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**MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES**

**MINES AND GEOLOGICAL DEPARTMENT**

# GEOLOGY

OF THE

# KITUI AREA

DEGREE SHEET 53, N.W. QUARDRANT

(with colored geological map)

**by**

**L.D. SANDERS, B.Sc.**

**Geologist**

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# FOREWORD

Mr. Sanders' report on the geology of the area east of Kitui, which for convenience is referred to as the Kitui area, extends the work begun in 1946 by J. J. Schoeman in the area west of Kitui (Report No. 14). The work has been made possible by the aid of a grant from the Colonial Development and Welfare Vote. Further quarter-degree sheets have been mapped both north and south of the area dealt with in the present report and accounts of the geology will become available in due course.

During his mapping Mr. Sanders proved two different styles of tectonics on either side of a large fault separating the higher ground nearer Kitui from the generally lower ground in the eastern two-thirds of the area. Near Kitui the ancient rocks that form the country are part of a broad major fold that extends westwards into the adjoining area, the axis being a belt of intense granitization. East of the fault, folding—as expressed in the Nuu and Mgongo monadnocks—is more acute and discontinuous. It is in these folds that Mr. Sanders has discovered extensive horizons carrying the alumino-silicate mineral, sillimanite. Though it appears unlikely that at present they will have economic significance, they may in the future provide a valuable reserve of refractory materials.

In 1950 a seam of lignite was discovered by a prospector in a well at Mui in the north-central part of the area, and during the course of his survey Mr. Sanders devoted considerable attention to mapping the prospect and examining drill cores. The lignite, of which three seams were proved, is unfortunately present as thin bands only, and lies 30 or more feet below the surface beneath river sands and gravels and among plastic clays that move readily when wetted. Under such conditions, the lignite cannot be considered to have economic possibilities. The occurrence, however, is a pointer to conditions that obtained in central Kenya during Pleistocene times, and other large wide valleys, where damming might have occurred with the formation of lakes in which vegetable matter could accumulate, might well be prospected for low-grade fuels.

Details of other mineral occurrences in the area are given, as well as a detailed account of all the rocks seen and their manner of formation.

Nairobi,
19th August, 1952.

WILLIAM PULFREY,
*Chief Geologist.*

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## MAP


Geological Map of the Kitui area (Degree Sheet 53., N.W. quadrant) Scale 1:125.000 At end

# ABSTRACT

The report describes an area of about 1,250 square miles in central Kenya some 90 miles due east of Nairobi, bounded by latitudes 1° 00′ and 1° 30′ S. and longitudes 38° 00′ and 38° 30′ E. Physiographically the area may be divided into three major units (*a*) the Kitui hills in the west, where much-reduced remnants of an older erosion cycle stand above the deeply dissected sub-Miocene peneplain, (*b*) the extensive comparatively flat end-Tertiary peneplain in the east, and (*c*) the hill groups of Nuu and Magongo, which rise from the end-Tertiary peneplain to summit heights concordant with that of the sub-Miocene erosion surface.

The rocks exposed in the area consist almost entirely of folded Basement System gneisses and migmatites of Archæan age, which include metamorphosed sedimentary rocks comprising crystalline limestones, calc-silicate granulites, garnet and sillimanite gneisses, and graphitic gneisses. These are accompanied by minor amphibolites, charnockites, and peridotites. The gneisses that display a recognizable sedimentary structural pattern have been intensely metamorphosed and have widely developed the high-grade index mineral sillimanite. Many of the crystalline gneisses approach the composition of granite but there are no granites of batholitic dimensions.

Post-Archæan rocks are restricted to (*a*) a pocket of Pleistocene sediments which occurs in the north, and includes sands, clays and lignite, (*b*) a superficial cover of Recent sands and brown earths which, together with subsidiary lateritic ironstones and concretionary secondary limestones, thinly mantle the Basement System rocks, and (*c*) a group of intermediate and basic dykes which cut Basement System rocks in the east.

A detailed account of the petrography of the rocks is given and their structure, metamorphism and tectonics discussed.

Investigations of occurrences of economic minerals of actual or potential value, particularly sillimanite and lignite, are described, and the water supply of the district is reviewed.

# GEOLOGY OF THE KITUI AREA

## I—INTRODUCTION AND GENERAL INFORMATION

A geological reconnaissance of the north-west quadrant of degree sheet 53 (Kenya Colony) was made between the months of November, 1950, and July, 1951. The area is bounded by latitudes 1° 00′ and 1° 30′ S. and longitudes 38° 00′ and 38° 30′ E., having an area of approximately 1,250 square miles.

The object of the survey was to assess the possibility of the existence of mineral deposits of economic value in the ancient metamorphic and granitoid rocks which, together with pegmatites, compose the greater part of the area. Interest was particularly stimulated by the reported presence of lignite near Mui, which is situated in the north-central part of the area. In October, 1950, an Exclusive Prospecting Licence was issued to a private individual on his undertaking to explore and develop this occurrence, which was also subsequently investigated by Government geologists. Further exploration was continued during the period of the survey, during which time trial borings were made, but subsequent results were discouraging.

*Maps.*—The topography of the geological map is based on air-photographs having a scale of approximately 1:38,000, for which the flight-runs were made in the early part of 1948. For map production these were controlled by a plane-table survey of the area based on Survey of Kenya Main Triangulation Chart No. 284D and Tertiary Triangulation Chart No. 10. Most place-names and some form-lines were taken from the Kitui Sheet, Africa South $\frac{\text{A-37}}{\text{I}}$ (1:250,000), published by the Ordnance Survey in 1912, and the Garissa Sheet, S.A. 372 (1:500,000), published by the East African Army Survey Group in 1940. Much of the topographical detail on these maps was found to be approximate and had to be considerably modified for use on the geological map.

Both the configuration and vertical interval of form-lines are approximate only, since they are controlled by barometric spot-heights.

Throughout the work geological data was plotted on air-photographs and subsequently transferred to a kodatrace overlay on the same scale, ultimate reduction to a suitable scale for printing being made by ideograph.

*Nature of the Country, Climate, Vegetation and Population.*—The area lies in the Central Province of Kenya Colony and falls entirely within the boundaries of the Kitui Native Reserve, which is administered from Kitui, situated at the western margin of the map. Kitui stands on a low spur at the south-western end of a group of hills which rise to over 5,000 ft. The township itself lies at an altitude of rather more than 3,800 ft. and consists of administration offices, a post office, Government school, and hospital, near to which are grouped the houses of Government officials. There is also a native market and trading centre.

The distribution of the tribal *Wakamba* population, and the character of the vegetation and cultivation, is strongly influenced by local variation in the annual rainfall, which in turn is largely determined by the physiography. The western hilly districts around Kitui naturally support the densest native population. Kitui Township receives an average annual rainfall of 41.27 in., and much of the higher country to the north receives a similar rainfall, which is concentrated in the months of April to May, and November to December. Whilst insufficient to permit easy husbandry

owing to excessive run-off and high rates of evaporation, this enables the planting of maize, beans, millet, cassava and sisal, whilst plantains and sugar-cane are grown close to the smaller watercourses. The mango flourishes in groves near to Kitui, and tobacco is produced locally on a commercial scale. Deforestation as a result of shifting tribal cultivation is almost complete, but some of the higher ridges are capped by indigenous trees including podo, brown olive, mvuli, and cape chestnut, and these have been supplemented by recent planting.

The low-lying, comparatively flat, tropical bushland, which extends from the Kitui hills eastwards to the Tana River, and is generally less than 2,400 ft. above sea-level, receives an annual rainfall of less than 30 in. and is notably warmer than the western part of the district. A combination of high temperature and low rainfall renders cultivation difficult, and the greater part of the area is covered with *Aristida* grasses, and stunted thorn bush mainly composed of species of *Acacia* and *Commiphora* together with occasional *Baobab*. The thorn scrub is seldom sufficiently open to permit free penetration on foot, especially when secondary ground-bush is well developed after seasonal rains, but native footpaths and game trails give reasonable access. The population is sparse, and stock-grazing is the main occupation of the inhabitants, although maize and millet are cultivated near the principal centres of settlement. Large tracts of country in the eastern and south-eastern parts of the area are uninhabited.

Isolated hills which rise sharply from the surrounding peneplain are densely bush-clad, and like the higher ridges of the Kitui hills produce a local increase in precipitation and support mist forest at their summits, which, during the rainy season are frequently enveloped in cloud.

Animal life of the district consists mainly of bush buck and baboons. Elephant move through the eastern parts of the area, and occasional leopard, giraffe, and buffalo are seen. Vulturine guinea-fowl are plentiful, whilst francolin, sand grouse, snipe, and lesser bustard are fairly common.

*Communications.*—A moderately good earth road links Kitui with the nearest railhead at Thika 90 miles distant, whilst a second, but inferior, road meets the Nairobi–Mombasa railway at Kibwezi, 94 miles from Kitui. Earth roads within the area are maintained in fair condition during the dry season, but may become locally impassable during heavy rain. The northern part of the area is best approached directly from the Mwingi–Garissa road which runs from east to west about 12 miles outside the northern boundary, and from which two secondary roads extend to Mui and Nuu respectively. The southern part is served via Kitui, whence a location road extends to Zombe and Nuu via Endau, crossing the Thowa River by means of a steel and concrete bridge at Inyuu. A further road follows the Ikoo valley between Mui and Zombe, but this is frequently rendered difficult during the rains by a wide river-crossing at Ikoo.

*Surface Exposures.*—Rock formations are well exposed in the west, where active seasonal streams have cut deep gorges showing almost uninterrupted successions in the metamorphic rocks. The intervening ridges are frequently sharp and craggy, but their rocks are generally deeply weathered.

Excellent exposures are also to be found in the Nuu hills, and on Magongo, but over much of the eastern peneplain the gathering of geological information is dependent on poor and infrequent outcrops in sand-choked stream beds, and on rock fragments scattered in the surface soils.

*Acknowledgments.*—Thanks are due to the administrative officers of the district for assistance during the survey, and in addition to Mr. E. O'Connor, Education Officer, Kitui, and Mr. J. Lyme-Watt (East African Tobacco Company), for their hospitality. The assistant of Mr. P. R. O. Bally, Botanist at the Coryndon Museum, Nairobi, in the identification of fossils is gratefully acknowledged.

## II—PREVIOUS GEOLOGICAL WORK

Probably the earliest geological reference to the Kitui district is that of the Rev. J. L. Krapf, who entered the area in 1849 and again in 1851, on each occasion making a foot safari from the coast. The presence of ironstone led him to observe that "The more precious metals have not yet been found in Ukambani; but there is an abundance of iron of excellent quality which is preferred by the people of Mombaz to that which comes from India". (Krapf, 1860, p. 358.)*

Half a century later a Government geologist traversed the western margin of the area, and as well as noting many exposures of gneiss and cellular ironstone remarked on the gradations between relatively pure crystalline limestone and garnet-pyroxene rock (Walker, 1903, p. 4).

In 1907, K. Joll, Government mining expert, panned the Thowa River between Kitui and Mutito, and obtained a concentrate of iron sand with no trace of gold, and also commented on the presence of hornblendic gneiss in the Kitui hills (letter to the Commissioner of Mines, 3/8/1907). Prior to this it seems that C. W. Hobley passed through or near to the area following on the Dundas expedition up the Tana River (MacDermott, 1893, p. 411), but his geological observations were presumably not published until some years later when they appear in an ethnological work. He remarks that "One finds a series of granitic gneissose mountain ranges all running approximately north and south, having an altitude varying from 5,000 to 7,000 ft., and rising about 2,000 to 3,000 ft. above the normal level of the country. These ranges are the crest of ancient earth folds, and great thrust faults are nearly always traceable on either the east or west side of the ranges" (Hobley, 1910, p. 3).

Later A. M. Champion traced the Thowa River to a point about 18 miles west of the Tana, where it lost itself in the plain, and during his journey noted granite gneisses and banded gneisses. He also postulated horizontally disposed Basement System rocks underlying thick sand deposits near the south-eastern corner of the area, and mentioned the finding of phonolite blocks similar to fragments he had seen north-east of Endau (Champion, 1912, p. 13). These were possibly dyke rocks.

In 1934 and 1935, safaris were made through the district by W. D. Harverson, and notes were made on the rocks between Nuu and Endau. A further geological reconnaissance of Kitui district was made by W. Pulfrey, Government Geologist, as part of a larger survey in 1942. The results of this reconnaissance are embodied in an unpublished report filed in the Mines and Geological Department, Nairobi.

Subsequently in 1948, A. O. Thompson, then geologist in a hydraulic section of the Public Works Department, carried out resistivity tests around Mui in an attempt to choose a well site. Later, in 1950, D. K. Hamilton (E.C.A. Geologist) accompanied by Thompson, investigated the lignite prospect at Mui, and their joint observations were included in a confidential report (51/A/3).

## III—PHYSIOGRAPHY

### (1) Topographical Features

The configuration of the western half of the area is strongly influenced by the geology, and consists essentially of a series of parallel north–south trending ridges, rising to heights of between 4,800 and 5,400 ft., which form the Kitui hills. The highest summits are those of Mtunguni (5,383 ft.), Mutito (5,205 ft.) and Kamitotia (4,980 ft.). This belt of deeply dissected hill-country displays a ribbed topography typical of that produced by the erosion of a para-gneiss succession, the more resistant granitoid rocks forming sharp ridge features, which alternate with parallel valleys eroded in the softer members of the series.

* References are quoted on p. 52.

Approximately ten miles east of Kitui there is a rapid descent to an undulating plain which has a gentle gradient to the south-east. Planation is imperfect over most of this area, the larger interfluves rising gently to more than 100 ft. above the main rivers, but eastwards the undulation is reduced, and outside the area an almost perfectly flat plain stretches towards the Tana River. East of the Kitui hills a considerable escarpment, which is apparently continued outside the confines of the area, overlooks the comparatively low plains. When viewed from the east it can be observed stretching from the vicinity of Gai in the north towards Kandziko (Kanziku) in the south, a distance of over 90 miles. It reaches its maximum height of 2,700 ft. above the plain at Mutito, and elsewhere though considerably reduced in height is nonetheless a prominent topographical feature. The monotony of the flat plainland is broken by isolated groups of hills which rise to altitudes of rather less than 5,000 ft. and are accompanied by outlying inselbergs. The principal hills of this type are those of Magongo and Nuu. Here, as in the Kitui hills, the disposition of geological formations strongly influences topography, but the Basement System rocks lack the same uniformity of structure, and sweeping structural arcuations tend to produce *domes* and *arenas* rather than a ribbed pattern.

### (2) Drainage

The distribution of drainage is determined by the watershed of the Kitui hills which form an axis between the south-westerly trending tributaries of the Tiva and those of the main watercourses passing through the area, the Thowa and Ikoo. The Thowa leaves the area in the south and thence trends eastwards towards the Tana, but eventually peters out in the semi-desert plainlands. In the extreme north and east drainage is northwards to the Nzui, which ultimately joins the Thowa outside the area, whilst the Tyaa leaves the north-western corner, and flows north-westwards towards the Tana.

The western half of the area is dissected by a trellised drainage pattern in which secondary tributaries of the Thowa and Ikoo are deeply entrenched parallel to the prevailing strike, and follow the softer members of a contrasting series of metamorphic rocks. The land surface here has reached a stage of maturity with maximum amplitude between the crests of ridges and their intervening narrow valley floors, which are incised to a depth of several hundred feet. Many of the minor stream profiles remain in a stage of youth, and are characterized by highly irregular gradients accompanied by falls and rapids. On reaching the eastern plains the main streams assume gentle gradients and broaden into sand-rivers in which lateral erosion dominates. The lower courses of the Ikoo and Thowa build sand-bars and develop braided channels.

Most streams within the area only carry flowing water for a few weeks during each rainy season, when they may become torrents for short periods. With the cessation of seasonal rain they rapidly dry up, but during the dry seasons water can usually be found by digging in their sand beds to a depth of a few feet.

### (3) Physiographical Evolution, Erosion Surfaces, and Tectonic Influences

At some unknown period after their formation the regionally metamorphosed rocks of the Basement System were uplifted and during an epoch of stability which probably lasted until the Cretaceous period, were subjected to a long period of erosion, culminating in final reduction to a peneplain. Remnants of this erosion surface have been recognized outside the present area in the summits of the Matthews range, the Karissa hills, and the Loldaika hills (Shackleton, 1946, p. 2), and elsewhere in Kenya at Mt. Nyiro, Machakos, and Kitale (Dixey, 1948, p. 26), in each of which an erosion level is identified at altitudes varying between 6,000 and 7,500 ft. above sea-level.

In the present area the highest hills reach an altitude of more than 5,000 ft. and probably represent much-reduced residuals of the old high-level peneplain referred to above (Fig. 1). In the west the hills stand above a lower and much-dissected erosion surface of elevation varying between 3,800 and 4,000 ft. This slopes gently westwards beneath the Yatta phonolite flow approximately 20 miles distant from Kitui (Schoeman, 1948,. p. 3). Planation of this surface was probably completed in immediate pre-Miocene times, and it is correlated with surfaces of similar altitude and of great extent and perfection in the Northern Province of Kenya, and in Uganda, southern Abyssinia, and Tanganyika Territory. It has been referred to widely as the Miocene or mid-Tertiary peneplain but in western Kenya it has been dated as sub-Miocene (Shackleton, 1946, p. 27).

The eastern half of the area is occupied by a lower erosion surface between 2,400 and 2,100 ft. in altitude, with a gradual easterly and south-easterly gradient. This younger surface is relatively immature, and locally rises towards the remnants of an older surface which is represented by isolated groups of hills. It forms part of the great end-Tertiary plain of eastern Kenya and the Northern Province, where it bevels both Basement System rocks and Tertiary sediments alike. The residual masses which stand on the end-Tertiary plain, notably Magongo, and the Nuu hills, reach altitudes of approximately 4,500 ft. and probably represent relics of the sub-Miocene surface.

The Mutito escarpment, which separates the sub-Miocene surface in the west from the end-Tertiary plain in the east, is a fault-line scarp produced by differential erosion on opposite sides of an Archæan tectonic feature. Some rejuvenation of movement on this axis probably took place in lower or middle Pleistocene times and presumably brought about the gentle westward tilt of the sub-Miocene surface. In a zone between Kitui Township and Mutito summit most watercourses are still obviously in their infancy, and yet are entrenched in a mature landscape with maximum amplitude between hill crests and valley bottoms. Such an effect is typical of that produced by the uplift of an area already dissected by an earlier but uncompleted erosion cycle.

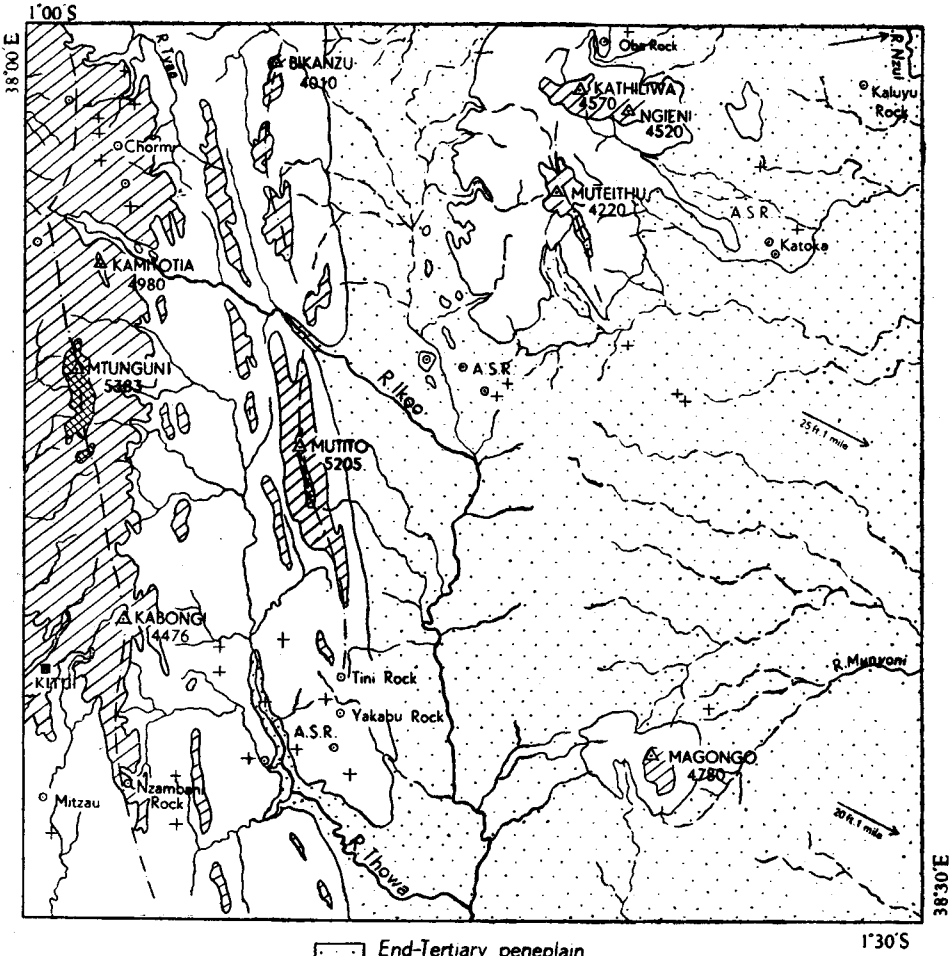
Faulting also influences the physiography in the north-western part of the area, and has produced a line of weakness transverse to the grain of the Kitui hills, and along which the Ikoo has incised a deep gorge. The chief summits of the Kitui hills are all grouped within five miles of the southern boundary of this fault-zone, and stand more than 1,000 ft. higher than the hills and ridges on its northern side, which conform closely to a sub-Miocene surface level of rather more than 4,000 ft.

### (4) Inselbergs and Pediplanation

Inselbergs, or bornhardts as they are sometimes called, occur widely within the area but only a few are developed to near perfection. The best examples are Nzambani rock, situated approximately four miles south-east of Kitui, Tini rock, five miles north-west of Zombe, and Oba rock, four miles north-west of Nuu. These enormous residuals are oval in plan, with major axes parallel to the regional strike. Their nearly vertical, smooth, comparatively unjointed rock walls, evenly rounded summits, and lack of vegetation, make them conspicuous landmarks.

Numerous tors, bald crags, and whalebacks, which, like the inselbergs, stand as isolated erosion residuals, are scattered throughout the area, but unlike the larger and more perfect examples they are strongly jointed, and this, more than any other factor, contributes to their rapid reduction under sub-aerial weathering.

The inselbergs are naturally preferentially developed in resistant, comparatively homogeneous and steeply dipping rocks, but they are not by any means restricted to a particular rock-type, and have been noted in granitoid gneiss, banded biotite gneiss, and hornblende migmatite. The majority stand on rock platforms, or pediments, which slope gently away from the foot of the rock wall. The pediments are sometimes mantled




End-Tertiary peneplain (2000–2500 feet, O.D.)

Post-Miocene dissection

Sub-Miocene or mid-Tertiary peneplain (3800–4000 feet, O.D.)

Relic end-Cretaceous peneplain (over 5000 feet, O.D.)

Main watersheds

General direction of slope of peneplains

Major inselbergs (over 150 ft high)

Minor inselbergs (over 50 ft high)

A.S.R. Areas of scarp retreat

Scale

5 0 5 10 MILES

**Fig. 1—Physiographical map of the Kitui area**

with exfoliation debris and at others stripped of superficial cover, and are generally convex in profile. The rock floors which foot the main escarpments within the area also tend to be convex, although the true profile is frequently obscured by superficial cover which thickens towards the scarp faces.

The production of pediments is considered to be characteristic of scarp retreat produced by lateral erosion under dry climatic conditions. During the operation of this process inselbergs remain standing on the pedimented floor as residuals of the retreating scarps, and subsequently become reduced to plain level during a late stage of the pedimentation cycle (King, 1948, p. 87). In the present area, inselbergs developed on the end-Tertiary surface occur peripherally to the main groups of residual hills. The close association between the two is striking; in nearly all instances the largest inselbergs occur within one or two miles of steep-sided hill features (*see* Fig. 1). No inselbergs were noted in localities completely remote from hills, nor were any observed in the vast plainlands between Kitui and the Tana River apart from those standing close to hills.

Inselbergs which stand on the sub-Miocene surface in the west are also clearly related to the hills between Kitui and Migwani and, like those of the end-Tertiary surface, represent the relics of a pediplanation cycle.

The physiographical features of the area therefore indicate that lateral erosion has played a considerable part in the production of the landscape, and during recent geological time may have dominated over vertical lowering of the land surface under river action, although this latter process was possibly the more active during humid periods.

## IV—SUMMARY OF GEOLOGY

The rocks of the area fall into four groups:—

1. Metamorphic rocks of the Basement System.
2. Lacustrine sediments of the Mui valley.
3. Superficial deposits of recent age.
4. Tertiary dyke intrusions.

### 1. The Basement System

The Basement System rocks in the area are gneisses, granulites, and schists including metamorphosed sediments as well as associated rocks of indeterminate origin, and are similar to Archæan rocks having a roughly north–south regional trend which have already been described from Kenya by Parkinson (1913, p. 534; 1947, p. 5), Shackleton (1946, p. 5), and Schoeman (1948, p. 12). They have close similarities to rocks of the Lower Basement Complex of Tanganyika referred to by Temperley (1938, p. 15; 1942), and Stockley (1939, p. 8; 1948, p. 12). These folded and granitized rocks, for which Stockley (1943, p. 161) has proposed the term Basement System, extend southwards into Mozambique from parts of which they have also been described by Holmes (1918), and there as well as in Kenya and Tanganyika, they possess petrographical and structural characteristics which were apparently produced during a common orogenic cycle.

The regionally metamorphosed rocks of undoubted sedimentary origin occur as crystalline limestones, graphitic gneisses, sillimanite gneisses, and quartzites. Much of the garnetiferous biotite gneiss which accompanies them is also probably of sedimentary derivation. Kyanite gneiss, which is a commonly developed metamorphosed sedimentary rock in some parts of the Kenya Basement System, is only of very rare occurrence in the present area. Biotite gneisses and quartz-felspar granulites are interstratified on a large scale with the above-mentioned rocks to complete the sedimentary series, throughout which granitization processes have locally contributed to the obliteration of original sedimentary fabrics. Relics which have survived granitization, however, often occur in the form of quartz-sillimanite knots, calc-silicate granulitic nodules, and almandine garnet banding.

Finally there are considerable areas of intensely migmatized rocks which approach a granitic composition, but they are frequently not entirely homogeneous, and retain dark streaks and lenses of ferromagnesian minerals. Hornblendic migmatites are also locally developed and show acute contortion indicative of plastic flow, and intimate injection with quartzo-felspathic material, which unlike that of the non-hornblendic migmatites does not approach the composition of granite.

Dark, compact, basic and ultrabasic rocks of the charnockite series occur in the gneisses and migmatites as attenuated lenticular bodies of no great individual extent.

The metamorphosed sedimentary rocks are located in fairly regular belts, which, in the western part of the area, strike steadily in a north-north-westerly direction, and occupy the eastern limb of a large anticline having a migmatite core in which regularity of foliation is lost. The axis of this anticline lies close to the western margin of the area, in the vicinity of Kitui, and continues north-westwards outside the confines of the present area (Schoeman, 1948, p. 40). The steady strikes and comparatively uniform easterly dips in this segment of the Basement System contrast with the structures in the eastern half of the area where large, open, monoclinal or isoclinal, pitching folds produce arcuate outcrop patterns. Here the metamorphosed sedimentary rocks are of stratiform disposition within the limbs of the folds, but blend into migmatites which are localized in the anticlinal cores, and frequently contain relic sillimanite bodies showing progressive dissolution into aggregates of secondary sericite. Linear elements within the gneisses indicate that the folds pitch at angles varying between 10° and 30°, which are notably higher than those recorded in the west, where pitch culminations and depressions comparable to those in the eastern part of the area are lacking, and most lineations are either horizontal or of gentle northerly pitch.

Where formation boundaries of the undoubted metamorphosed sediments can be plotted with accuracy over any distance, the foliation in the associated biotite gneisses and granulites closely parallels planes of lithological discontinuity, and appears to be coincident with the original stratification. The parallelism of foliation and original bedding applies to most of the area, except at the noses of folds where, however, a superposed axial-plane foliation has not entirely obliterated a weakly defined bedding foliation.

### 2. Lacustrine Sediments of the Mui Valley

A group of sands, clays, carbonaceous marcasite clays, thin shales and lignites of Pleistocene age, which have been proved locally to a depth of 420 ft., occupy a narrow sedimentary pocket in the valley of the Mui River. Apart from the upper beds of the succession, which to a depth of 30 or 40 ft. consist of unconformable river sands and gravels, the sediments represent a deposit of argillaceous material showing a rhythmic variation in carbon content. The more carbonaceous clays contain marcasite nodules and thin sporadically developed lignite. Thin nodular cherts have yielded plant remains.

These sediments were evidently deposited from the waters of a lake which owed its origin to tectonic movements (*see* Structures, p. 41).

### 3. Superficial Deposits of Recent Age

The Basement System rocks are thinly mantled with red and brown sandy residual soils, which tend to be lateritic and locally develop a surface crust of cellular ironstone or *kunkar* limestone. Over much of the area chemical action dominates over mechanical processes of erosion in the production of soil, variations in the character of which are frequently a reflection of the contrasting nature of the underlying rocks. Where the altitude exceeds 4,000 ft, and vegetation is comparatively heavy, dark soils are formed, but generally the peneplain soils are rich in ferric oxide and poor in humus. Dark clay soils are rare but occur in small areas of stagnant drainage.

### 4. Dyke Instrusions

A series of Tertiary dykes having almost vertical contacts extends in a north-north-westerly direction through the eastern part of the area. They vary in thickness from three to 50 ft., and are mainly pink- or buff-weathering porphyritic trachytes, the advanced alteration of which makes classification difficult.

In the south, between Endau and Magongo, dark compact fine-grained lamprophyres occur together with the trachytic dykes.

## V—DETAILS OF GEOLOGY

### 1. The Basement System

The rocks of the Basement System may be classified into the following groups for purposes of description:—

(1) Metamorphosed calcareous sediments—
- (*a*) crystalline limestone;
- (*b*) calc-silicate granulite and gneiss;
- (*c*) talc-actinolite schist.

(2) Metamorphosed pelitic sediments—
- (*a*) sillimanite para-gneiss and granulite;
- (*b*) biotite gneiss with quartz-sillimanite *faserkiesel*;
- (*c*) pseudo-sillimanite gneiss;
- (*d*) garnetiferous para-gneiss and granulite;
- (*e*) graphitic gneiss;
- (*f*) albite-oligoclase porphyroblast gneiss.

(3) Metamorphosed semi-pelitic sediments—
biotite gneiss and granulite.

(4) Metamorphosed psammitic sediments—
- (*a*) quartz-felspar-biotite para-granulite;
- (*b*) quartz-felspar para-granulite;
- (*c*) quartzite and muscovite-quartzite.

(5) Migmatites—
- (*a*) hornblendic migmatites; hornblend gneiss (part), amphibolite and plagioclase-amphibolite (part);
- (*b*) granitic migmatites (microcline-oligoclase biotite-hornblende gneisses).

(6) *Anatectic or palingenetic rocks—
- (*a*) granitoid gneiss;
- (*b*) pegmatite.

(7) Metamorphosed extrusive and intrusive rocks—
- (*a*) hornblende gneiss (part);
- (*b*) meta-gabbro;
- (*c*) amphibolite (part);
- (*d*) charnockitic rocks (perknites);
- (*e*) norite;
- (*f*) peridotite.

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* The term *anatectic* is here applied to granitoid rocks whose composition has been produced by the soaking of "emanations" into metamorphosed sedimentary and igneous rocks. Fluids entering into this process need not necessarily be of magmatitic origin and may represent those present in the original rock. The process is effectively one of alkaline metasomatism.

*Palingenetic* rocks are those produced by a culmination of anatexis, whereby granitic magma is ultimately generated and emplaced at higher crustal levels.

### (1) Metamorphosed Calcareous Sediments

The metamorphosed calcareous sediments occur as three closely related rock types; (*a*) crystalline limestones; (*b*) calc-silicate granulites and gneisses; and (*c*) talc-actinolite schists.

#### (*a*) *Crystalline Limestones*

The limestones are grey to white, rarely pink, and coarsely crystalline. The best exposures noted are in the south of the area, close to the Thowa, where one major and several minor bands strike slightly west of north and cross the road 400 yards west of Inyuu Bridge, whence they extend along the eastern flanks of Kimokomo to the southern margin of the area, a distance of approximately six miles. This zone may represent a continuation of limestones which have a similar strike in the Kandziko area, 30 miles to the south. Other exposures were noted four miles north-west of Zombe.

The limestone bands vary in thickness from one to 100 ft. Indicated dips are steep to the east, but contacts are obscure, stream exposures being frequently masked by cellular *kunkar* limestone, whilst outcrops between watercourses are smooth and well rounded, the surfaces displaying a fine rhombohedral etching. Protruding from the surfaces there are nodular, contorted, and sometimes ptygmatically folded bodies, representing siliceous inclusions in the original limestone which are now converted to calc-silicate aggregates. Fine banding within the limestone is a constant feature, and a reliable dip element. It is sometimes produced by concentrations in bands of either graphite or calc-silicates, the latter usually being epidote and diopside, and occasionally phlogopite. Blades of tremolite occur in specimen 53/329A*, taken from a thin limestone band half a mile due south of Inyuu Bridge, whilst an olivine-bearing specimen (53/34) was collected three miles east-south-east of Kimokomo.

The majority of thin sections of the limestones show coarsely sutured aggregates of calcite and dolomite, with rare silicates.

#### (*b*) *Calc-silicate Granulites and Gneisses*

These rocks are found as bands and lenses within the biotite gneisses, the lenses ranging from several yards in length to small isolated knots not more than two inches across (Plate III, Fig. 2). Some thin bands appear to extend for considerable distances and where sufficiently exposed can be employed as mappable horizons. Such rocks are frequently concentrated in the strike continuation of crystalline limestones where limestone itself is no longer present, and are associated with biotite-hornblende gneisses, amphibolites and garnet amphibolites. Dark-green calc-silicate inclusions, which are often nodular, but are sometimes banded, commonly occur within crystalline limestones (53/529N, 53/529M, 53/529), and are petrographically similar to calc-silicates within the gneisses. Reciprocally small inclusions of crystalline limestone, rarely more than a few inches across, occur within the larger calc-silicate exposures.

Calc-silicate rocks and crystalline limestones are petrographically and spatially related within the area, the former representing in the present area a granitization product of the latter. Originally impure limestones were probably more susceptible to this process than the pure members. Hornblendic gneisses and garnetiferous amphibolites within calc-silicate zones may represent a further stage in the migmatization of calcareous sediments, conversion of omphacitic pyroxene to hornblende being a common microscopic feature.

A broad north–south trending zone of calc-silicate rocks extends through the western half of the area and is well displayed in the broad Thowa valley, between Kimokomo and Yakubu Rock. Other notable exposures occur in a belt passing immediately east of Bikanzu, also in the upper Tyaa valley, and on the western flanks of the hills between Mui and Nuu.

* Numbers prefixed by 53/ refer to specimens in the Mining and Geological Department, Nairobi.

A granulitic texture is usually exhibited by these rocks, diopsidic pyroxene and plagioclase being the principal constituents, together with accessory sphene, garnet, epidote, ziosite, hornblende and ilmenite. Rarely, however, compact and almost mono-mineralic diopsidic pyroxenites occur and were particularly noted in a locality four miles north-west of Zombe (53/7, 53/59, 53/60) and also four miles south-east of Kimokomo (53/48). Those granulites with a relatively minor proportion of coloured minerals usually contain quartz and are gneissose. In thin sections taken from a large variety of calc-silicate granulites the characteristic mineral is an emerald-green weakly pleochroic pyroxene which has the optical properties of a diopsidic member of the diopside-hedenbergite series. In most specimens the green pyroxene is poikiloblastic towards colourless diopside and sphene. The proportion of felspar varies considerably. It may either be a minor component interstitial to granular pyroxene, or form up to one-third of the rock in subhedral grains. It is usually clear and unaltered, shows pericline and albite twinning, and frequently falls in the andesine-labradorite range, but in some cases is bytownite. In the gneissose and more felspathic varieties (53/15, 53/97, 53/120, 53/199, 53/202, 53/238), in which pyroxene is subsidiary, feldspar which is poorly twinned and more albitic than usual has replacive margins against quartz and encloses it poikiloblastically.

Salmon-pink garnet enters frequently into the composition of the calc-silicate granulites, producing dull resinous purple-coloured bands and nodules in which it forms complex diablastic intergrowths with plagioclase. In these, hypidiomorphic garnets are evenly distributed in plagioclase with distorted twinning. This is especially well shown in specimen 53/40, collected three miles south-south-west of Zombe, and also in 53/47 from the Thowa valley between Zombe and Kimokomo, 53/361 from one mile north-east of Thukua, and 53/414 from the Ikoo gorge four miles east of Kamitotia. In some instances garnet is idiomorphic, forming granulitic banded concentrations (53/2), and in others encloses, or forms coronas about, hornblende (53/207).

Idiomorphic granules of epidote, pleochroic in yellow and lemon green, are a frequent accessory, and in some instances form up to one-quarter of the rocks as in specimens 53/207 and 53/222 which were taken from a calc-silicate zone between Nzia and Bikanzu. Coloured epidote is sometimes accompanied by colourless zoisite polarizing deep blue and yellow, as in specimens 53/199 and 53/202 from a narrow zone three miles due west of Kathiliwa.

Hornblende occurs generally as a secondary mineral after pyroxene, and is intensely pleochroic in green to brown. Pink and brown weakly pleochroic hypersthene with schiller inclusions is an uncommon constituent of the calc-silicate rocks. Calcite was noted in some specimens and, rarely, reaches notable proportions as in specimen 53/521, from four miles south-east of Magongo.

(*c*) *Talc-actinolite Schists*

A few specimens of friable talc-actinolite rock were collected from thin bands among the calc-silicate granulites and their associated and enclosing amphibolites and hornblende-biotite gneisses, in the Thowa valley north of Inyuu Bridge. Talc is usually a minor constituent, the bulk of the rock being composed of radiating or roughly aligned amphibole prisms. Localized lenticular talc concentrations were noted at the contact of a crystalline limestone, where the talc was associated with tremolite and granular epidote.

### (2) Metamorphosed Pelitic Sediments

Sillimanite and garnet-bearing gneisses, exposures of which are often flaggy, suggestive of bedding, are considered to be the metamorphic equivalents of argillaceous sediments.

The wide distribution of sillimanite, occurring in a variety of mineral associations, is a notable feature of the rocks of pelitic derivation, which are closely similar to those previously described from the Nanyuki-Maralal area (Shackleton, 1946, p. 9). In typically pelitic gneisses the mineral occurs as a silky prismatic aggregate in strongly foliated dark biotite gneiss, and is often associated with almandine garnet, but it is also found in whispy streaks in quartzo-felspathic granulites, muscovite-quartz granulites, and muscovite quartzites. It is also an essential constituent of *faserkiesel,* ovoid quartz-sillimanite bodies which range in size from one to twenty centimetres across, and appear as nodular inclusions in granitoid rocks, often adjacent to exposures of sillimanite-garnet gneiss. Some granitoid gneisses contain sericite in localized nodular concentrations, which in rare cases enclose relic shreds of sillimanite, and they have therefore been classified as "pseudo-sillimanite gneisses" in the pelitic group. Examples are specimens 53/200, 53/238, and 53/285, from a belt which extends from a point five miles north-east of Mui to the northern boundary of the area, and 53/511 from Magongo. It is considered that much of the sericite recorded in the area is of secondary development after sillimanite. The association of sillimanite and sericite is not restricted to the granitoid rocks, but has also been noted in massive muscovite quartzite, where sericite is concentrated about localized sillimanite aggregates.

Garnetiferous rocks of pelitic derivation are either leucocratic, massive, and sparsely biotitic, containing well-developed garnets, or dark and well foliated, with generally minute but liberally distributed garnets. Garnet on occasion is concentrated into bands, the relics of which sometimes continue into more highly granitized rocks.

In areas in which the metamorphosed pelitic sediments are moderately granitized, felspar porphyroblasts are well developed in broad belts of biotite gneiss, which is sometimes interstratified with thin granitized sillimanite or garnet gneisses. The porphyroblastic gneisses are also considered to represent granitized argillaceous sediments.

Sillimanite- and garnet-bearing gneisses are well exposed in the Ikoo gorge about one mile up-stream from the point where the Mui–Mutito road crosses the Ikoo, and they can also be located in streams draining westwards from Muteithu and its adjacent ridges, where considerable exposures of *faserkiesel* gneiss occur. Pseudo-sillimanite gneisses outcrop between Muanamba and Magongo, and on the north-easterly slopes of Ngieni.

The metamorphosed pelitic sediments are described under the following headings:—

(*a*) Sillimanite para-gneisses and granulites.
(*b*) Biotite gneisses with quartz-sillimanite *faserkiesel.*
(*c*) Pseudo-sillimanite gneisses.
(*d*) Garnetiferous para-gneisses and granulites.
(*e*) Graphitic gneisses.
(*f*) Albite-oligoclase porphyroblast gneisses.

(*a*) *Sillimanite Para-gneisses and Granulites*

(i) *Sillimanite Para-gneisses.*—Dark, flaggy and thinly foliated rocks, containing mats and sheaves of sillimanite needles which have a whispy silken appearance when seen on foliation planes, form comparatively inconspicuous bands in the pelitic series. In thin sections of examples (53/182, 53/183) taken from typical exposures in the Ikoo River, approximately two miles west of Ikoo, the quartzo-felspathic folia show a granular mosaic of strain-polarizing quartz, microcline, and untwinned plagioclase, with scattered prisms of sillimanite, which is otherwise concentrated into fibrous sheaves (fibrolite), forming almost continuous folia. Red-brown biotite, and iron ore, are the remaining minor constituents.

One band of sillimanite gneiss situated 3,000 yards due east of Mui Trading Centre is about 50 yards wide, ash white in outcrop, and consists almost entirely of sillimanite and quartz with accessory rutile, epidote, sericite and apatite (53/242).

(ii) *Sillimanite Paragranulites.*—In outcrop these are typically mauve or pink, poorly to non-foliated granulites, which resist erosion. They are flecked white or streaky where sillimanite reaches any degree of concentration.

In thin section, recrystallized quartz and alkali-felspar, which is dominantly microcline, form a granoblastic mosaic, microcline showing prominent replacive borders again quartz, particularly in specimen 53/208 from three miles north-north-west of Nzia. Sillimanite has a sheafy habit similar to that in the gneisses described above, but the fibrous aggregates are not conspicuously foliated.

(*b*) *Biotite Gneiss with Quartz-sillimanite faserkiesel*

Distinctively reddish-mauve in outcrop, with massive and resistant exposures frequently forming ridge features, these rocks are characterized by a white dappled appearance, produced by ovoid quartz-sillimanite *faserkiesel* which are sufficiently concentrated in some exposures to form one-quarter of the rock. The ovoids are evenly distributed, or locally concentrated into bands (Plate II) and usually have their major axes parallel to the lineation of the host-rock, which is essentially a granulite of granitic affinity. Microscopic examination shows that these white compact bodies are virtually felspar-free nodules, in which interlacing fibrous sheafs of sillimanite are enclosed in a quartz mosaic. Magnetite is a common and well-developed accessory. Rutile and biotite were noted in some instances. Almandine garnets are also developed in *faserkiesel* particularly where the neighbouring sillimanite gneiss is garnetiferous. Specimen 53/558 from four miles north-east of Mui is typical.

Sections of the host-rock, of which 53/505 taken from between Magongo and Muanamba is typical, contain quartz and alkali felspar, both microcline and albite-oligoclase having replacive margins against quartz, and enclosing isolated quartz droplets. Red-brown biotite forms about 1 per cent of the rock, and iron ore and sericite are accessory.

(*c*) *Pseudo-sillimanite Gneisses*

The pseudo-sillimanite gneisses are leucocratic, pink or grey, weakly foliated granitoid rocks containing both biotite and sericite, much of the latter occurring in clustered aggregates which may contain relic shreds and fibres of sillimanite. They contain more microcline and less quartz than the sillimanite gneisses and granulites, and represent an advanced stage in the granitization of the latter. A good example of this type of gneiss outcrops at Nuu, and specimen 53/269, which contains large radial sericite clusters, was taken from a point 50 yards north-east of the spring.

Some estimated modes* of the sillimanite rocks are as follows:—

| | 53/242 | 53/182 | 53/208 | 53/511 | 53/285 | 53/283 | 53/558 |
|---|---|---|---|---|---|---|---|
| | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* | *per cent* |
| Quartz .. .. .. | 40 | 45 | 35 | 30 | 25 | 20 | 65 |
| Microcline .. .. | — | 10 | 40 | 50 | 35 | 50 | — |
| Plagioclase .. .. | 15 | 15 | 5 | 10 | 25 | 15 | — |
| Sillimanite .. .. | 35 | 20 | 15 | 2 | 3 | 3 | 20 |
| Biotite .. .. .. | — | 4 | — | 3 | 4 | 1 | 1 |
| Garnet .. .. .. | — | — | — | — | — | — | 4 |
| Myrmekite .. .. | — | — | — | — | 1 | — | 1 |
| Sericite .. .. .. | 3 | 2 | 1 | 3 | 4 | 4 | 2 |
| Iron ore and accessories .. | 4 | 4 | 2 | 2 | 3 | 2 | 4 |

Sillimanite gneisses, 53/183, two miles west of Ikoo and 53/242, 3,000 yards due east of Mui Trading Centre.

Sillimanite granulite, 53/208, three miles NNW. of Nzia.

Pseudo-sillimanite gneisses, 53/283, five and a half miles NE. of Mui D.C. Camp. 53/285, six miles NE. of Mui D.C. Camp. 53/511, one and a half miles ENE. of Magongo summit.

Quartz-sillimanite *faserkiesel* with garnet, 53/558, two miles WNW. of Muteithu.

* All modes quoted in this report are volumetric.

PLATE I

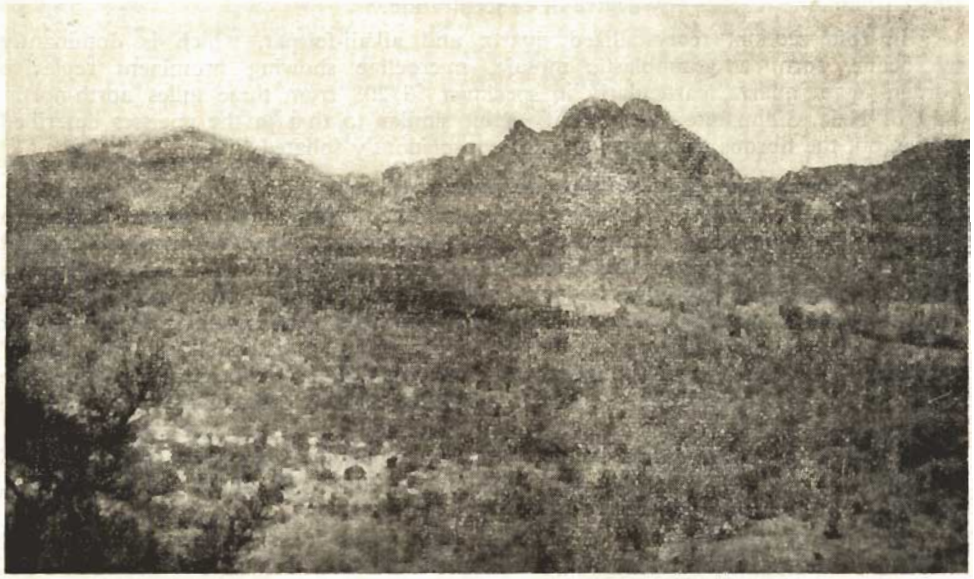


Fig. 1.—The Eastern Thowa valley, from near Inyuu bridge. Yakabu Rock right middle foreground, Mutito (5,205 ft.) left background.

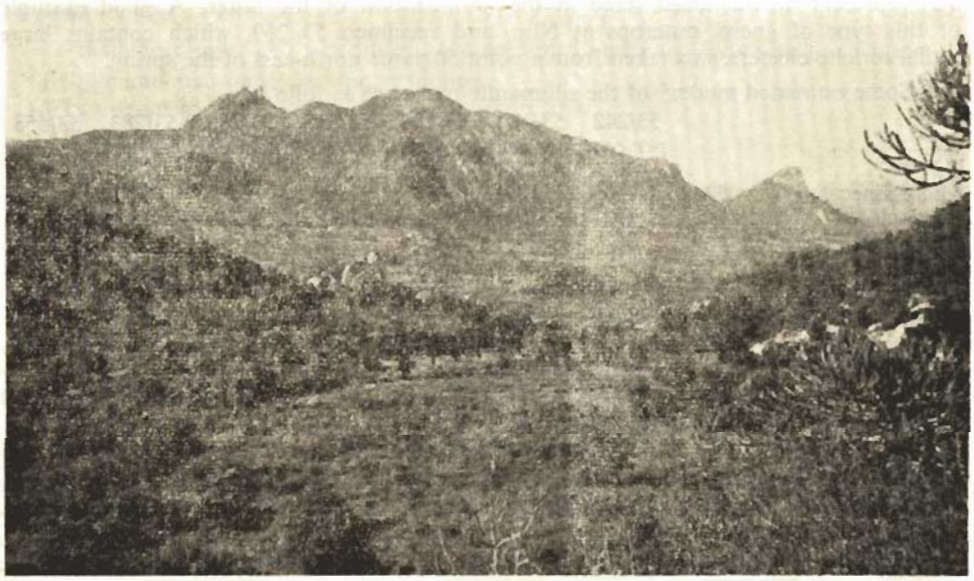


Fig. 2.—Part of the Nuu hills from the northern slopes of Kathiliwa. Oba Rock right middle distance.

## PLATE II

**Sillimanite Migmatites.—Progressive stages in the transition from sillimanite gneiss to granitoid gneiss with faserkiesel**

**Fig. 1.—Five undisturbed ribs of quartz-sillimanite gneiss between which the intervening gneiss has been metasomatically replaced by granitic material in which the surviving sillimanite bands have undergone some dissolution.**

**Fig. 2.—Further dissolution of the sillimanitic bands—the original gneissic foliation remains (from lower left to upper right of exposure) and is conformable to that in adjacent non-migmatized sillimanite gneisses.**

**Fig. 3.—Sillimanite faserkiesel. A preferred orientation is not megascopically apparent.**

**Fig. 4.—Sillimanite faserkiesel in granitoid migmatite—the ovoids show plastic distortion and are drawn-out parallel to flow banding in the host-rock.**

*(d) Garnetiferous Para-gneisses and Granulites*

(i) *Garnetiferous Para-gneisses.*—The garnet gneisses are dark grey, well-foliated, flaggy biotite-rich gneisses which are sprinkled with small red-brown garnets. They are interstratified with biotite gneisses of pelitic or semi-pelitic derivation, and are often distinguished by local banded concentrations of garnet which are otherwise inconspicuously distributed.

In thin sections of specimens 53/23, 53/383, 53/393, 53/489, 53/492, which were taken from a narrow zone stretching from a point two miles east of Kimokomo in the south of the area to the Tyaa valley in the north, garnet shows a preferential development in the biotitic folia, the intervening folia being crystalloblastic and quartzo-felspathic, with only sparse biotite. The garnet is pale pink and frequently sieved with quartz and shreds of biotite, which is strongly pleochroic from pale to deep brown.

Oligoclase is the typical felspar and is accompanied by variable amounts of microcline whilst apatite, iron ore, and zircon are accessory.

(ii) *Garnetiferous Para-granulites.*—Well-jointed, massive, leucocratic granulites, which often weather in pale-brown colours, occur as thin ribs in the pelitic succession and, like the garnetiferous para-gneisses, contain banded garnet concentrations which on smoothly eroded outcrops sometimes appear as a series of sunken spots. A coarse slabby parting is characteristic.

In thin sections, quartz, microcline, and plagioclase, which is generally albite-oligoclase, are present in approximately equal proportions. Microcline has prominent replacement margins against quartz and encloses quartz droplets. The garnets are pale in colour, well rounded, and apparently free from inclusions. They are accompanied by rare biotite and sericite shreds.

Some estimated modes of garnetiferous para-gneisses and granulites are as follows:—

| | 53/405 *per cent* | 53/408 *per cent* | 53/489 *per cent* | 53/492 *per cent* | 53/284 *per cent* |
|---|---|---|---|---|---|
| Quartz .. .. .. .. | 35 | 35 | 30 | 25 | 35 |
| Microcline .. .. .. | 5 | — | — | — | — |
| Plagioclase .. .. .. | 35 | 35 | 45 | 50 | 55 |
| Biotite .. .. .. .. | 10 | 15 | 15 | 15 | 1 |
| Garnet .. .. .. .. | 4 | 8 | 5 | 5 | 2 |
| Iron ore, apatite, etc. .. .. | 6 | 4 | 3 | 2 | 1 |

Garnetiferous para-granulite, 53/284, three miles NE. of Mui Trading Centre.

Garnetiferous para-gneisses, 53/405, two miles ENE. of Kamitotia. 53/408, two and three-quarter miles east of Kamitotia. 53/489, one and three-quarter miles WNW. of Kimokomo. 53/492, two and a half miles west of Kimokomo.

*(e) Graphitic Gneisses*

Small flakes of graphite occur in some quartz-biotite gneisses, especially those near the contacts of crystalline limestone. In most cases the graphite is a minor constituent and difficult to detect, especially when associated with a high proportion of biotite. In the more quartzose gneisses, however, a thin sprinkling of graphite usually conspicuously spangles the quartz matrix. The graphitic gneisses are soft, and their poor exposures are restricted to watercourses.

In thin sections the main constituents are found to be quartz and felspar in approximately equal proportions, together with biotite and graphite. One specimen (53/397), which was located two miles due east of Chormi, is highly quartzose and contains staurolite, garnet and apatite, together with graphite.

*(f) Albite-oligoclase Porphyroblast Gneisses*

Exposures of strongly gneissic rocks which are brown or dark grey in colour, and dappled with conspicuous white felspathic knots, are prominent in the western part of the area, and occupy a broad belt from Kimokomo in the south to Kamitotia in the north. They contain little or no sillimanite or garnet, but are interstratified with gneisses containing these minerals, as well as with thin bands of calc-silicate granulite, and they are therefore classified as partly granitized metamorphosed sediments.

The foliation is generally even and parallel to that in the adjacent pelitic gneisses, but in some exposures, however, moderate contortion occurs and is accompanied by an increase in the size of visible felspar aggregates and by some pegmatitic reticulation. With increase in the development of potash felspar, notably microcline, the sedimentary texture becomes progressively obscured and the porphyroblast gneisses grade into granitoid rocks and migmatites.

Thin sections show prominent folia of clear recrystallized quartz, together with finely granular strain-polarizing quartz, and alkali felspar, some of which is microcline. Large, rounded and subhedral albite-oligoclase porphyroblasts of late growth are conspicuous. They are frequently cloudy and untwinned, but some show albite twinning, and more rarely, fine, indistinct, pericline twins. Inclusions of sericite and zeolite are numerous within the porphyroblasts, and are often accompanied by small rounded quartz droplets. Myrmekite is sometimes developed marginally to the porphyroblasts, which in turn have replacive relationships both with quartz and microcline, as in specimen 53/466 from four miles due north of Kitui.

Specimen 53/494 from the Kisui River four miles east-south-east of Nzambani Rock shows well-aligned biotite flakes, pleochroic from pale brown to dark brown or black, which are arranged in sharply defined folia and accompanied by accessory iron ore, sericite, apatite, and zircon. Representative estimated modes of the albite-oligoclase gneisses are as follows:—

| | 53/424 *per cent* | 53/430 *per cent* | 53/466 *per cent* | 53/494 *per cent* |
|---|---|---|---|---|
| Quartz .. .. .. .. | 15 | 15 | 15 | 15 |
| Microcline .. .. .. .. | 20 | 8 | 10 | 12 |
| Albite-oligoclase .. .. .. | 50 | 60 | 60 | 60 |
| Biotite .. .. .. .. | 7 | 8 | 10 | 7 |
| Myrmekite .. .. .. .. | 3 | 1 | 2 | 1 |
| Ore, apatite, sericite, etc. .. .. | 4 | 4 | 3 | 4 |

53/424, two and a quarter miles SSW. of Kamitotia.

53/430, two and a quarter miles SSE. of Kamitotia.

53/466, three miles NNE. of Nzambani Rock.

53/494, two and a half miles WNW. of Kimokomo.

### (3) Metamorphosed Semi-pelitic Sediments

Gneisses and granulites which are believed to be derived from semi-pelitic sediments are interstratified with sillimanite- and garnet-bearing gneisses, but do not themselves contain these index minerals. They are frequently flaggy, fine-grained, granulitic rather than gneissose, and grey in colour. They contain less biotite than the metamorphosed pelitic sediments, but more than the quartzo-felspathic granulites derived from metamorphosed psammitic sediments. Evenly distributed biotite and iron ore gives them a finely speckled appearance. Rocks of this type are best exposed in the hills immediately south of Muteithu summit, and also west of Nzia, in the gorge of the Ikoo, but occur widely in other localities.

In thin section it is found that quartz and oligoclase are the major constituents and are present in approximately equal proportions. The oligoclase is fresh and clear, exhibits albite and pericline twins, and has conspicuous replacement margins against

quartz, which it often deeply embays and encloses. The plagioclase composition range is in most cases $An_{20}$–$An_{10}$ but some albite ($An_8$) was noted in one specimen. Microcline is subsidiary to plagioclase but occasionally forms large grains, the margins of which replace oligoclase.

In a typically granulitic specimen (53/298), from one mile south of Muteithu summit, biotite occurs in unorientated flakes, but in the more gneissose members it usually forms poorly defined folia, as in specimen 53/363 from one mile north-east of Thukua. Iron ore, rutile, sphene, and apatite are accessory.

Some estimated modes are as follows: —

| | 53/152 *per cent* | 53/286 *per cent* | 53/298 *per cent* | 53/363 *per cent* | 53/381 *per cent* |
|---|---|---|---|---|---|
| Quartz .. .. .. .. | 45 | 35 | 25 | 40 | 40 |
| Microcline .. .. .. | — | 10 | 20 | 4 | 7 |
| Plagioclase ($An_{20}$-$An_7$) .. .. | 45 | 45 | 45 | 50 | 45 |
| Biotite .. .. .. .. | 6 | 4 | 6 | 5 | 5 |
| Iron ore, apatite, etc. .. .. | 1 | 4 | 3 | 1 | 1 |
| Sericite .. .. .. .. | — | 1 | 1 | — | — |

Semi-pelitic granulites, 53/152, three miles ESE. of Mui Trading Centre. 53/286, three miles NNE. of Mwalano. 53/298, half a mile south of Muteithu. 53/381, three and a quarter miles NNE. of Chormi.

Semi-pelitic gneiss, 53/363, one and a half miles NE. of Thukua.

### (4) Metamorphosed Psammitic Sediments

Metamorphosed sandstones, quartzites, felspathic quartzites, and arkoses, are believed to be represented by rocks which vary from coarse, massive quartzites containing variable amounts of muscovite, to fine- or medium-grained quartzo-felspathic granulites, some of which are weakly gneissose. Titanomagnetite is a characteristic accessory in the latter, and is sometimes accompanied by sparse biotite.

The strong resistance to erosion of the metamorphosed psammitic sediments causes them to form prominent hill features, and in some localities physiography is strongly determined by their distribution, as in the case of the Nuu hills. A consistent joint pattern is well developed (*see* Structures, p. 41). Master joints which parallel the dip and strike impart a massive flaggy appearance to some exposures, whilst transverse jointing breaks the continuity of outcrops and produces enormous rectangular blocks which are reduced to tors and bald crags by exfoliation.

The granular rocks, where megascopic texture is not far removed from that of an original sandstone, frequently show stratiform layering (Plate IV, Fig. 1) in which laminations produced by variation in grade are apparently rhythmic, and in some instances show a low-angle truncation by other lamellæ, reminiscent of cross-bedding.

With the exception of the quartzites, the rocks of this group are strongly granitized and some approach the composition of granite. Where isolated crags occur in open country, and no contacts are visible, they are difficult to distinguish from granitoid and migmatitic gneisses, but unlike the latter they are generally free from streaky local concentrations of ferromagnesian minerals which form the schlieren and xenoliths of the migmatitic granites. Microscopic indications are that much of the felspar, notably microcline, has been metasomatically introduced and has replaced pre-existing quartz and felspar. A relic sedimentary texture in the form of small palimpsests of granular quartz which have evidently escaped recrystallization is often present. The most conspicuous evidence for distinguishing these rocks from granitoid or migmatitic rocks lies, however, in their field distribution, in that they closely conform to the structural pattern of the metamorphosed sediments with which they are interstratified.

The metamorphosed psammitic sediments are classified as follows:—

(*a*) Quartz-felspar-biotite para-granulites.

(*b*) Quartz-felspar para-granulites.

(*c*) Quartzite and muscovite-quartzites.

(*a*) *Quartz-felspar-biotite para-granulites*

These are massive, well-jointed, brown and pink weathering, leucocratic, highly felspathic granulites, which are generally medium-grained, but are sometimes coarse. They are resistant to erosion, and when they occur in thin bands in poorly exposed geological sections they are virtually the only rock type recorded. Where, however, they are developed over a considerable strike width, and are associated with other psammitic rocks, they strongly influence the physiography, as instanced by the Mutito ridge which is a prominent topographical feature stretching between Ikoo and Zombe.

Although in bulk dominantly felspathic, the rocks of this group often contain thin, coarsely crystalline, quartz lenses, which frequently have a felspathic selvedge. The most conspicuous dark mineral is iron ore, which is either ilmenite or magnetite in various stages of oxidation to martite. In the more gneissose members it often forms streaks, but generally occurs as octahedral crystals with coronal haematite, and imparts a speckled appearance to the rocks. Octahedra up to half a centimetre across are not rare, whilst pegmatitic segregations are often rich in ore and sometimes contain larger crystals up to two or three centimetres across.

In thin section these granulites show an irregular mosaic of quartz, microcline, perthite, and acid plagioclase, which is generally albite-oligoclase but in some cases is albite. Plagioclase frequently shows albite edging, which is only present at margins between microcline and plagioclase and is well shown in specimen 53/263 from one mile north of Muteithu. Poorly aligned flakes of green-brown biotite, and iron ore with occasional coronal sphene and haematite, are the general remaining minor constituents.

Some estimated volumetric compositions are as follows:—

| | 53/133 *per cent* | 53/135 *per cent* | 53/263 *per cent* | 53/313 *per cent* | 53/333 *per cent* |
|---|---|---|---|---|---|
| Quartz .. .. .. .. | 40 | 30 | 30 | 30 | 25 |
| Microcline .. .. .. | 25 | 35 | 45 | 50 | 55 |
| Plagioclase .. .. .. | 25 | 25 | 20 | 15 | 15 |
| Biotite .. .. .. .. | 1 | 1 | 1 | 1 | 2 |
| Iron ore .. .. .. .. | 2 | 2 | 2 | 3 | 1 |
| Sphene, sericite, etc. .. .. | 1 | 1 | — | 1 | 1 |

53/133, two and a quarter miles NE. of Mui Trading Centre.

53/135, one and three-quarter miles ENE. of Mui District Commissioner's Camp.

53/263, one and a quarter miles north of Muteithu summit.

53/313, one and a half miles SE. of Mui Trading Centre.

53/333, one and a half miles WNW. of Etulu.

(*b*) *Quartz-felspar para-granulites*

Exposures of these rocks are similar to those of well-bedded sandstones. They are fine-to medium-grained, equigranular rocks which weather in various shades of pink and rose. In rare exposures they show signs of faint graded bedding. The colour is superficial, and beneath an oxidized crust which varies from one-quarter to six inches in thickness they are generally pure white and sugary, and are sometimes speckled with pyrite or black magnetic ore.

They contain quartz, which in the main is clear and recrystallized forming irregularly lobed grains, but sometimes occurring in simple strain-polarizing granules.

Felspar, which forms more than half the rocks, is dominantly an acid oligoclase which frequently tongues and embays quartz, and encloses round droplets of it. Microcline is subsidiary to plagioclase and partly replaces it.

Apart from pyrite and magnetite which are visible in hand-specimens, further accessories noted are zircon, rutile, sericite, and haematite.

Some estimated modes are:—

| | 53/140 *per cent* | 53/155 *per cent* | 53/197 *per cent* | 53/400 *per cent* |
|---|---|---|---|---|
| Quartz .. .. .. .. | 20 | 25 | 30 | 35 |
| Microcline .. .. .. .. | 30 | 15 | 25 | 30 |
| Plagioclase .. .. .. .. | 45 | 55 | 35 | 30 |
| Iron ore .. .. .. .. | 3 | 1 | 5 | 2 |
| Sericite .. .. .. .. | 2 | 1 | 2 | 1 |

53/140, three and a quarter miles ENE. of Mui District Commissioner's Camp.
53/155, one and a half miles ENE. of Mui District Commissioner's Camp.
53/197, four miles NNW. of Kathiliwa.
53/400, two and a quarter miles east of Chormi.

(*c*) *Quartzites and Muscovite-quartzites*

Pure quartzites occur as massive, well-jointed, and frequently finely cleaved rocks and are similar to Basement System quartzites which have previously been described by Parkinson (1947, pp. 13–15, 18), Shackleton (1946, p. 12), and Schoeman (1949, p. 14). They are the most resistant of all rock groups described within the present area, and where dips are steep they form a central rib or spine in many sharp ridge features, at whose summits they are only found *in situ* over a small thickness, although quartzite blocks and talus shed from the central rib may completely mantle the flanking gneisses, giving a false impression of width to the quartzite member. Contacts are often marked by sharp cliffs, which on the south of the Kathiliwa-Ngieni massive are virtually sheer for several hundred feet (Fig. 4b, p. 40). Quartzite cliffs which stretch for several miles are also a feature of the ridges extending northwards and southwards from Muteithu summit, where ash-white or pink-weathering, castellated summits are conspicuous. Elsewhere, if dips are low, the quartzites form low hillocks that are readily recognized by their sparse cover of vegetation and their mantle of coarse, white or pink, quartz gravels, which often carry an abundance of muscovite.

The pure quartzites are virtually homogeneous, white or grey-green, translucent, and coarsely crystalline, often showing irregular roughly equidimensional grains up to two or three centimetres across. Under the microscope they show a simple, sutured, strain-polarizing quartz mosaic with minute dusty inclusions. They are interstratified with muscovite quartzites which are more common than the pure quartzites, and grade through sparsely micaceous quartzites to coarse quartz-muscovite gneisses. Muscovite is concentrated in thin foliation bands, and where these are parallel to darker bands due to dusty and sometimes carbonaceous inclusions they are regarded as representative of bedding (Plate IV, Fig. 2). In some micaceous bands, shreds and fibres of sillimanite were noted at several localities and it is probable that a considerable part of the muscovite is secondary after sillimanite.

The massive nature of quartzites in the Nuu-Mui area renders them comparatively impervious to ground-water, and when they are in contact with well-jointed gneisses, and their structure is favourable, they form aquifers, and give rise to springs and seepages at their contacts (*see* pp. 50, 51). In this area also the quartzites are sufficiently well-exposed to give some indication of the Basement System structure, both by their distribution and minor structural features.

## (5) Migmatites

Much of the Basement System within the area under description, although highly granitized, retains a sedimentary structural pattern, and contains rock types which are clearly derived from the metamorphism of sediments. These rocks, however, grade into tracts of migmatite in which recognizable sedimentary features are largely obliterated, and contrasting components enter into a complex which in parts exhibits acute random contortions indicative of viscous flow. Such rocks may be classified into two groups—

(*a*) hornblendic migmatites; and

(*b*) granitic migmatites.

### (*a*) *Hornblendic migmatites*

These are heterogeneous rocks which are only moderately resistant to erosion and are frequently deeply weathered. They occur widely in the Thowa and Tyaa valleys, where they are associated with calc-silicate granulites, and are well-exposed in the north-western corner of the area, particularly west of the Tyaa River. Occurrences were also noted over considerable tracts betweeen Magongo and Endau, and north of the Kathiliwa quartzite mass.

The rocks contain three readily distinguishable components which determine their heterogeneous character. They are—

(i) hornblende-biotite banded gneisses;

(ii) amphibolitic rocks;

(iii) felspathic granulitic gneisses.

(i) Hornblende-biotite banded gneisses have dark and light bands alternating rapidly, individual bands being generally not more than two inches in thickness and frequently having sharp contacts with their neighbours. In some exposures the banding imparts an even foliation and shows little contortion apart from localized pinching and swelling, but more often it is thrown into swirling contortion with puckers, crenulation, and minor shearing (Plate III, Fig. 1). In thin section the dark-coloured bands are seen to contain aligned blades of hornblende, strongly pleochroic from straw-brown to deep green, and biotite in a granular mosaic of plagioclase with subordinate quartz. The plagioclase falls in the basic oligoclase to acid andesine range. Iron ore and apatite are often conspicuously present together with sphene and epidote.

The light-coloured bands, which are sometimes visibly knotted with plagioclase porphyroblasts, consist of a granoblastic mosaic of quartz and plagioclase with subsidiary hornblende and biotite. The plagioclase is generally basic oligoclase and forms the bulk of the bands, some of which show evidence of intraformational shearing during crystallization, many of the grain margins being shredded and granulitized, as in specimen 53/362 from one mile north-east of Thukua.

(ii) Dark, compact, amphibolitic rocks are enclosed in the banded hornblendic gneisses, either as ovoid or lenticular bodies or as sharply angular blocks. In size they vary from a few inches to hundreds of feet across, but commonly occur as small isolated ovoids or drawn-out strings of *boudins* having the same strike as the enclosing gneiss. (Plate III, Fig. 3.) The banding of the host gneiss wraps around the dark ovoids which sometimes themselves contain thin uncontorted acid bands that do not enter the enclosing gneiss, and are unrelated to its local strike.

**PLATE III**

**Structural features of hornblende migmatites**

**Fig. 1.—Minor transverse shearing in evenly banded migmatite. The coarse felspathic material occupying the shear-plane is mainly oligoclase-andesine.**

**Fig. 2.—Diopside-pyroxenite knots—relics of a calcareous band in hornblende-migmatite.**

**Fig. 3.—"Boudinage"—a plagioclase-amphibolite inclusion which has undergone plastic deformation.**

**Fig. 4.—Agmatite. Angular fractured blocks of plagioclase amphibolite enclosed in dioritic gneiss.**

**PLATE IV**

**Fig. 1.—Cross-bedding in quartz-felspar paragranulite.**

**Fig. 2.—Muscovite-bearing bedding planes in quartzite.**

**Fig. 3.—Granitoid knots and lenses in granitic migmatite.**

Angular blocks or slabs of plagioclase amphibolite are less common than ovoid or boudinage bodies, but where they occur are often associated in groups, and display like fracture faces, each piece having moved only a few inches from its neighbour as in the "agmatite" of Sederholm (Plate III, Fig. 4). The acid material which fills the fractures is typically coarse, unfoliated, and white in colour. It has a composition similar to that of the leucocratic bands in the hornblende banded gneiss.

In thin section it is found that dark minerals form not less than half the bulk of the amphibolite blocks (53/57, 53/293 and 53/370). Well-developed poikiloblastic hornblende occurs in interlocking groups showing little preferred orientation. Plates of subsidiary biotite have formed marginal to hornblende and also as poikiloblasts, or as shreds within the hornblende cleavages. The light-coloured minerals are plagioclase, which is usually acid labradorite, and subsidiary quartz. Iron ore is common and sometimes forms more than 5 per cent of the rocks. Sphene and apatite are nearly always present in subsidiary amounts.

(iii) The third component entering into the composition of the hornblendic migmatites is acid granulitic gneiss, which is nearly always white, and contains little or no potash felspar. The characteristic felspar is oligoclase which frequently occurs in large blue-grey schillerized porphyroblasts.

Where plastic contortion is intense, large bodies of the acid component reticulate the other members of the complex, and often enclose blocks of compact amphibolite, but in less acutely disturbed occurrences stringers of similar material conform to the plastic deformation pattern of the enclosing gneiss. The stringers are distinguishable from later granitic veining, which is invariably pink due to a high microcline content and shows cross-cutting relationships, transecting all components of the hornblende migmatite alike.

(*b*) *Granitic migmatites*

Immediately west of the Kitui hills a broad migmatite zone extends north to south, and continues up to and beyond the western margin of the area. In composition much of the migmatite within this zone is granitic or grano-dioritic, but its various components have considerable petrographical differences. Comparatively homogeneous granitic rocks are only of local occurrence, and are associated with sheets and lenses of palingenetic granite. Some of the migmatites are mylonitized and strong microscopic shearing is evident, but most of the rocks appear to have undergone plastic flow during deformation followed by recrystallization after movement had almost ceased.

Like the hornblendic migmatites these rocks may for descriptive purposes be classified into three components—

(i) a gneissic host-rock;
(ii) dark ovoids or schlieren;
(iii) granitoid lenses, streaks and sheets.

(i) The massive gneissic host-rock has ill-defined foliation, which is locally contorted and is produced by alternating pink quartzo-felspathic bands and subsidiary grey biotitic folia. The darker parts of the gneiss are generally dappled with pink microcline porphyroblasts.

Thin sections show elongated folia of clear recrystallized quartz which are invariably fractured transverse to the foliation. Microcline is the dominant felspar, and occurs both as large, clear porphyroblasts and as small grains in a fine-grained quartz-microcline-oligoclase matrix. Oligoclase also occurs as prominent porphyroblasts, but in contrast to the microcline they are clouded with inclusions. They often show clear albitic margins against microcline, as in specimen 53/500 from two miles east of Nzambani Rock. Roughly aligned flakes of shredded biotite which are dichroic in yellow and brown, or bleached, form up to 4 per cent of the rock.

The texture, composition and field distribution of this migmatitic component shows that it is closely related to the oligoclase-porphyroblast gneisses (p. 17), which are interstratified with metamorphosed pelitic sediments. A steady transition, which is dependent on the development of potash felspar can be traced from the oligoclase gneisses to the microcline migmatitic gneisses throughout which a relic sedimentary texture is retained.

(ii) Dark streaky ovoids or "schlieren" drawn out parallel to the foliation are of local occurrence in the component described above. Unlike some of the enclosures in the hornblendic gneisses these bodies are apparently never angular, and are dominantly biotitic rather than hornblendic. They are also more felspathic than the amphibolite enclosures in the hornblendic migmatites and frequently show signs of dissolution, producing a host-rock locally rich in biotite.

In thin section the dark minerals, which are often in gneissose alignment, are found to form half the rock. Biotite is more abundant than hornblende and is of two kinds, one a deep brown chloritized and weakly pleochroic variety, and the other clear and highly cleaved, with dichroism from yellow to brown. Hornblende is patchily altered to biotite, particularly at its periphery. The remaining minerals usually consist almost entirely of oligoclase-andesine with notable amounts of accessory sphene and apatite, as in specimen 53/478b from two miles south-south-east of Mitzau.

(iii) Pink- and brown-weathering, coarse, granitoid streaks, knots, lenses, and sheets are extensively developed and are a conspicuous component of the granitic migmatite. Being relatively resistant to weathering their surfaces often project sharply from that of the host-rock (Plate IV, Fig. 3). The smaller bodies are concordant with the foliation, but some of the sheets, ranging in size from six inches to one hundred feet across, are slightly discordant, their contacts truncating the foliation of the host-rock obliquely. The discordance seldom exceeds five degrees.

In thin section this migmatitic component is seen to be granitic or granodioritic in composition, but has a granoblastic texture, which is typically displayed in specimen 53/416 from four miles south-east of Kamitotia. Lobed grains of quartz form about 30 per cent of the rock, the remainder being composed mainly of microcline and acid oligoclase in approximately equal proportions. There is also some orthoclase and microcline-perthite, with occasional myrmekite and less than 2 per cent of biotite and iron ore. Oligoclase forms large turbid porphyroblasts, which only show faint albite twinning at their edges. They often have clear albitic margins at their contacts with microcline, which is invariably unaltered and has apparently partly replaced them.

At their margins the granitic sheets are gneissose, and may be mylonitic, as in specimen 53/390 from one mile east of Chormi. Thin sections show folia with streaked and shredded quartz in a finely granulitized quartz-felspar matrix. Strain shadowing in quartz, and incipient *en echelon* shearing within the large microcline and oligoclase porphyroblasts, is a common feature. Many of the porphyroblasts appear to have undergone rotation, and finely shredded biotite exhibits a quasi-fluxional arrangement about them.

The migmatites are further discussed, and their regional significance considered, in a subsequent chapter (p. 37).

### (6) Anatectic or Palingenetic Rocks

#### (*a*) *Granitoid gneisses*

Rocks of granitoid composition, in which the dominant potash felspar is invariably microcline, are of widespread occurrence in the Basement System. The most homogeneous members are medium- to coarse-grained, non-porphyritic granulites resembling sandstones, which conform to the structural pattern of their enclosing

metamorphosed sediments. These rocks appear to have achieved their present composition by felspathization in the solid state and apparently have not been raised to any high degree of plasticity. They are classified as metamorphosed sediments and have been described on an earlier page (p. 19).

The remaining granitoid gneisses, which in this area are subsidiary to those mentioned above, are found in migmatite zones. They are massive, medium- to coarse-grained, pink and grey gneisses, which contain well-developed porphyroblasts or phenocrysts. A contorted foliation is usual, and small dark biotitic amphibolite streaks and schlieren are common. Many exposures are reticulated with coarse-grained microcline pegmatite. The boundaries of these rocks are difficult to place on a map as they merge imperceptibly into migmatites, of which they appear to be a more homogeneous member. Like much of the surrounding migmatite they appear to have reached mobility, and display contortional features produced by viscous flow.

Granitoid gneisses of this type are best displayed on the western side of the Nzeo River, one to three miles south of Mulango Mission, but exposures are also common both north and south of Kitui in the Nzeo and Ngoni Rivers.

Thin sections from these localities (53/477, 53/463, 53/478a, 53/473, 53/456, 53/476), closely resemble those taken from the granitic component of the enclosing migmatite. Quartz, which forms rather more than a quarter of the volume of the rocks, occurs in large, clear, roughly gneissose aggregates, and is associated with clear microcline, or microcline-microperthite, and orthoclase. Plagioclase, ranging from albite to basic oligoclase, or rarely andesine, is the dominant felspar, and is generally an oligoclase which has albite edges against microcline. Like the orthoclase it is nearly always clouded with inclusions, and albite twinning is rarely conspicuous, but some plagioclase shows selective sericitization, twin lamellæ being alternately turbid and clear especially in 53/473, an effect that is often noted in granitic rocks (c.f. Emmons and Gates, 1943, p. 296).

The remaining minerals are a yellow-brown dichroic biotite, associated with white mica that may be in fact bleached biotite, and accessory magnetite, zircon, apatite, and sphene. Hornblende is of rare occurrence, but is usually accompanied by sphene and magnetite, particularly where calc-silicate granulites and gneisses tail out in the migmatite zones.

Texturally the rocks are xenomorphic, but show a closer approach to a typically granitic hypidiomorphic texture than the xenoblastic granitized psammitic sediments. Inter-crystalline replacement features, notably deeply tongued and embayed crystal margins are not so prominently developed as in the latter. Cloudy oligoclase relics are often enclosed in unaltered microcline, and quartz droplets in both oligoclase and microcline.

The similarity in both fabric and composition of the larger bodies to the small films and lenses in the surrounding migmatite suggests that they are of anatectic origin within the migmatite zones, and finally achieved viscous mobility.

*(b) Pegmatites*

Pegmatites are of widespread occurrence in the Basement System, and are conspicuously developed in a zone of migmatites and granitoid gneisses which occupy the western margin of the area. Elsewhere they are commonly found in massive granitoid rocks, but were less frequently noted in non-migmatized metamorphosed pelitic sediments, notably the sillimanite-, garnet-, and biotite-bearing gneisses.

The mode of occurrence of the pegmatites is highly variable. They form small lenticular or irregular segregations in granitoid gneisses, or, when more strongly developed occur as ramifying vein systems, roughly conformable sheets, or cross-cutting

dyke-like bodies. The last at their largest measure more than 50 ft. across, but the majority are between 6 in. and 2 ft. in thickness. They are generally pink or brown in colour, and are often more resistant to erosion than the rocks in which they are found, so that they stand out from weathered surfaces.

In contrast to their variety of form, the pegmatitic bodies show a fairly uniform composition. Pink felspars, the largest individuals of which reach six inches across, are prominent components and are accompanied by clear or cloudy blue-grey quartz, biotite, which sometimes forms small "books", muscovite, and magnetite or ilmenite. With the exception of black tourmaline (53/294), which was recorded in quartz pegmatites immediately south of Bikanzu summit, and also in the Tyaa valley two and a half miles east of Chormi, traces of mineralizing volatiles appear to be absent. Magnetite or ilmenite is locally well developed in some of the pegmatites, however, and forms granular aggregates often arranged parallel with, and close to, the contacts. The ore sometimes shows striated octahedral faces, and individuals measure two or three inches across. Visible magnetite mineralization of this type appears to be restricted to those pegmatites found in pink and brown massive granitoid gneisses, which are here classified as metamorphosed psammitic sediments (p. 18), and which themselves invariably contain magnetite as virtually the only dark mineral. In these rocks in particular pegmatitic auto-segregations are frequent, and appear as closed lenses or stringers having a quartzitic core surrounded by coarse perthitic felspar and subsidiary quartz, which grades outwards into the enclosing granulitic gneiss and in some cases is surrounded by a thin biotite-rich sheath. Biotite selvedges of this type are not restricted to the small lenticular bodies, but commonly appear at the edges of many larger cross-cutting pegmatites.

The perthitic character of much of the felspar entering into the composition of the pegmatites is apparent to the unaided eye. Microscopic examination shows it to be almost exclusively microline-perthite of the film and string type, which consists of an intricate and irregular network of microscopic sub-parallel streaks and anastomosing veins of clear albite in microcline. In some instances the perthitic felspars contain more conspicuous veins of albite, which sometimes show polysynthetic twinning having a composition plane parallel to that of pericline twinning in the enclosing microcline. These albitic veins on occasions merge into larger areas of albite enclosing small islands of microcline which are in optical continuity with the host.

The detailed texture of the pegmatitic microcline-perthites is virtually identical to those of the enclosing gneisses, particularly where the latter are of the type that are considered to have reached their present composition by felspathization without having reached mobility. Consequently the field distinction of pegmatite from host-rock depends on the coarseness of the quartzo-felspathic constituents, rather than on any distinguishable deviation in composition or in general of texture between pegmatite and host-rock. Typical perthitic gneisses are represented by specimen 53/64 from two miles south-east of Yakubu Rock, 53/305 from two miles south of Muteithu, and 53/417 from the Ikoo gorge three miles east of Kamitotia.

### (7) Metamorphosed Extrusive and Intrusive Rocks

#### (*a*) *Hornblende gneisses*

Banded hornblende gneisses together with plagioclase amphibolites and plagioclase-garnet amphibolites often form part of the migmatites (p. 21). In contrast to these migmatitic rocks several exposures of dark-green, even-grained, very finely laminated and uncontorted hornblendic gneisses were noted, particularly in the Munyoni River between Magongo and Kathai, and also in tributaries of the Munyoni and Kakame a few miles north of the Zombe–Endau road. They are comparatively easily eroded and usually form inconspicuous exposures, which are, however, readily distinguished by a fine green diopsidic banding which contrasts with enclosing dark-green hornblende-rich bands.

In a thin section of specimen 53/555, from six miles north-north-east of Magongo, the dominant mineral is a pale hornblende, pleochroic in yellow-brown, green, and blue-green, prisms of which have a gneissose alignment, and which differs in colour from the dark hornblende of the migmatitic gneisses. The remainder of the rock consists of a crystalloblastic mosaic of andesine, and subsidiary pale-green to colourless diopside granules, which, like the hornblende, have a banded distribution. Iron ore and apatite, which are ubiquitous accessories in the hornblende migmatites, are lacking.

These rocks are intimately interstratified with pale-green epidotites, which in some cases consist almost entirely of a fine-grained granoblastic mosaic of epidote. Of these, specimen 53/550 from the Munyoni River four miles south-east of Endau, and 53/557 from six miles north-north-east of Magongo, are typical.

It has been suggested by Shackleton (1946, p. 14) that hornblendic rocks of this type were derived from metamorphosed basic tuffs, and since in the present area they differ notably from hornblende gneisses considered to have been produced by the metamorphism of calcareous sediments, and also contrast sharply with the hornblende gneisses and amphibolites of the migmatite zones, there is some support for their possible volcanic origin.

(*b*) *Meta-gabbro*

Meta-gabbroidal rocks are rare, but occur in an area approximately four miles east and north-east of Magongo, where they are associated with basic and ultrabasic types. On the eastern flanks of Kathai there are exposures of coarsely speckled, green-black and white, unfoliated rocks which in thin section (53/518) are found to contain hornblende and plagioclase in approximately equal amounts.

Hornblende forms xenoblastic aggregates consisting of numerous small individuals which together preserve the original ophitic or intergranular structure of pyroxene, of which there are a few remnants in the hornblende. Plagioclase has reformed as an equi-granoblastic mosaic, mainly of clear unaltered andesine, but at the centres of the original plagioclase individuals sericitization is conspicuous.

(*c*) *Amphibolite*

Dark-green, heavy and compact, hackly-fracturing amphibolites, which occur as lenticular bodies, notably in the Thowa valley and near the Migwani–Tulia road immediately east of Nzaoni, represent the few rocks of their kind to which an igneous origin can be ascribed with certainty. They are deeply weathered, an outer relatively soft skin of green secondary fibrous amphibole and chlorite enclosing an extremely tough, dark-green interior, which on fracture planes shows a decussate texture with pseudomorphs of stout pyroxene prisms measuring up to one centimetre across, which now consist almost entirely of fine fibrous amphibole.

In section 53/60 from two miles south-south-east of Yakubu Rock, original pyroxene is pseudomorphosed by fibrous aggregates of pale yellow-green actinolite, colourless tremolite, and yellow-brown antigorite which forms coronal growths about pseudomorphs, and also patchy replacements within them. Small unaltered areas of weakly pleochroic pink hypersthene indicate that these amphibolites are related to basic members of the charnockite series, probably perknitic in composition, which are described below.

(*d*) *Charnockitic rocks* (*perknites*)

Coarsely crystalline, dark blue-grey, tough, homogeneous pyroxene-bearing rocks occur as small bodies in the Thowa valley and between Tulia and Migwani, and also in larger complex bodies approximately four miles due east of Magongo, whence they extend for several miles northwards in a narrow belt. The largest single body forms a steep-sided, grass-covered hillock, Kathai, which has few outcrops and rises

about 200 ft. above the level of the surrounding plain. Here, as elsewhere, exposures consist of groups of iron-stained boulders, rounded by exfoliation, and having a thick oxidation skin.

Petrographically these rocks are very similar to the basic hypersthene-bearing rocks located immediately east of Kierra hill in the Embu-Meru district, which have been described by Pulfrey (1946, p. 67), and Schoeman (1951, p. 17) and, like the Kierra hill occurrences, they are located in a belt of thinly laminated amphibolite gneisses. The majority of specimens examined are perknites, which essentially contain hypersthene and augite in variable amounts, together with hornblende and subsidiary plagioclase. Green pleonaste spinel is recorded elsewhere as an accessory in this type of rock, and was noted in pan-residues taken from the lower slopes of Kathai, but does not, however, appear in thin sections. Uralite, tremolite, actinolite, antigorite and epidote are of frequent secondary development.

The hypersthene, which is variable in optical properties, usually displays a characteristic pink pleochroism. It is optically negative, with 2V ranging from 50° to 70°. Platey schiller inclusions are nearly always present.

The augite is a colourless or pale-green variety, which occasionally exhibits a faint pleochroism and usually possesses a prominent diallage parting parallel to (100). Most extinction angles measured ranged between 50° and 58°. Like the hypersthene much of the augite contains small schiller inclusions.

The hornblende is characteristically pleochroic in yellow-brown to olive-green, and exhibits conspicuous reaction relationships to the pyroxene, frequently forming granular coronal aggregates about its margins, and patchy replacement growths in both augite and hypersthene. The replacements sometimes coalesce to form continuous plates of hornblende preserving the cleavage of the original pyroxene, as in specimen 53/436 from 500 yards south-east of Nzaoni.

Felspar, which is usually andesine or acid labradorite, forms not more than 10 per cent of most specimens collected, and often is only a minor interstitial constituent. It is invariably surrounded by a corona of small hornblende granules. Twin lamellæ, where distinguishable, are sometimes curved, and strain polarization is common. One specimen (53/55) from four miles south-east of Kimokomo exhibits a remarkable diablastic intergrowth of plagioclase and hornblende, in which vermicules of optically continuous hornblende are enclosed in rounded porphyroblasts of clear andesine with distorted twin lamellæ.

In addition to secondary amphibole and chlorite mentioned above, accessory iron ore, pyrite, biotite and epidote are minor constituents.

Some estimated volumetric modes are as follows:—

| | 53/55 *per cent* | 53/528 *per cent* | 53/538*a* *per cent* | 53/539 *per cent* | 53/540 *per cent* | 53/546 *per cent* |
|---|---|---|---|---|---|---|
| Plagioclase .. .. .. .. | 10 | — | 6 | 5 | 1 | 1 |
| Hypersthene.. .. .. .. | 8 | 50 | 20 | 20 | 40 | 35 |
| Augite .. .. .. .. | 25 | 35 | 58 | 55 | 45 | 50 |
| Hornblende .. .. .. .. | 40 | 7 | 8 | 9 | 6 | 7 |
| Tremolite and antigorite .. .. | 15 | 4 | 7 | 5 | 3 | 4 |
| Iron ore .. .. .. .. | 2 | 2 | 1 | 1 | 2 | 2 |
| Quartz .. .. .. .. | — | — | — | 2 | — | — |

53/55, three and a half miles SE. of Zombe.
53/528, Kathai summit.
53/538a, Kathai, western slopes.
53/539, Kathai, western slopes.
53/540, Kathai, western slopes.
53/546, Endau–Magongo road, five miles NNE. of Kathai.

Certain olivine-bearing rocks described below ((*e*) and (*f*)) contain both hypersthene and augite with optical properties close to those of the pyroxenes contained in the perknites, and they may therefore represent compositional variations in a "charnockitic suite". Since, however, they were only recognized in small isolated masses which, in their exposures, showed no notable transition into perknites, they are classified appropriately by their mineralogical composition.

(*e*) *Norites*

Several small exposures of dark-green compact honey-comb-weathering norite were noted in a deep gorge one and a half miles north-east of Nzambani rock. In thin section (53/470), it is seen that the essential constituents are plagioclase, olivine, hypersthene, and hornblende. Plagioclase (acid andesine) forms large optically continuous grains which are finely clouded with inclusions of secondary albite and zoisite, arranged parallel to the indistinct twin lamellæ. Idiomorphic prisms of olivine are enclosed in the plagioclase, and surrounded by broad coronas of radially disposed pale-green antigorite, with some brown bowlingite. The fractures in the olivine are serpentinized and crowded with iron ore granules.

Hypersthene, which has a weak pink pleochroism and is sometimes altered to bastite, occurs in idiomorphic individuals in plagioclase, or more commonly in allotriomorphic groups, and has thin reaction borders of antigorite and uralitic hornblende, particularly against plagioclase.

The norite is strongly differentiated, and in parts of the rock which are plagioclase-free, dark-brown hornblende forms large optically continuous patches with fine schiller inclusions, and encloses both hypersthene and olivine. Much of the hornblende appears to replace hypersthene, and in such cases the rock has the composition of a hornblende picrite rather than a norite, a type of variation that is not uncommon in the noritic rocks, and which has been described from the Huntley Complex in Aberdeenshire (Read, 1923, p. 104).

Apart from the serpentinous minerals mentioned above the remaining accessories are biotite and iron ore.

(*f*) *Peridotite*

A small dyke-like body of dark-green, heavy, serpentinized, peridotite having a strike similar to that of the enclosing gneiss, was noted in the Ikoo River about two and a half miles north-west of Ikoo.

In thin section (53/189) rather more than half the rock is found to be composed of olivine together with derivative serpentine, which is invariably bright yellow, or green, and extensively developed in open fractures within the olivine, where it is accompanied by streaks of ore. The remainder of the rock is composed of pyroxene, including both augite and hypersthene, though the former predominates. Both varieties of pyroxene are densely schillerized, and the augite shows a well-developed diallage parting.

## 2. Lacustrine Sediments of the Mui Valley

In the north-central part of the area a considerable thickness of Pleistocene clastic sediment occurs west of the Nuu hills. The precise extent of the deposits is unknown, but test-drilling, water-borings, and wells in the vicinity of Mui, show them to be distributed over an area of several square miles, and it would appear that they occupy much of the gently undulating valley-zone north of the Ikoo River.

The sedimentary series consists of two groups which are separated by an unconformity. The upper group, which varies from 30 to 100 ft. in thickness, is dominantly arenaceous, and consists of recent, unconsolidated, red-brown earths, grading downwards

carbonaceous clay and are being examined by Professor R. Kraeusel of the Palæobotanical Department, Senckenberg Museum, Frankfurt-am-Main. In the absence of further fossils from the remainder of the succession correlation of the carbonaceous horizons with specific interpluvial periods is virtually impossible. Since, however, the carbonaceous beds are restricted to the upper part of the sequence it is suggested that the considerable thickness of fine clastic sediments below them was deposited in early middle Pleistocene times during a long, cold, and humid climatic period, when lake levels throughout East Africa were particularly high and when, following on lower Pleistocene tectonic disturbances, considerable thicknesses of lacustrine sediment were deposited elsewhere in Kenya, e.g., near Lake Rudolf, in Kamasia, the Nakuru-Naivasha basin, Kinangop, Kedong and Magadi, and in many other localities (Great Pluvial, Nilsson, 1935, p. 17, or Kamasian 2nd Pluvial, Leakey, 1950, p. 63).

Details of trial borings made near Mui, together with analyses of lignite are furnished below (p. 43; Fig. 5, p. 45; Fig. 6, p. 46; Fig. 7, p. 44).

### 3. Superficial Deposits of Recent Age

The Basement System rocks are mantled with red and brown sandy soils, which locally develop cellular lateritic ironstone and concretionary *kunkar* limestone. Over much of the peneplain in the eastern half of the area residual soil cover is comparatively thin, and rarely exceeds a depth of 20 ft., but on the sides of some of the hills, where torrential outwash fans are developed, deep gullies reveal sections of soil, alluvium, and rudaceous deposits, up to 40 ft. in thickness. Such piedmont deposits no doubt exceed 100 ft. in thickness in some localities, particularly on the eastern flanks of the Mutito ridge.

The soil cover throughout the area is typically red and ferrallitic (Robinson, 1949, p. 409), containing a high proportion of sand and quartz gravel. The prevalence of high temperatures and low rainfall contribute to the destruction of plant residues, and in all soils, apart from darker varieties of the wooded regions above the 4,000-ft. contour, the growth of humus appears to be inhibited.

Surface drainage of the end-Tertiary peneplain is comparatively sluggish, and rivers only carry run-off for a short period during the rainy seasons. The formation of superficial deposits, therefore, depends rather on chemical action, assisted and maintained by the circulation of ground-water, rather than on mechanical processes of erosion. Thus cellular lateritic ironstone and *kunkar* limestone are produced by the alternation of powerful leaching during periods of seasonal rainfall, with desiccation and upward capillary migration of solutions during the dry season, which is attended by the deposition of colloidal hydroxides of aluminium and iron, and also carbonates of calcium, magnesium and iron. Local rainfall is not sufficiently intense or sustained to produce true soil laterization by this process, much of the hydrous alumina formed by leaching during the rains being subsequently re-silicated during capillary rise throughout the following dry period.

The deep decomposition of Basement System rocks, concomitant with the formation of ferralitic soils which have suffered no mechanical transportation, is illustrated by the unbroken continuity of pegmatites in the underlying rock with intensely decomposed pegmatite residuals in the ferrallitic top-soil. Such remnants are often the only rocks exposed in districts of low relief. The felspars in them are completely kaolinized and the materials of the veins are incoherent, only the muscovite and quartz escaping decomposition.

The composition of the soil cover tends to uniformity in the west, were erosion is active, but in the eastern peneplain areas, where transport is restricted, the variation in the character of the soil is a reflection of the contrasting nature of the underlying rocks. *Kunkar* limestone is preferentially developed over rocks which have a relatively

high content of soluble lime, and often masks exposures of crystalline limestone. In the Munyoni and Kakame Rivers a thickness of over 15 ft. of *kunkar* was observed above rock-brash and ferrallitic soil derived from the underlying metamorphosed semi-calcareous sediments. Quartzites locally yield unconsolidated quartz gravels, which are frequently pink in colour and sparsely covered by vegetation. The para-gneisses and granulites are overlain by yellow and pink ilmenite-magnetite sands, whilst the pelitic and semi-pelitic rocks are mantled by darker, brown biotitic sands, containing occasional garnet and, finally, the ultrabasic rocks give rise to a characteristic chocolate-coloured sandy soil, darkened by ferromagnesian minerals.

Dark-grey or black soils are rare, but were noted with patchy distribution in the Mui valley, where local drainage is poor and the underlying rocks are mainly clays. These soils are possibly unstable and undergoing degredation, with loss of organic matter, following on the cessation of stagnant drainage conditions, as is suggested by their present environment and light surface colour.

In the deeply dissected area immediately east and north-east of Kitui the steeply graded torrential stream beds carry considerable accumulations of ill-sorted boulders, but on reaching the Thowa and Ikoo valleys the seasonal streams rapidly lose their carrying capacity, and in consequence the broad river valleys have accumulated stratified sands and gravels which contain occasional boulders of Basement System rocks. The sands of minor streams are frequently heavily streaked with magnetite and ilmenite.

### 4. Tertiary Dyke Intrusions

Unmetamorphosed, or post-Archæan dyke rocks are comparatively rare, particularly in the west, but occur elsewhere in a zone extending in a north-north-westerly direction from the vicinity of Endau to the Nuu hills.

They are of two types, each having minor variations—

(1) porphyritic-trachytes; and

(2) lamprophyres.

The former are the most common, nearly all the dykes noted in the western part of the Nuu hills being trachytic. Some of them are highly altered and specific classification is difficult.

#### (1) Porphyritic-trachytes

These are best exposed in streams immediately west and south-west of Muteithu, which is the main hill-feature between Nuu and Mui. Here, at least three parallel dykes of respective widths two, fourteen, and thirty feet, have nearly vertical contacts with migmatized semi-pelitic gneisses, and extend southwards for a distance of five miles to a point near the Nuu–Mui road, on which they are not exposed. They again appear approximately five miles south of the road where the principal member, in conjunction with its flanking gneiss, forms a low ridge which extends for a distance of about four miles over an otherwise featureless plain. Farther to the south-west similar dykes occur in the Kololo and Kathioka Rivers, and also cross the Endau–Nuu road close to the Ngamba-Sosoma fork, approximately five miles north of Endau. In addition to these exposures angular fragments of trachyte are liberally distributed in the sandy, flat, bush-covered area, west of Endau.

Exposures of these rocks are pink or yellow-brown, and are invariably honeycombed due to the differential weathering of zeolitic pseudomorphs which gives a superficial appearance of vesicularity. Fresh fracture surfaces are often conchoidal, mauve to grey in colour, and dappled with zeolites, but in rare cases individual glassy felspar phenocrysts can be distinguished.

Thin sections of specimen 53/280 from three and a half miles north-east of Mui, and 53/330 from two miles west of Kathiliwa, have a well-developed trachytic texture with sanidine occurring as large, clear, idiomorphic, or partly corroded phenocrysts,

often showing Carlsbad twinning. The phenocrysts are set in a groundmass of innumerable sanidine microlites arranged in flow lines which wind around them. Quartz, which is probably secondary or derived from foreign inclusions, occupies minute cavities within the groundmass, and is interlaced with fine anisotropic, brown needle-microlites. The remaining constituents are iron ore, which is scattered throughout the groundmass, and red-brown biotite in rare partly corroded flakes.

Many of the dykes are intensely altered and in specimens taken from one mile south of Muteithu (53/291, 53/297) felspar, both of the phenocrysts and groundmass, is converted to an aggregate-polarizing base of quartz, kaolin, sericite, calcite and zeolites, with occasional chlorite-iron ore streaks, which are possibly derived from biotite. In a less-altered specimen (53/553) taken from a point where the Nuu–Endau road leaves the eastern margin of the area, the phenocrysts retain visible zoning and Carlsbad twinning, and in the most-altered dykes the idiomorphic or glomero-porphyritic habit of the phenocrysts, together with the trachytic texture of the groundmass, is not obliterated.

The dyke contacts are sharp with fine-grained margins, and sometimes contain foreign inclusions represented by corroded quartz (53/117). The wall-rock is at times brecciated and recrystallized over a width of two or three inches. One specimen (53/559a) taken from a dyke-gneiss contact, contains sharply angular quartz and microcline fragments, together with fresh orthoclase and oligoclase, in a granulitized and aggregate-polarizing matrix.

### (2) Lamprophyres

Dark blue-grey, fine-grained dyke rocks, some of which are spotted with white zeolitic vesicles or show minute dark serpentine pseudomorphs, were particularly noted in the Munyoni River, south-west of Endau, and also immediately east of Endau where a fine example occurs in the Kololo River. Similar rocks also occur west of the Endau–Nuu road, about five miles north of Endau, and again in the north-west corner of the area between the Tyaa valley and the Migwani–Mwingi road.

Thin sections of specimens 53/365 and 53/380 taken from exposures in a western tributary of the Tyaa, close to the northern margin of the area, contain pseudomorphs with the typical pointed terminations of idiomorphic olivine, containing green and yellow serpentine with a cross-mesh of chrysotile fibres. The pseudomorphs are enclosed in a pilotaxitic matrix of hornblende and augite, associated with evenly distributed iron ore granules and a multitude of fine apatite needles, in a base largely composed of calcite and zeolites. Much of the zeolite is probably analcite. Titan-augite forms colourless to pale pink, faintly pleochroic prisms, which tend to occur in glomero-porphyritic groups, the larger individuals being sometimes zoned. It is accompanied by elongated prisms of hornblende, strongly pleochroic from brown to deep red-brown, with the optical characters of barkevikite.

Other specimens of similar dyke rocks from the Munyoni and Kololo (53/549, 53/554), are highly altered and contain much aggregate-polarizing calcite and zeolite. The enclosed pseudomorphs, however, preserve the shape of original olivine or pyroxene, and the pilotaxitic texture of the original pyroxene-amphibole matrix, in which rods and granules of iron ore, together with biotite, are the only unaltered remnants, still remains.

The majority of these lamprophyres are classified as amphibole monchiquites.

## VI—METAMORPHISM AND GRANITIZATION

The Archæan rocks of the Basement System have suffered intense regional metamorphism, which was possibly only completed after more than one pre-Cambrian orogenesis. Before metamorphism the sediments ranged from shales and mudstone to sandstones and arkose, and included locally developed semi-calcareous sediments

and limestones and intercalations of volcanic rocks and basic or ultrabasic injections. Subsequent to their deposition these rocks were involved in a crustal downbuckle, brought about by great horizontal stress and accompanied by folding and overthrusting of the surface layers. At the same time parts of the series were thrust deep into the earth and ultimately transformed to a crystalline gneiss complex which includes rocks of granitic composition. A relaxation of compressive forces and a slow return to isostatic equilibrium accompanied by deep erosion over a long period of geological time eventually revealed a metamorphic assemblage of great complexity.

Within the present area the metamorphosed argillaceous sediments characteristically contain the high-grade index mineral sillimanite, which is sometimes found together with almandine garnet, but these minerals are only developed in comparatively narrow belts and were evidently formed in the more aluminous members of an argillaceous series that was otherwise transformed to felspathic biotite gneisses, in certain zones of which albite-oligoclase porphyroblasts are a prominent constituent. These rocks are interstratified with widely distributed calc-silicate granulites, which are highly sensitive to mineralogical change during regional metamorphism and in this area develop a stable and characteristic mineral assemblage consisting of pale-green pyroxene, medium plagioclase, and garnet. Such an assemblage may be correlated with rocks of the pyroxene-hornfels facies of Eskola (1920, p. 146) which has been shown to be developed in, and isofacial with, high-grade sillimanite zones of regional metamorphism occurring in south-western Norway (Goldschmidt, 1915), the eastern United States (Barth, 1936), and the western Scottish Highlands (Kennedy, 1949).

Pure dolomitic limestones show little mineralogical response to metamorphism apart from complete recrystallization and the growth of forsterite, but they have a close zonal association with bands and lenses of calc-silicate granulite, which in turn are found together with larger bodies of amphibolite, some of which contain calc-silicate granulite knots and streaks, and in rare cases residual calcite or dolomite. There can be little doubt that the massive limestones represent relatively pure members that resisted transformation to calc-silicate granulite and amphibolite which, when enclosed as lenses, bands and streaks in banded hornblendic gneisses mark former impersistent or feeble continuations of the limestones.

The metamorphosed equivalents of the arenaceous sediments are petrographically similar to aplites or non-porphyritic granites, but have an entirely concordant disposition within the sedimentary sequence, and invariably contain a small but easily visible proportion of crystallized magnetite which nowhere rises to economically workable proportions. In this feature, and in most others, they correspond closely to the "järngneiss" (iron gneiss) of south-western Sweden (Holmquist, 1933, p. 313) which, although possessing close affinities with granites, have been differentiated as para-gneisses in the Swedish Archæan complex for over half a century (Törnebohm, 1889).

Alkaline metasomatism on a considerable scale is implied by the present composition of the Kitui gneisses, which contain a high proportion of microcline invariably with replacive margins against corroded plagioclase. It is considered unlikely that such a high proportion of potash felspar could have been produced by the redistribution of clastic felspar in an arkose, though it may also have formed partly at the expense of original mica.

In the same way soda metasomatism appears to have been operative in the formation of albite-oligoclase porphyroblast gneisses which, in the western part of the area, are marginal to a belt of granitic gneisses and migmatites. East of Kitui, in a zone about six miles wide, albite-oligoclase gneisses show a progressive westward transition into microcline-oligoclase augen gneisses and granitic migmatites. The change is essentially one of progressive microcline development, soda felspar being almost exclusively developed in a zone remote from the granitization belt (Fig. 2).

The relationship between albitic porphyroblast gneisses and granitization centres is described in the classic account of the Stavanger area in southern Norway (Goldschmidt, 1921, p. 113), and more recent work (Barth, 1948, p. 57) has indicated the comparatively small ionic interchanges necessary to produce profound mineralogical alterations during metamorphism, particularly in the felspathization of metamorphosed sediments. The observed initial growth of soda-felspar in preference to potash felspar during progressive granitization is considered to be determined by the smaller ionic radius and consequent greater mobility of the sodium ion as compared to the potassium ion, in an advancing zone of alkaline metasomatism (Lapadu-Hargues, 1945, p. 290).

In the present area the felspathization of both arenaceous and argillaceous sediment apparently occurred without mobility of the rocks being reached, but in the migmatites some granitic material was apparently mobile or semi-fluid and represents either injections from below, or quartzo-felspathic segregations in process of being fused out of the enclosing rock. If squeezing-out of the lower-melting constituents of the rocks during orogeny occurred on any scale, many of the crystalline metamorphic rocks must have been changed by the loss of granitic material, and should in some cases have assumed an extreme composition. This may be illustrated by the coarsely crystalline quartzites which are found in the eastern part of the area. It is difficult to reconcile their complete resistance to granitization, when other arenaceous members of the metamorphic complex have been intensely granitized. If, however, they were originally more arenaceous sediments and granitic components were removed from them during differential re-fusion, progressive residual quartz enrichment would possibly have led in the end to the formation of pure quartzites.

The granitic rocks of the Basement System in Kitui appear to have been produced almost entirely by metasomatic processes. Sheets and lenses with intrusive contacts form a very minor proportion, and are considered to be palingenetic. There are no granites of batholithic dimensions.

In the eastern half of the area granitoid gneisses occupy the cores of anticlinal structures with steep and variable pitch, and this may indicate some degree of diastrophic emplacement. These rocks are conspicuous for their content of ovoid quartz-sillimanite bodies which sometimes occur in strings and bands, and are apparently digested representatives of quartz-sillimanite bands in the neighbouring pelitic gneisses. The non-porphyritic and granulitic texture of the enclosing rocks continues undisturbed up to the edges of the quartz-sillimanite knots. Ragged biotite relics within the enclosing gneisses show stages of replacement by patchy sillimanite, whilst pseudo-sillimanite gneisses occur locally where the sillimanite has largely retrograded to muscovite, which forms ovoid radiating clusters containing small fibrous sillimanite remnants.

Possible explanations for the formation of sillimanite *faserkiesel* vary from late metasomatism during waining regional metamorphism (Watson, 1948), to differentiation of an aluminous fraction from a granitic magma (Adams and Barlow, 1910). *Faserkieesel* already recorded in Kenya (Shackleton, 1946, p. 9) have been considered to represent the last visible stages in the dissolution of sillimanitic gneiss in migmatite, and in this connexion it is interesting to note that similar sillimanitic knots in Norwegian granites have been interpreted as armoured relics which were formed in pelitic schists before granitization, and owe their survival to protection by a skin of muscovite (Bugge, 1945). In the present area *faserkiesel*-bearing granitoid gneisses are closely associated with relatively non-granitized sillimanite gneisses, the more quartzose bands of which resist granitization until a late stage, when they undergo further dissolution into ovoid bodies (Plate II).

## VII—STRUCTURE

The most prominent structural features are expressed in the topography of the area, particularly in the west where a belt of para-gneisses displays a persistent north–south regional trend and has a constant easterly foliation dip of between 60° and 80°. At the extreme western margin, in the vicinity of Kitui, foliation dips tend to be westerly but this region is one of intense migmatization in which much of the sedimentary fabric is destroyed and irregular foliation dips tend to be obscured by flow structures. A broad belt of westerly dipping gneisses occurs immediately outside the western margin, however, and this pronounced change of dip would appear to indicate the axis of a steep anticline with north-north-west trend about which the meta-calcareous rocks that floor the Thowa valley are repeated immediately west of the Tiva outside the confines of the present area (Schoeman, 1948, p. 40).

In the east, structures are only revealed in the hills, exposures over most of the flat bush-covered areas being comparatively few. Large-scale open folding of meta-sediments is evident in the Nuu hills.

It has been generally accepted that a considerable portion of the Basement System rocks represents metamorphosed sediments, but there has been some uncertainty concerning the relationship between the visible layering, or foliation, and the original stratification of the ancient sedimentary rocks. Over the greater part of the present area the conformable attitude of rocks which are both foliated and non-foliated (e.g., crystalline and silicated limestones), essentially presents a sedimentary structural pattern, and layered mineral structures are considered to be parallel to the original bedding.

Lineations* are generally inconspicuous but were noted as fine ribbings on vertical joint-planes in massive to flaggy granulites. In quartzo-felspathic granulites the only dark minerals present occur as streaks of ilmenite or magnetite and impart a linear fabric to the rock, whilst some of the finer-grained and more biotitic gneisses show a fine linear wrinkling produced by the intersection of foliation and cleavage planes. In the Kitui hills lineation observations show a near-horizontal or northerly pitch, whilst eastwards in the Nuu hills and Magongo where the relatively sharp southerly axial pitch of folds is clearly displayed both in air-photographs and on the ground, southerly pitch of up to 25° degrees is indicated. One synclinal structure in particular produces a magnificient elongated arena about three miles across, north of the Mui–Nuu road. This feature is open to the south, but surrounded by hills rising to nearly 1,000 ft. above its floor on the remaining three sides. Immediately west of Nuu a second syncline, which is larger but not so clearly defined, pitches south-east, and within the associated gneisses the preponderance of a small number of lineation observations show a southerly pitch, so that the entire fold system of the Nuu hills is interpreted as homo-axial (Fig. 3). The fold pattern, however, shows variation both in degree of axial pitch and tightness of folding, which may indicate the diastrophic emplacement of the granitoid rocks that occupy the anticlinal cores. In this connexion, Magongo, situated some 15 miles south of the Nuu hills, resembles a dome in structure, being surrounded by para-gneisses which dip radially outwards at 25° to 30°. The structural plan is, however, ovoid, although this is obscured by faulting, and the major structural axis is aligned with an anticlinal axis in the Nuu hills. The structure may therefore represent a sharp anticlinal pitch culmination.

* A descriptive and non-genetic term for any kind of linear structure within or on a rock. (Cloos, E., 1946, p. 1.)

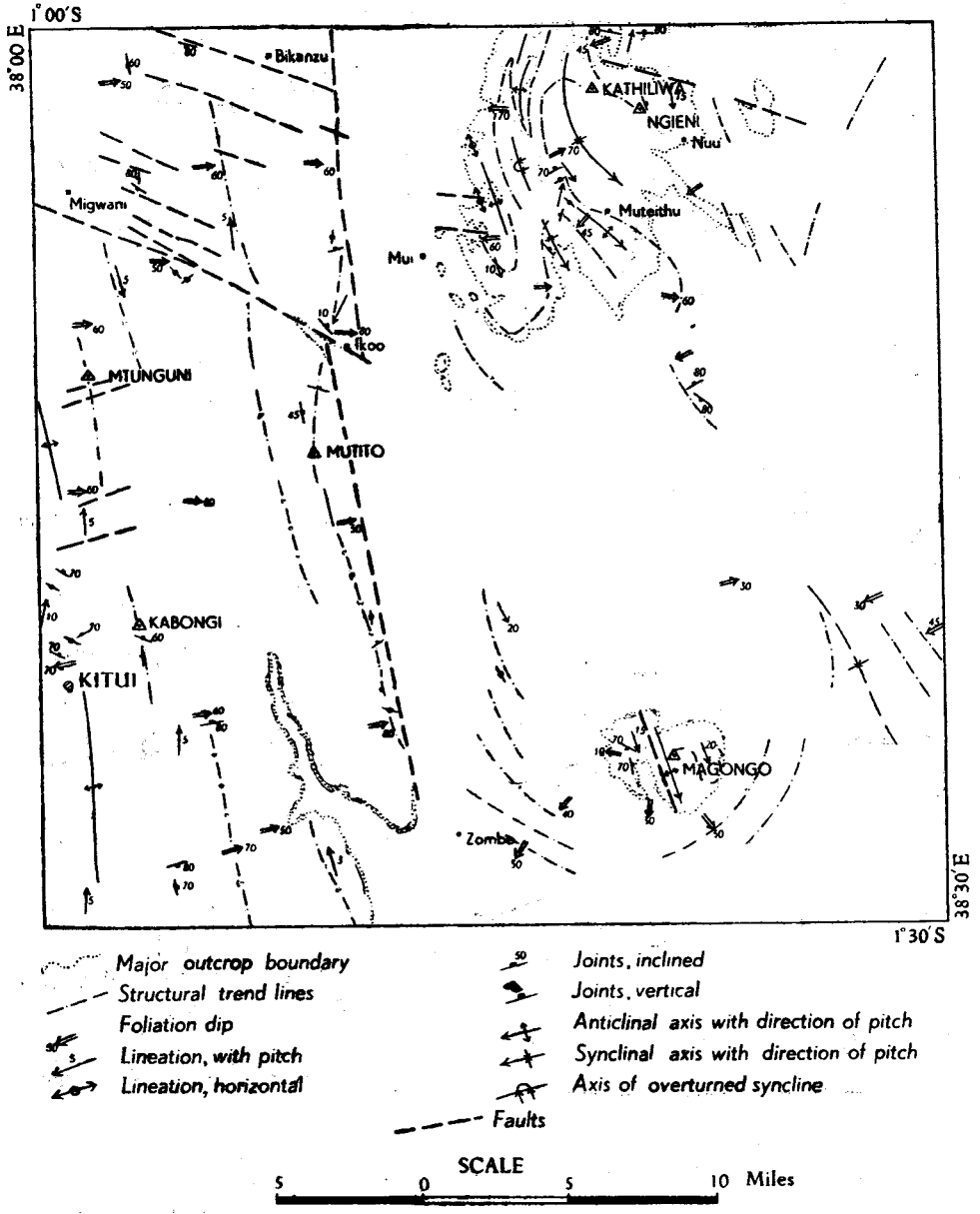



**Fig. 3.—Structural sketch-map of the Kitui district**

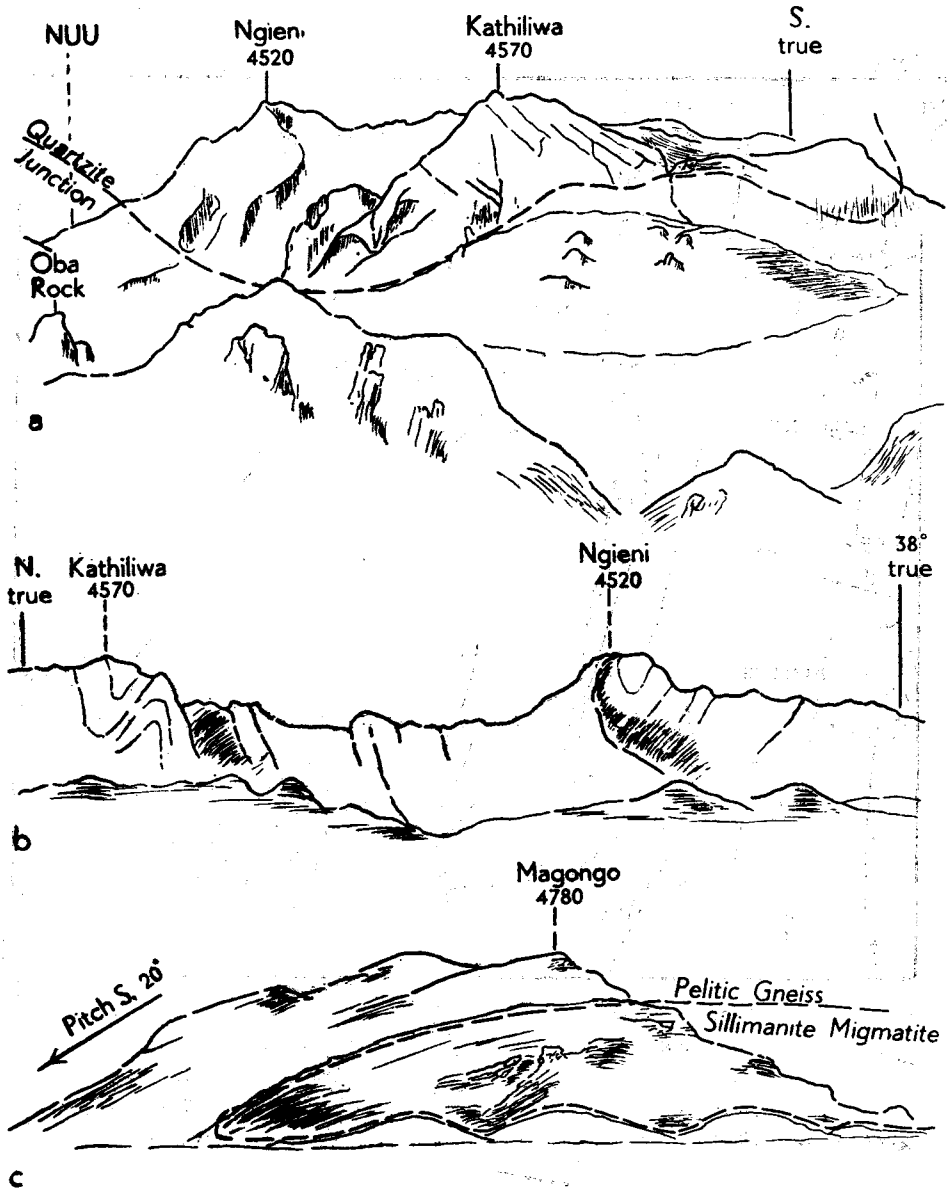



**Fig. 4.—Fold structures in the Nuu hills and Magongo**

**(a) Nuu quartzite mass, northern side, from Kyui (4,050 ft.). The culmination of a southerly pitching synclinorium.**

**(b) Nuu quartzite mass, southern face, from Muteithu (4,220 ft.).**

**(c) Magongo from the east. A southerly pitching anticline with domed migmatitic core.**

Minor folding is not common, but in some well-laminated gneisses puckers and crenulations are conspicuous though their axial planes show no consistent arrangement either between themselves or in relation to major folding. This applies particularly to the migmatitic gneisses in the western part of the area, and is in contrast to minor disharmonic folding within the coarsely crystalline quartzites, which produces a fine ribbing parallel to the axes of the major folds. This is only apparent at the noses of the principal folds, where intense compression has produced minor recumbent folding which is almost entirely obscured by subsequent recrystallization.

Clearly defined cleavage is rare within the area but cleavage jointing is fairly common in the massive metamorphosed arenaceous sediments, and particularly in quartzites, where a closely spaced tabular joint system is developed parallel to the axial planes of folds.

Most of the Basement System gneisses are well jointed, especially the massive granitoid rocks. In the Kitui hills a systematic joint system can be distinguished and in many exposures consists of a pair of master strike-joints separated by a vertical angle of 50° to 80°. One member is invariably a bedding joint-plane. These are intersected by an almost perpendicular set of dip joints which trend east–west and are either vertical or of steep northerly inclination. Transverse joints of this type impart a remarkable castellated appearance to the crests of ridges immediately to the west of the Inyuu bridge. The rectilinear pattern of dip and strike jointing is bisected by a subsidiary system of nearly vertical joints which trend north-west and north-east respectively, and form a conjugate shear system comparable with east–west compression.

Open strike-jointing at anticlinal crests in the Nuu hills probably represents post-Archæan tension fractures. Almost vertical Tertiary dykes, which follow an anticlinal axis south of Muteithu summit, have been emplaced in comparable planes.

The major tectonic pattern is obscure and depends for its interpretation on petrographical contrasts, physiography, and local structural discordances, rather than on identification of specific planes of movement.

In the north-western part of the area a considerable fault extends between Migwani, at the western margin, and Ikoo. Here the upper Ikoo River follows a narrow and virtually straight gorge which cuts sharply across the grain of the Kitui hills, and in places is over 1,000 ft. deep. Foliation dips and strikes within this zone are variable and granitic reticulation of the gneisses is common. The principal fault is paralleled by numerous small tear faults which produce lateral displacement visible in air-photographs. Relative movement is to the east on the northern side of most of them, and movement on the main fault would appear to be in the same direction.

The eastward extension of the Ikoo-Migwani fault across the floor of the Mui valley is marked by a series of low undulations on the northern side and also by the sharply rising inselberg Mwalano. Disruption was apparently sufficient to prevent southerly drainage at this locality and to lead to lake formation in the vicinity of Mui (*see* p. 31).

The eastern margin of the Kitui hills presents a straight mountain front which extends from Bikanzu in the north towards Zombe in the south and is suggestive of faulting. Along this line there is some ultra-basic intrusion, local brecciation and mineralization, which is almost exclusively restricted to magnetite. The topographical break is abrupt, with the straight-edge of the fault-line scarp truncating the ribbed para-gneiss topography at an acute angle in the south. There are no outlying minor hills.

In the belt east of Kitui Township some of the gneisses are crushed and partly mylonitized, and are intercalated with ultra-basic intrusions. It would appear that powerful shearing parallel to the present Mutito fault-line scarp took place in Archæan

times, and this may account for the local intensity of granitization, since ancient deep shearing of the crust has been held to provide a locus of granitization (Read, 1939). In this connexion the distribution of greatly attenuated granites has been associated with major zones of shearing in Tanganyika (McConnell, 1948, p. 206).

The magnitude of the Mutito fault-zone is evidenced by the contrast between the regular structural pattern of the Kitui hills in the west and the irregular sweeping structural forms of the Nuu hills and Magongo in the east. In the Kitui axis granitization is more intense than elsewhere and much of the sedimentary fabric is obliterated, but eastwards the sedimentary series is well preserved, and quartzites, which are completely lacking in the Kitui hills, form prominent outcrops. In addition no acid or intermediate dyke rocks similar to those of the eastern plainlands were located in the Kitui hills.

A structural feature of the Basement System in the eastern half of the area is the rapidity of pitch culmination and depression shown by folds with approximate north–south axes. These could have been produced either by the diastrophic emplacement of mobilized migmatite between the folds, or by the intersection of two regional orogenic trends. If the latter is the correct hypothesis it is considered that the folds developed during the north–south orogeny, which acted throughout the well-defined Mozambique belt with slightly west-of-north trend (Holmes, 1951, p. 256), were the later, and virtually obliterated all traces of the supposed earlier tectonic cycle.

## VIII—ECONOMIC GEOLOGY

Apart from a comparatively thin ferrallitic soil cover, and a small area of locally developed clay sediments, the area is entirely composed of metamorphic rocks of the Basement System in which there is no evidence of large-scale granitic intrusion accompanied by mineralization. Minerals of economic importance are therefore largely restricted to those produced directly by regional metamorphism or carried in pegmatites of palingenetic origin. Of the former only sillimanite was noted in anything approaching workable concentration, whilst magnetite is virtually the only ore mineral developed on any scale in the pegmatites.

### 1. General

#### (1) Lignite

In early 1950 S. D. Shah of Thika reported the finding of lignite in a well which had been used as a prospecting pit at the Mui Trading Centre, in the north of the area. In July of that year Messrs. D. K. Hamilton (E.C.A. Geologist), and A. O. Thompson (Kenya Government geologist), investigated the occurrence and confirmed that the pit contained a lignite seam 18 in. in thickness, having its base at a depth of 61 ft. below the surface. Some time later an African well, sited approximately one mile due south of the prospect pit, was investigated by the writer and found to contain a four-foot seam of lignite with its base at a depth of 39 ft.

Both the prospect pit and the well had been dug through river sands resting unconformably on sandy clays, of which further details are given on p. 30.

In October, 1950, Exclusive Prospecting Licence No. 93, covering 140 square miles in the vicinity of Mui, was granted to S. D. Shah with whom Messrs. Karlsson and Finne, Nairobi, subsequently contracted to drill three test bore-holes each sited at a distance of half a mile from the prospect pit, and arranged in a triangular pattern about it. The drilling programme was started in December, 1950, using a 2⅛-in. rotary drill, but was not completed until July, 1951, considerable delay being caused by the necessity to complete the contract with a percussion drilling machine since it was found that the semi-consolidated sediments gave unsatisfactory core-recovery.

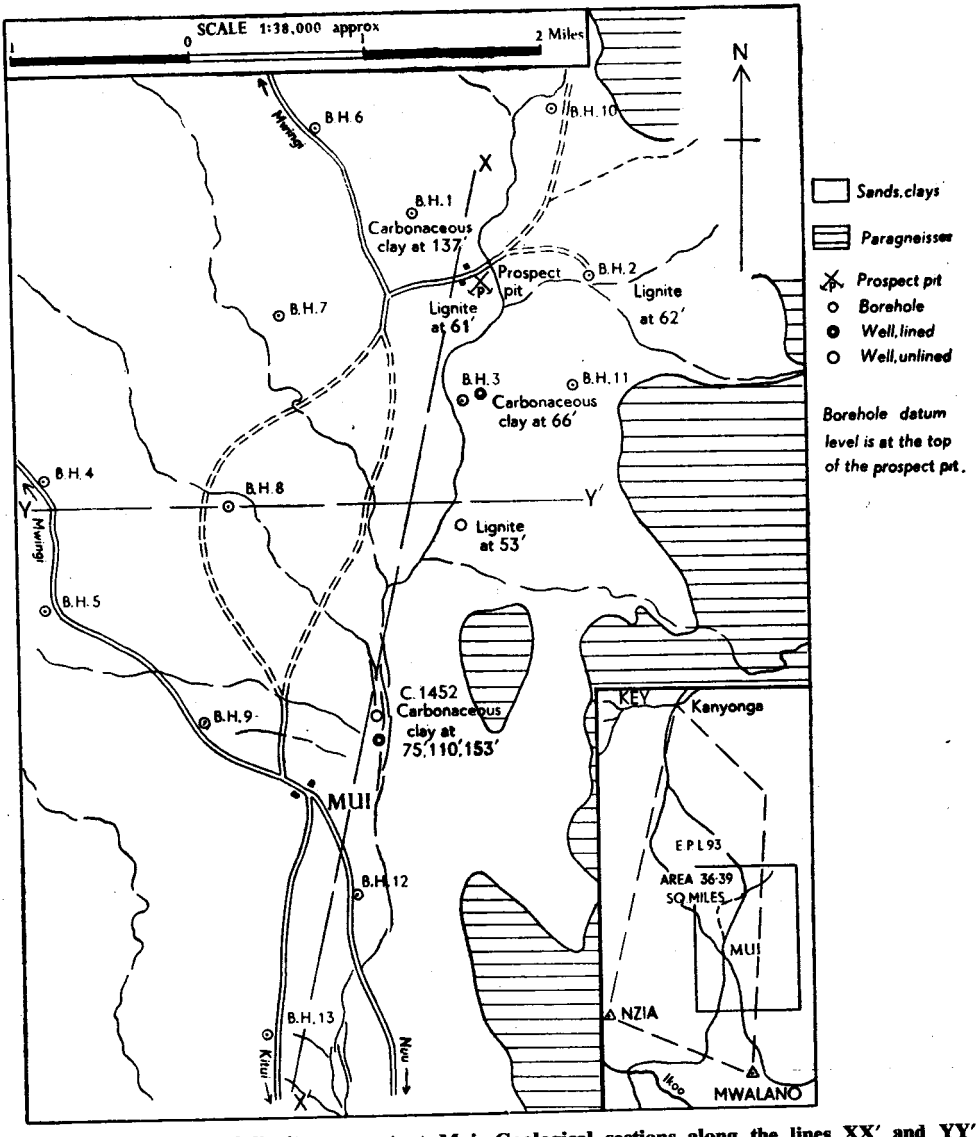



**Fig. 5.—Sketch-map of lignite prospect at Mui. Geological sections along the lines XX′ and YY′ are given on Fig. 7**

Of the three test bore-holes the most northerly (No. 1) was driven to a depth of 200 ft. and passed through highly carbonaceous clay and poor lignite from 150 to 153 ft. The most easterly bore-hole (No. 2) penetrated two feet of lignite between 68 and 70 ft., whilst the most westerly bore-hole (No. 3) passed through carbonaceous clay without lignite at 53 ft.

Further geological information was obtained from a percussion water-boring site approximately three miles south-south-west of the prospect pit at Mui Trading Centre. This boring (P.W.D. No. C.1452) was completed during February and March, 1951, by the Craelius Drilling Co. (E.A.), under contract to the Kenya Public Works Department, and was extended to a depth of 420 ft. without reaching Basement System rocks. It passed through three horizons of black carbonaceous marcasite clay, at depths of 65, 100, and 143 ft. respectively, each of which, however, contained only very thin lignitic lamellæ. The bore-hole record here was particularly interesting since the carbonaceous levels showed close agreement with the minima of an earth resistivity curve (No. 2238, Fig. 6) taken over the site in August, 1948, during a water survey conducted by A. O. Thompson, then geologist in the Hydraulic Branch of the Public Works Department.

In early 1952 the Exclusive Prospecting Licence held by S. D. Shah was renewed until October, 1952, the area being reduced from 140 to 38 square miles, and ten further bore-hole sites were selected in this locality, spaced at one-mile intervals on the corners of a square grid, but subsequent shallow percussion drilling by H. C. Grue of Thika in partnership with S. D. Shah failed to prove lignite (*see* Figs. 5 and 7).

*Assessment of the Prospect*

In the restricted area in which trial drilling has been completed existing bore-hole records indicate that the upper arenaceous series of sediments are at a minimum thickness immediately to the east of the Mui River, where they rest unconformably on a series of clays containing at least three carbonaceous horizons. In these, lignite is sporadic in distribution and can rarely be expected to exceed three feet in thickness. Its composition is variable, but the best analyses bear comparison with those of some South African lignites (*see* below).

In an area approximately two miles north-east of Mui removal of a minimum of 35 ft. of overburden would be required to reach the upper lignite seam by opencast methods, and it is considered that this would not prove to be an economic proposition, and would in fact be difficult to execute since the prospect lies on the drainage axis of the Mui River. Considerable difficulty in preventing flooding of workings during the rainy season would be experienced. The semiconsolidated sands and plastic clays in which the lignite is located are particularly unfavourable for the alternative method of extraction by mining.

Proximate analyses of lignite samples from Mui are as follows:—

TABLE I

| Sample Number | Cal. Val. (lb./lb.*) | Per cent Moisture | Per cent Ash | Per cent Volatiles | Per cent Fixed Carbon |
|---|---|---|---|---|---|
| 21298 .. .. | 6·5 | 34·60 | 10·70 | 39·80 | 14·90 |
| 21299 .. .. | 5·9 | 16·90 | 29·50 | 36·40 | 17·20 |
| 21271 .. .. | — | 22·56 | 11·20 | 53·54 | 12·70 |
| 22806 .. .. | — | 35·0 | 38·14 | 13·70 | 13·15 |
| 22807 .. .. | — | 35·0 | 20·51 | 19·90 | 24·55 |

* Calorific value (lb./lb.) indicates pounds of steam obtained from one pound of the material tested.

21298, 21299. Anal. Fuel Research Institute, South Africa.

21271, 22806, 22807. Anal. W. P. Horne, Chemist and Assayer, Mines and Geological Department, Nairobi.

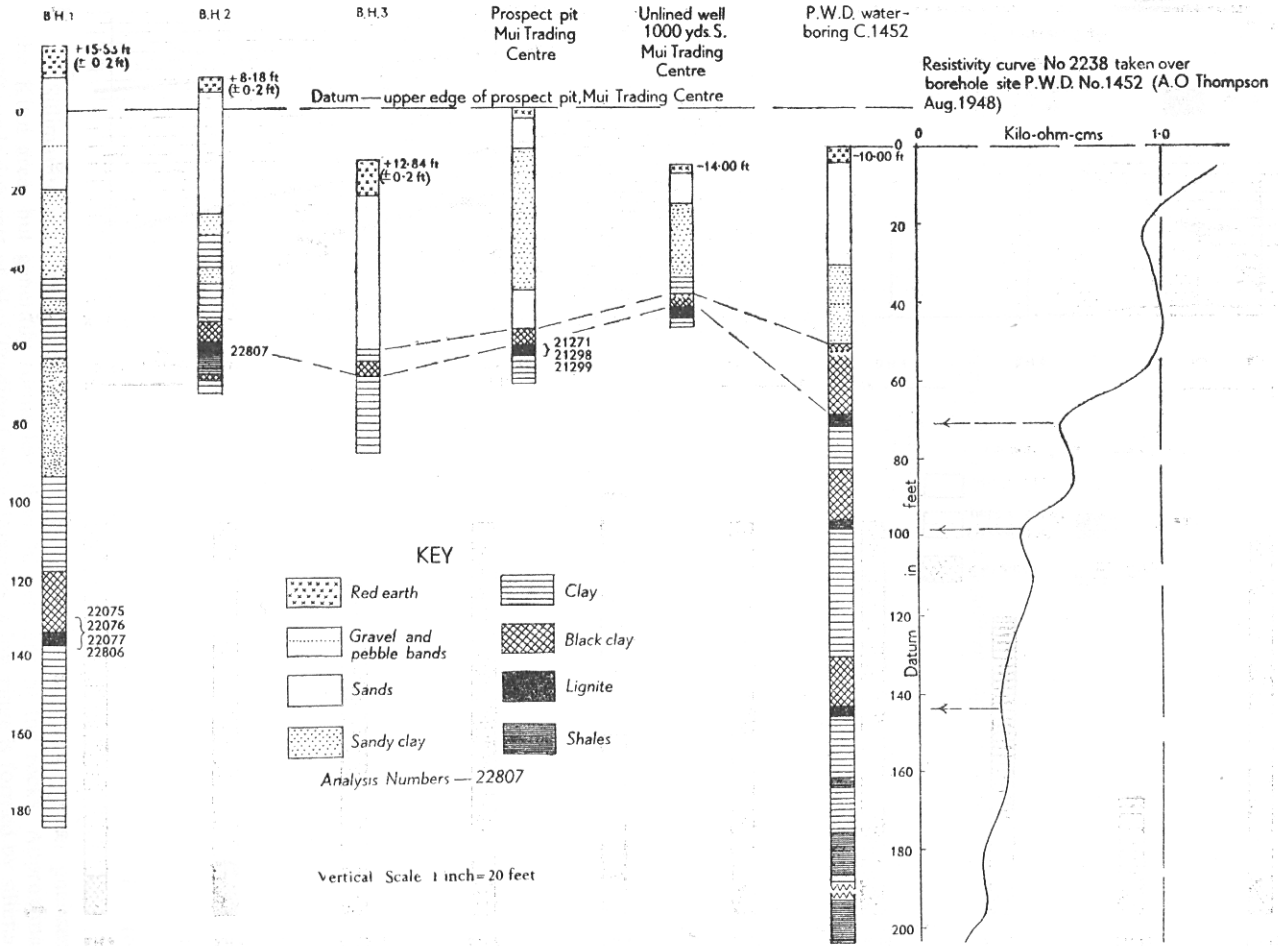



**Fig. 6.—Sections of wells and bore-holes near Mui lignite prospect, January–July, 1951**

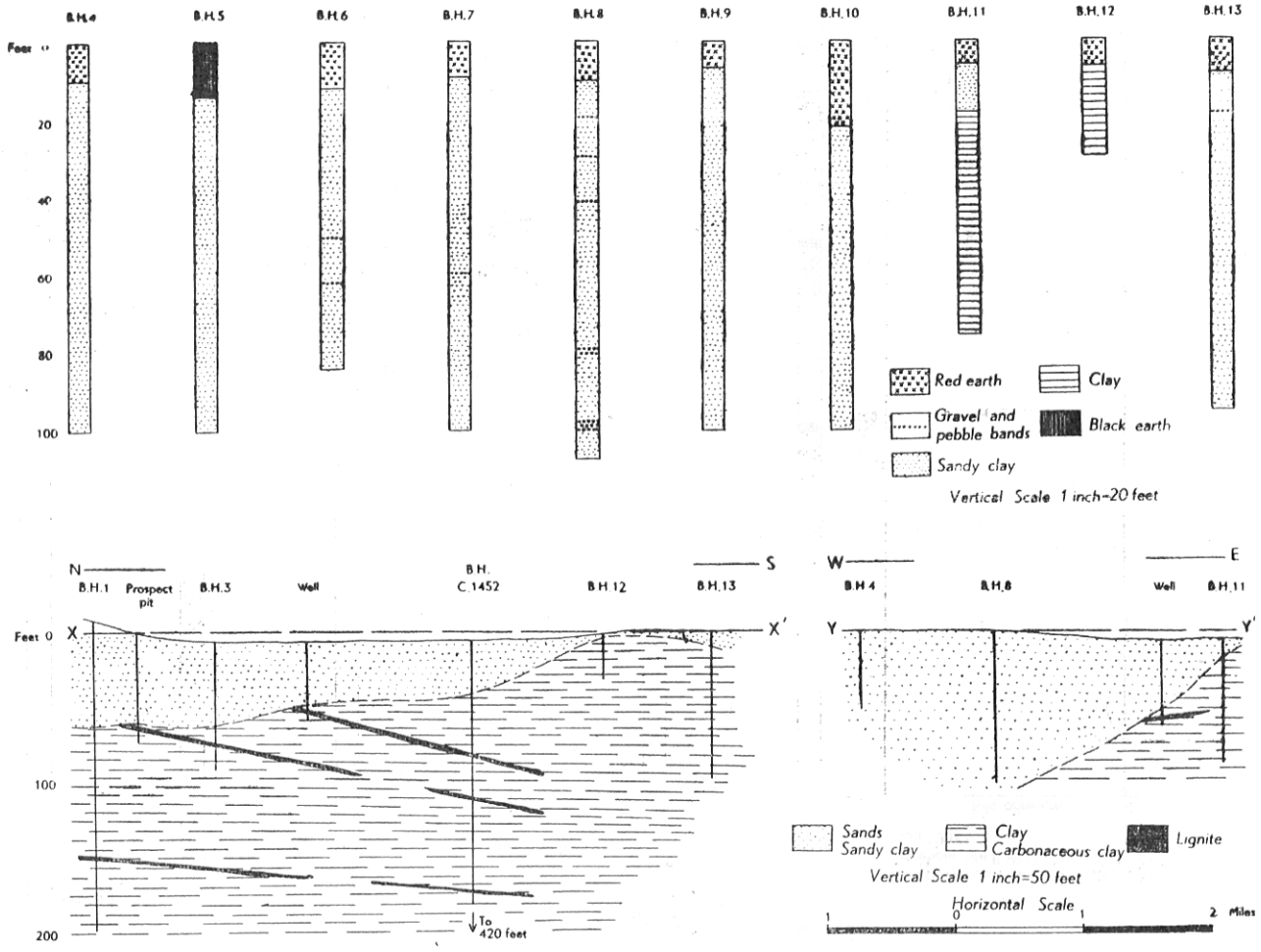



**Fig. 7.—Sections of bore-holes near Mui lignite prospect, February–March, 1952, and geological sections. The lines of sections XX′ and YY′ are shown on Fig. 5**

The depth and location of samples are given on Fig. 6. Other analyses of samples 21298 and 21299 were given in the Annual Report of the Mines and Geological Department for 1950 (p. 16). It should be noted that there is a considerable divergence of moisture content of the two Mui samples analysed in South Africa, and this is thought to have been caused by unsatisfactory sealing of specimen No. 21299, with consequent loss of moisture during transit. Analyses Nos. 22806 and 22807 were completed on dry material and the results recalculated to allow for an initial moisture content of 35 per cent.

For comparative purposes analyses supplied by the Geological Survey of South Africa of some South African lignites are quoted below:—

TABLE II

*Analyses of four lignites from Knysna (Southern Cape Province)*

| | Cal. Val. (lb./lb.) | Per cent Moisture | Per cent Ash | Per cent Volatiles | Per cent Fixed Carbon |
|---|---|---|---|---|---|
| (1) .. .. | 6·0 | 44·0 | 7·0 | 26·6 | 22·4 |
| (2) .. .. | 7·3 | 31·7 | 3·2 | 35·4 | 29·7 |
| (3) .. .. | 6·8 | 25·0 | 13·3 | 35·6 | 26·1 |
| (4) .. .. | 6·0 | 26·5 | 21·5 | 33·6 | 18·4 |
| *Analyses of two lignites from van Rhynsdorp (S.W. Cape Province)* | | | | | |
| (1) .. .. | 8·1 | 9·5 | 23·9 | 36·6 | 30·0 |
| (2) .. .. | 7·3 | 1·7 | 22·4 | 51·4 | 24·5 |

These South African lignites are Recent, and rest on rocks of Palæozoic and Archæan ages.

Some analyses of carbonaceous clays with which lignite is interstratified at Mui are as follows:—

TABLE III

| Sample Number | Per cent Moisture | Per cent Ash | Per cent Volatiles | Per cent Fixed Carbon |
|---|---|---|---|---|
| 21286 .. .. .. | 9·0 | 62·4 | 25·1 | 3·5 |
| 22075 .. .. .. | 16·0 | 71·9 | 11·9 | 0·1 |
| 22076 .. .. .. | 12·1 | 70·5 | 16·6 | 0·9 |
| 22077 .. .. .. | 12·2 | 61·8 | 22·9 | 3·2 |

*Anal.* W. P. Horne.

(2) SILLIMANITE

Sillimanite is a widespread alumino-silicate in the Basement System gneisses of the Kitui area, but generally forms less than 10 per cent of the rocks. Approximately 3,000 yards due east of Mui Trading Centre, however, a low ridge is formed by sillimanite gneisses ash-white in outcrop or locally stained in buff colours, which consist almost entirely of sillimanite and quartz. The outcrop is about 30 yards in width and several hundred yards in strike. Samples contain 35 to 40 per cent sillimanite, and a representative sample assayed 21.77 per cent alumina. Thin bands within the gneiss are composed almost entirely of sillimanite,

The sillimanite needles are generally less than one centimetre in length and form fibrous intergrowth with quartz. Their separation by mechanical means would hence be difficult, and the deposit is not considered to have any immediate commercial value, although the tonnage available may be considerable.

### (3) Limestone

Although some exposures of crystalline limestone in the Kitui area contain bands and knots of calc-silicate minerals and flakes of graphite as impurities, others are relatively pure. One limestone that crosses the road 500 yards west of Inyuu Bridge is extremely coarse, containing large blue-grey rhombohedra of calcite measuring up to three centimetres across, and is only slightly dolomitic. A representative sample on analysis was found to contain 96.51 per cent calcium carbonate, and 2.76 per cent magnesium carbonate. The outcrop is approximately 60 ft. in width and has been followed intermittently for about six miles. Several thousand tons of limestone are available in the immediate vicinity of the road and might prove suitable for burning for agricultural or building lime, and probably for Portland cement manufacture since in certain bands the magnesia content is as low as 1.3 to 1.4 per cent.

### (4) Talc

Lenticular pockets of talc up to nine inches across were noted at the western contact of the above-mentioned crystalline limestone which was pitted to a depth of 12 ft. The talc is concentrated, together with actinolite and diopside, in a contact zone about two feet wide. It also occurs as a minor constituent of hornblende-actinolite schists exposed in the Thowa valley.

### (5) Clay

Beneath the superficial river sands of the Mui location a considerable thickness of fine grey and blue-green clays occur and have been referred to elsewhere (p. 31).

Analyses of three representative samples are given in the following table together with an analysis of argillaceous material used in cement manufacture for comparison:—

| | *Per cent* | *Per cent* | *Per cent* | *Per cent* |
|---|---|---|---|---|
| $SiO_2$ .. .. .. | 46·52 | 45·40 | 45·76 | 54·80 |
| $Al_2O_3$ .. .. | 20·81 | 24·39 | 29·62 | 14·40 |
| $Fe_2O_3$ .. .. | 9·64 | 7·24 | 2·75 | 8·10 |
| MgO .. .. .. | 1·09 | 0·83 | 0·52 | 1·63 |
| CaO .. .. .. | 0·78 | 0·66 | 0·70 | 2·97 |
| Loss on ignition .. | 19·60 | 19·36 | 19·00 | 15·29 |
| $TiO_2$ .. .. .. | 1·05 | 1·15 | 1·40 | — |
| | 99·49 | 99·03 | 99·75 | 97·19 |

1. Sample 53/M1/40, Mui borehole No. 1 at 40 ft. depth.
2. Sample 53/M1/180, Mui borehole No. 1 at 180 ft. depth.
3. Sample 53/M2/53, Mui borehole No. 2 at 53 ft. depth.

A. Medway mud.

Used in the correct proportions in conjunction with a limestone similar to that referred to above these clays would probably be suitable for the manufacture of Portland cement of a quality that would meet the British Standard Specification. Gypsum is available in nearby areas to the north-east. The clay and limestone, however, are situated approximately 30 miles apart and the former lies under an overburden of 20 to 30 ft. of sand and superficial soils and, since the location of both is remote from the railway, the possibility of economic production is doubtful.

Bricks for local use are at present made at Ikoo. The material employed is superficial red earth dug from the banks of the Ikoo River close to the water-holes. The earth puddles fairly well but the brick produced is brittle and would be improved if the red earth were mixed with clay. More suitable material for brick-making would be available if a clay-pit was opened at Mui, but the water supply in the locality is unfortunately poor, water-holes in the Mui River drying out more rapidly than those at Ikoo.

(6) Ilmenite and Magnetite

Titanium-bearing iron ores in various stages of alteration to hematite are widely distributed in the para-gneisses of the area and occur as small streaks or octahedra. In the larger pegmatites associated with these rocks iron ore segregations are often conspicuous and sometimes contain individual crystals measuring several inches across, but are not of economic significance. The ore is particularly high in titanium oxide, one pegmatitic sample assaying 49.99 per cent ferric oxide and 44 per cent titanium oxide.

River sands, particularly in the smaller streams, are invariably heavily streaked with iron ore minerals but no economic concentrations occur.

(7) Mica

The larger pegmatites, which are best developed in the hills situated east and north-east of Kitui, contain books of mica up to about four inches in diameter, but they are invariably finely fractured and of little value.

(8) Graphite

Sparsely distributed graphite occurs in the crystalline limestones of the Thowa valley and also in flaggy biotite gneisses associated with them, but in all observed cases the concentration was low, and no graphite schists were noted.

(9) Ochre

Red ochre was noted approximately one mile south-west of Muteithu summit where Tertiary dyke rocks are associated with a deeply iron-stained kaolin, which fills joints at or near their contacts. It is used as a pigment by the natives.

(10) Magnesite

Thin veins of magnesite reticulate parts of a perknite which outcrops at a small hillock, Kathai, situated east of Magongo. They are rarely developed to a width greater than half an inch.

(11) Gold

Quartz veins are comparatively few within the area and do not appear to carry gold, nor do the alluvials of the streams draining the Kitui and Nuu hills contain sufficient gold to produce a visible tail on panning.

Quartzose granulites which are characteristically speckled with pyrite (p. 19) do, however, contain a trace of gold, generally less than one pennyweight per ton, and this is presumably contained in the pyrite.

**2. Water**

Water supply for both the native population and their livestock is obtained throughout the area from rivers, which usually carry running water during the wet months of April and November, but rapidly dry out after the short rainy seasons. The upper courses of streams usually carry water for a few weeks after the sand-rivers of the plains have become dry. The deep sandy beds of the sand-rivers form an effective blanket against evaporation and enable water to be obtained by digging to a depth of a few feet. Water-holes in the Thowa and Ikoo are re-excavated after each rains and usually yield water throughout the intervening dry season,

Remaining water supplies are provided by springs, bore-holes and wells. Springs are comparatively few, but sometimes occur at the foot of massive para-gneiss or quartzite ridges. This applies particularly to quartzite structures in the Nuu hills which give rise to an excellent running spring at Nuu, providing water for the local native population and their livestock throughout the year. The massive and comparatively impervious quartzite forms two open synclines in the district, and where it is in contact with well-jointed para-gneisses produces several minor springs, the distribution of which is shown on the accompanying sketch map (Fig. 8). Although the structures and nature of the rocks in this locality are suitable for the collection of artesian water the rainfall is small and the quartzite aquifer dips steeply, so that any water-boring intended to tap a sizeable catchment would need to be particularly deep. Some raising of the water-table near the inner synclinal contact of the Nuu quartzite is, however, to be expected and this might advantageously be tapped by shallow borings.

Several water-borings have been completed for the Public Works Department within or close outside the boundaries of the area but, apart from two, have been either dry or saline or have given poor yields.

Of two water-borings sited approximately two miles south-west of Kitui the first to be completed has the highest yield of all borings within the area (50,400 gallons per day). Elsewhere borings have been made at or near Endau, Nuu, and Mui (*see* Fig. 8). Of two borings completed at Endau one was saline, and the other dry. At Nuu, results have also been discouraging, two boreholes being dry, whilst a third is of low yield. A recently completed bore-hole at Mui gives a moderate yield, and in view of the local geology which has been detailed elsewhere (p. 30), this locality should provide favourable conditions for further restricted shallow borings.

There are also two concrete-lined wells in the vicinity of Mui, one of which carries water for a considerable period after the rains but is liable to dry out during periods of drought. Both wells are apparently of insufficient depth to tap the unconformity between superficial river sands and their underlying clays.

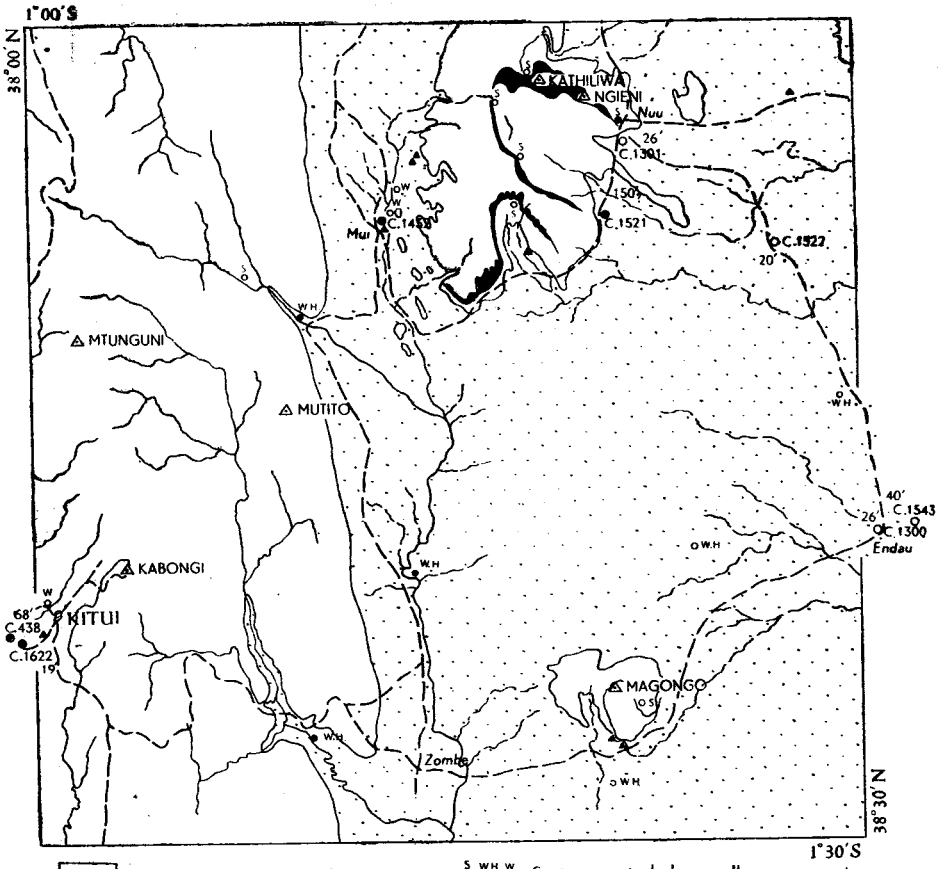
Details of water-borings supplied by the Public Works Department are as follows:—

TABLE IV

| Locality | PWD No. | Depth (in feet) | Water Struck (feet ) | Water Rose to (feet) | Yield per day (gallons) |
|---|---|---|---|---|---|
| Kitui No. 1 .. | C438 | 200 | 176 | 114 | 50,400 |
| Kitui No. 2 .. | C1,622 | 440 | 175 | 140 | 2,280 |
| Mui .. .. | C1,452 | 420 | 55 | 43 | 21,312 |
| Nuu No. 1 .. | C1,301 | 360 | Nil | Nil | Nil |
| Nuu No. 2 .. | C1,521 | 330 | Unknown | 235 | 864 |
| Nuu No. 3 .. | C1,522 | 140 | Nil | Nil | Nil |
| Endau No. 1 .. | C1,300 | 320 | 38 | 27 | 8,040 (saline) |
| Endau No. 2 .. | C1,543 | 200 | Nil | Nil | Nil |

### 3. Suggestions for Further Prospecting

In the present area the chief minerals possibly favourable for development in economic quantity are graphite and sillimanite. Of the former, few indications were observed during what was of necessity a rapid reconnaissance, but it should be noted that thin graphitic bands are included in some of the limestones, and the possibility




Exposed Archaean rocks

Superficial sands, clays and laterites

C.1521 Water-boring, successful (P.W.D.No.)

C.1301 Water-boring, unsuccessful

Earth conservation dams seen during the survey

S W.H. W Springs, waterholes, wells; permanent

S W.H. W Springs, waterholes, wells; seasonal

Quartzite aquifer

Roads

20' Thickness of superficial cover in feet

SCALE

5 0 5 10 Miles

**Fig. 8.—Distribution of water-borings, wells, aquifers, and springs in the Kitui district**

of adjacent graphite schist occurrences should not be overlooked. The most favourable areas for further prospecting in this respect are (1) the Thowa valley from Inyuu bridge northwards, (2) the lower eastern slopes of Kimokomo, (3) the Ikoo gorge, westwards from a point three miles west of Ikoo, and (4) the Tyaa valley.

Sillimanite gneisses are of wide development, but rich quartz-sillimanite gneisses are comparatively rare. The most favourable prospects for sillimanite gneisses are in a belt extending from a point approximately one mile east of Bikanzu southwards towards Nzia, and in a further locality three to four miles north-east of Mui, where north–south-striking sillimanite gneisses occur in the western foothills of the Nuu hills.

Whilst the prospect of economically recovering lignite from the Mui valley is at present thought to be slight, it should be pointed out that existing drilling has been completed in a comparatively small area, and that the limits of the sedimentary pocket have not been proved in depth, since none of the bore-holes reaches the Basement System gneisses beneath the clays and lignites.

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