

(1) White *sand* suitable for concrete manufacture is found in the dry river-beds, notably those of the rivers Tyaa, Katze and Nziu. Local demand is small.

(2) *Road-metal* in the form of lateritic earths is only found in small isolated lenses and bands and consequently is little used. Nearby decomposed rock and fine-grained gravels that lie on them are most commonly used for road making.

(3) No satisfactory *building stone* occurs in the area and buildings are made from imported concrete blocks or from locally kiln-burnt and sun-dried bricks. Valley soils are commonly used for the manufacture of the bricks. At Katze, by the Kamuwongo borehole, and where the Nairobi-Garissa road crosses the river Kanginga near Mwingi there are brick-pits. The bricks are sun-dried for one day, then built into a clamp which is then fired for about ten days. The resultant bricks are hard, even-grained and compact. The pit at Katze is continuously used and produces about 12,000 bricks a month.

4. Alleged Coal Deposits

From time to time samples of bituminous coal have been brought in from the Mwingi area. During the course of the survey a prospector became interested in specimens submitted to him by Africans and attempted to discover coal deposits. A visit was paid to localities near Twanagau in his company and that of an African guide who stated he had found the coal, but neither coal nor indications of it were seen. On geological grounds it is most unlikely that coal deposits would be found in the Mwingi area and it is considered that the specimens recovered there are the remains of consignments of coal taken into the area during the 1939-1945 war.

5. Water

(1) Surface Water

The procurement of water in the dry northern and eastern part of the Kamba Native Reserve presents a difficult problem. During the rains and for a few weeks afterwards in the present area there is surface water in the rivers Tyaa and Katze and in a few low-lying basins. The only perennial natural water is found in the Mumoni hills in the headwaters of the rivers Mwengo and Ndatha, and in a spring at the base of Etinda. During the dry season water is obtained from wells, pits and bore-holes or from small catchment dams.

The Local Native Council has constructed 23 small earth dams at the time of writing, with an average capacity of about two million gallons. Trouble has been caused by porosity of the floors of the reservoirs and by the bursting of the dams during heavy rains because of inadequate spillways. The porosity is gradually annulled by the settling of fine suspended mud into the pores of the soil on the floors of the reservoirs making them water-tight.

(2) Ground-Water

Ground-water occurs in the area in the lower part of the zone of weathering, the base of which forms an uneven surface roughly reflecting the topography. Water flows down this surface and accumulates in its hollows and in valleys. The Africans tap the water in the valleys by digging pits up to 30 ft. deep in the dry river-beds, and by using concrete-lined wells sunk by the Local Native Council alongside river-courses. Large resources of water can be expected where there are natural channels and storage basins in the weathered zone, such as are formed where barriers of unweathered rock cross otherwise deeply weathered valleys.

Bore-holes that penetrate below the zone of weathering can hope to tap water only if they strike permeable bands, such as fracture zones, planes of discontinuity, etc. The following list, supplied by the Hydraulic Branch of the Public Works Department enumerates the bore-holes in the Mwingi area and their productivity:

Bore-hole Number	Locality	Date completed	Depth (feet)	Water struck at (feet)	Rest-level	Yield (galls./day)
96	Mwingi	1930	297	163	154	960
C.104	Mwingi	1940	297	?	27	4,560
SA. 56	Mati R.	1940	253	—	—	Nil
SA.92	N. of Gai	1941	156	—	—	Nil
C.696	Gai No. 1	1948	534	250	220	2,880
C.1583	Gai No. 2	1951	301	148	123	3,480
C.134	Tumboni	1940	275	168	168	600
C.573	Waita No. 1	1947	500	66	158	1,920
C.617	Waita No. 2	1947	435	140; 425	120	7,200
C.919	Ngomeni	1949	308	170; 250	150	14,760

The sites of the bore-holes have in most cases been inserted on the map from geographical co-ordinates supplied by the Hydraulic Branch, and should be regarded as only approximate.

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GEOLOGICAL MAP OF THE MWINGI AREA