Report No. 37



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

GEOLOGY

OF THE

SOUTH KITUI AREA

DEGREE SHEET 53, S.W. QUARTER
(with coloured geological map)

by

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FOREWORD

The report on the southern Kitui area continues to the south the geological survey of the main belt of hills in the Kitui district that was published in Report No. 30 (1954). Accounts on the area farther west, i.e. on the area west of Kitui township and on the south-east Machakos area were published in 1948 (Report No. 14) and 1952 (Report No. 25) respectively. No regional survey has, however, yet been carried out east of the south Kitui area, and on the south there is a gap of some 40 miles before Mtito Andei is reached, which is at the northern boundary of an area mapped in 1940–42 (Report No. 13, 1947).

The south Kitui area is particularly interesting as there are extensive graphite-bearing beds in its southern part, and in recent years extensive prospecting has been carried out on them, in one case leading to production. During the survey Dr. Saggerson mapped the deposits in detail, and the report includes drawings on a large scale of his results. Maps of geophysical surveys carried out over a section of the deposit are also included, and indicates the usefulness of such surveys in following up graphitic beds where exposures are not prolific.

In the south-eastern part of the area there is a cluster of dunite pipes, similar in general character to that known for many years at Kinyiki hill, near Mtito Andei. Few such intrusions are known in Kenya, and it is remarkable that they appear to lie in a relatively narrow meridional zone passing through the middle of the Colony. They are always associated with deposits of economic minerals which, however, are often apparently present in small quantities only. In the present case small deposits of vermiculite, talc and anthophyllite asbestos are present, and perhaps larger deposits of magnesite. The vermiculite is interesting in so far as it is a true vermiculite and not a hydrated mica as is the case with many so-called vermiculites. It is used by soil chemists and X-ray workers as a standard reference for vermiculite.

The rocks in the area are almost entirely gneisses and schists of the Basement System, which is assumed to be of Archaean age. An attempt was made during the relatively short period that could be spent on the survey to determine their structures. The tectonic pattern is complex, however, and it is unlikely that it will be satisfactorily unravelled until selected parts of the area can be mapped and studied in detail. The account given in the report is a preliminary attempt at a synthesis.

Nairobi,
3rd December, 1953.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological map of the South Kitui area (degree sheet 53, S.W. quarter) scale 1:125,000 at end

ABSTRACT

The report describes an area of approximately 1,200 square miles in the Kitui District, bounded by latitudes 1° 30′ and 2° 00′ S. and longitudes 38° 00′ and 38° 30 E.′ Physiographically the area may be divided into three units: (1) The central Kitui–Kanziku hills, (2) The eastern end-Tertiary peneplain, (3) The south-easterly sloping plain in the west, lying at a general level between that of the end-Tertiary peneplain and the summits of the central ranges of hills.

The area is composed almost entirely of Basement System rocks of presumed Archaean age, which have suffered compression and have been folded. It is suggested that the rocks, which have locally developed the high-grade index mineral sillimanite, are mainly metamorphosed sediments. Along a major anticlinal axis granitoid gneisses and migmatites have developed.

Post-Archaean rocks consist of two small patches of phonolite, which occur in the south-west corner of the area and are extensions of the lava flow of the Yatta Plateau west of this area. More recent deposits are represented by soils, sands and gravels of Pleistocene to Recent age, which thinly cover the Basement rocks throughout the area.

A detailed account is given of the petrography, structure, granitization and metamorphism of the rocks, and the tectonic history of the area is discussed. Economic occurrences of graphite associated with limestones are described and an account is given of vermiculite, talc, magnesite and asbestos deposits found in four basic intrusives.

GEOLOGY OF THE SOUTH KITUI AREA

I—INTRODUCTION

The area mapped for this report comprises degree sheet 53 S.W. (Kenya), bounded by latitudes 1° 30′ and 2° 00′ S. and longitudes 38° 00′ and 38° 30′ E., and having an area of approximately 1,200 square miles. Although it forms only a part of the southern section of the Kitui District it is convenient to call it the South Kitui area as farther south the district is practically uninhabited, except near the main Kitui–Kibwezi road.

The area falls within the Southern Province of Kenya Colony and is administered from Kitui, which lies seventeen miles to the north of Kisasi in the north-western corner of the area. It comprises the greater part of the southern half of the Kitui Native Land Unit.

For a number of years it has been known that graphite deposits exist in the area and detailed prospecting of likely portions gave sufficient reasons for more extensive geological work to be carried out. The geological reconnaissance of the area was carried out between January and June, 1952. The possibility that other mineral deposits of economic value might exist was also taken into account. In 1951 an Exclusive Prospecting Licence was issued to Bewick, Moreing and Co. Ltd., on the undertaking that graphite deposits in an area of about 422 square miles in the southern part of the map area be fully prospected.

Maps

Existing topographical maps covering the area are the Kitui sheet, Africa South A37/I (1:250,000) published by the War Office in 1912, the Garissa sheet E.A.F. 680 (scale 1:500,000) published by the army in 1945 and a rough map (1:250,000) produced by the P.W.D. in 1940 showing the location of water-supplies and proposed improvements. Form-lines were taken from the Kitui sheet but had to be considerably modified as they were found to be only approximate. The drainage system shown on the geological map is based on aerial photographs taken in 1948 under the direction of the Director of Colonial Surveys. These were controlled by preliminary plots of the area to the west, by the map produced by L. D. Sanders of the Kitui area (1954) and by plane-table survey based on Survey of Kenya Main Triangulation Chart No. 284. Geological data was plotted direct on to kodatrace overlays on the photographs, the plots being subsequently reduced to a scale suitable for printing.

Communications

The principal road passes roughly north-south through the area near the western border and is the road linking Kitui, north of the area, to Kibwezi, on the Mombasa-Nairobi railway line, forty miles to the south. It is an earth road maintained by the Public Works Department and is reasonably good on account of the little traffic which passes over it. Where it crosses water-courses concrete drifts have been constructed. The remaining roads link the principal African centres on this main road with the more distant centres to the east. These secondary earth roads are inferior motor tracks maintained by the Local Native Council. The little attention they receive is understandable in view of the fact that District Officers are almost the only people using them. Recently tracks have been constructed westwards to the river Tiva from the trading centres at Ikanga and Mutomo, and enable veterinary officers to reach the more inaccessible parts along the western border in their drive to combat the tsetse fly.

An inferior sandy track links Mutha with Malindi on the coast. This track is practically impassable in parts, but has a considerable historical interest as it was the track used by the Arab slave dealers when they travelled to and from the coast to the more heavily populated parts of Kenya.

Most of the roads are impassable during the wet seasons when small gullies and streams quickly develop and break up the earth surfaces. At least three originally motorable tracks in the northern half of the area have been permitted to lapse and are now unusable. New

tracks, however, are being constructed by local Africans from Mutha and Voo and others will link these eastern trading centres with the area north of the present one. Numerous native tracks give reasonable access to the country which, however, in part is impenetrable due to thick thorn bush.

Climate and Vegetation

Rainfall occurs in the periods March–May and October–December, the heaviest rainfall generally occurring in the middle month of each period. As in other parts of the Colony the rains occur at the change of the monsoons. The dispensaries at the four main trading centres—Kanziku, Mutha, Mutomo and Voo—have kept rainfall records over a period of two to nine years and all indicate that there is a slight preponderance of rain during the October–December period. A study of statistics produced from records kept at stations just north of the present area shows that the heaviest total annual rainfall probably occurs in the north-west corner, near Kisasi, whilst observations during the present survey indicated that considerable thunderstorms centre over the Ndulukuni area especially during the warmer periods.

TABLE I

Rainfall Statistics of the South Kitui Area

(From the Annual Summary Reports of the East African Meteorological Department)

Station	Altitude in feet	Total Rainfall in inches in 1952	Number of rainy days, 1952	Heaviest single rainfall, 1952 (inches)	Years Recorded	Average annual rainfall (inches)
Kanziku Dispensary ..	2,400	18·51	29	2·60	9	23·69
Mutha Dispensary ..	2,400	27·07	40	—	2	21·90
Mutomo Dispensary ..	2,800	23·30	52	2·03	9	24·33
Voo Dispensary ..	2,000	13·94	36	2·04	8	18·18

North–west—south–east ridges of hills east of the main road and the Tiva and Nzeo valleys are the most highly cultivated areas, the main crops including maize, cassava and the castor oil plant, and less frequently, beans and millet. Crops are confined to the banks of the main streams as the high rates of evaporation do not permit of easy cultivation in other parts. Eastwards from the main central hills the land falls to below 2,000 feet above sea-level. These low-lying flat areas receive less rainfall than elsewhere and in addition are extremely hot, and support only low, stunted, dense thorn bush with thick undergrowth and occasional baobab trees. Similar conditions prevail in the extreme west near the Yatta Plateau. Practically the whole area is devoid of forest except on the slopes of the higher hills such as Mutha, which produce local increases in precipitation and early morning mists and showers.

Population

The Akamba is the indigenous tribe and is concentrated in the hilly locations where cultivation of crops is easiest and water-supplies are more readily obtainable. The tribe is largely agricultural and is responsible for the deforestation that has taken place in the area, but some sections of it are semi-pastoral in habit. The Wakamba are also hunters using bows and poisoned arrows to kill their game. It is of interest that the poison they use is supplied by members of the Giriama tribe, who travel into the eastern part of the area on foot through the practically uninhabited parts of the Colony between the Coast and the Kitui District. Large tracts of the country remain uninhabited although Government is preparing various schemes whereby certain tracts are to be cleared of tsetse fly, bore-holes sunk, and then the land opened to the tribe for controlled cattle-grazing. This will tend to move the population and permit those parts which have developed into "bad lands" to recover and once again be cultivated, to the tribe's ultimate benefit.

The south-western part of the district is well stocked with game which move to and from the neighbouring Yatta Plateau. Eastwards, however, only duiker and dik-dik are met with, although various game birds are still plentiful.

ACKNOWLEDGMENTS

Thanks are due to the Administration Officers of the district for assistance during the survey and to the American missionaries at Mulango (near Kitui) and the Education Officer, Kitui, for their generous hospitality.

II—PREVIOUS GEOLOGICAL WORK

One of the earliest geological references to the Kitui District is that of the Rev. Dr. J. L. Krapf who made foot *safaris* from the coast to the area in 1849 and 1851. He makes reference to ironstone in the district and the lack of more precious metals (Krapf, 1860, p. 358)*. At the beginning of the twentieth century C. W. Hobley passed through the area, remarking on the granitic gneissose ranges, the numerous springs and the flat, thorn-bush covered country both east and west of the ranges (Hobley, 1910, p. 3). In 1902, E. E. Walker (1903, p. 4), who was seconded to the East Africa Protectorate to make geological traverses, passed through the western side of the area. He commented that the "Kitui district consists entirely of gneiss", and remarked on the presence of superficial cellular lateritic ironstone Later, in 1907, K. H. B. Joll, Government mining expert, apparently traversed the north-western corner of the area and panned the Tiva river, obtaining iron ore concentrates with no trace of gold. He then passed north-eastwards towards Kitui, and commented on the nature of the hills there (letter to the Commissioner of Mines, 3/8/1907). Captain L. Aylmer of the King's African Rifles also explored the area in 1907 (Aylmer, 1908, p. 55). He entered the area by the Malindi track passing through Mutha to Vor (Voo) and on to Sambi (Zombe) a little north of the present area, whence he climbed the Mutulani (Matulani) range. He made a collection of rock specimens but stated that "nothing of value was found". He noted that "quartz abounds everywhere, but no shale formation was seen that gave promise of coal".

A. M. Champion was stationed in the area and in 1912 published a paper on the Thowa (or Thua) river, and noted "granite gneisses" at Tulima, approximately ten miles east of Mutha (Champion, 1912, p. 15). In 1934 and 1935 W. D. Harverson, then Government Geologist, made *safaris* through the district and unpublished notes were made on the rocks forming the ridge east of the road at Mutomo and on the marble at Kanziku. Areas around Kapoponi† hill, approximately eight miles N.N.W. of Kanziku, were mapped by C. S. Hitchen in 1940. Most attention was devoted to dunite intrusions and associated magnesite deposits. Metamorphosed gabbroic rocks, an "eclogite" and an augite-phlogopite-labradorite rocks were also discovered in the vicinity.

Later, in 1941, a certain amount of work was carried out by the Department on graphite deposits associated with marbles, near the Kanziku–Ikutha road, six miles west of Kanziku. Further work was carried out in this area by W. Pulfrey, Government Geologist, during a survey made in 1942. He also made reference to the Mutomo ridge and described in greater detail the Kanziku marble. The results of his work are embodied in an unpublished report filed in the Mines and Geological Department, Nairobi.

Subsequently in August, 1950 an E.C.A. geologist, Dr. D. K. Hamilton, began further investigations of the graphite deposits west of Kanziku and in conjunction with a Government prospector, D. Hobden, prospected these deposits up to September, 1951.

So far as the writer knows no further geological work, other than that described in the present report, has been carried out in the area, though more than one party has worked in the Kanziku section of the country in connection with the extraction of minerals. The Kanziku graphite deposits have been prospected in detail.

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*References are quoted on p. 49.

†Named "Kipiponi" in earlier departmental reports.

III—PHYSIOGRAPHY

As in the area to the north (Sanders, 1954) the geology greatly influences the topography. The series of parallel ridges forming the Kitui hills swings to a N.W.–S.E. trend in the present area forming similar conspicuous ridges, which gradually decrease in height as they pass south-eastwards towards Kanziku. This eleven mile wide belt of hills, which is composed of granitoid, migmatitic and para-gneissic rocks, is deeply dissected.

West and south-west of the hills is a gently sloping plain which has a gradient from north–west to south-east. The direction of the gradient parallels the strike of the country-rock which is also parallel to the Kitui-Kanziku ridges. A prominent escarpment forms the north–east boundary of the Kitui hills and decreases rapidly in height southwards and is non-existent near the Ikanga-Voo road. This escarpment overlooks the low-lying plain of the Thowa valley and the area to the south–east, where the gently rolling country is broken by isolated hills. On this eastern plain sinuous strike trends have been mapped or observed on aerial photographs, and are responsible for arcuate domes and arenas.

The only reliable geological datum-level in the area is the base of the Yatta Plateau which is seen in the south–western corner. The phonolite forming this feature is presumed to have flowed out over the sub-Miocene peneplain (Schoeman, 1948, p. 3; Dodson, 1953, p. 3) and has an average gradient of fifteen feet per mile in the area to the west (cf., Dodson, 1953, p. 4), where the base of the phonolite is at approximately 3,200 feet O.D. If the sub-Miocene peneplain has the gradient stated, then the height of the peneplain in the north-eastern corner of the present area must be about 3,700 feet which corresponds to the bevel in the Kitui area (Sanders, 1954). From an examination of the map it is seen that the higher peaks of the Kitui-Kanziku ridges correspond to relics of a higher peneplain upon this sub-Miocene peneplain, if it is considered that the peneplain in this area also has a south-easterly gradient of fifteen feet per mile. The extent of the sub-Miocene surface is shown on Fig. 1.

The eastern half of the area is part of the end-Tertiary peneplain which here has an elevation between 2,000 and 2,500 feet and a gentle gradient to the south–east, where it is recognized in the Mackinnon Road area (Miller, 1952, p. 4). Numerous hills are residual on this peneplain and include those near Kanziku, Mutha and Voo. Those such as Kanzokea, Ebwa, Dilili and Mwanavya have summit levels which can be correlated with the sub-Miocene surface, whilst smaller hills are probably eroded relics of the same surface. Nzwani and Mutha are larger hills, rising nearly 1,200 feet higher than the sub-Miocene bevel, which can be recognised as much-eroded benches around them. In western Kenya a higher, possibly end-Cretaceous, peneplain lies approximately 1,500 feet above the sub-Miocene bevel whilst, in the western part of the Kitui area Sanders has recognised "much reduced residuals" of this older surface. It is likely, therefore that Nzwani and Mutha and the peaks of the Kitui ridges are also denuded relics of this older surface which, like the younger surfaces, slopes gently to the south-east.

To the west and south-west of the main ridges the gently declining plain, with a gradient slightly steeper than that of the sub-Miocene peneplain, is considered to be a slope between the end-Tertiary and the sub-Miocene peneplain and is the product of post-Miocene dissection.

The Kitui-Kanziku rise forms a divide between easterly streams flowing to the Thowa and south-westerly flowing tributaries of the rivers Tiva and Nzeo. The Tiva and Nzeo have incised themselves to a depth of fifty feet into the less resistant members of a banded gneiss series, and in general follow the prevailing strike of these rocks which is N.W.–S.E. Falls and rapids are common in the middle reaches of their courses. These rivers are responsible for the post-Miocene dissection in the west and are extending their courses, involving lengthening of their head-waters by headward erosion and multiplication of tributaries. The rejuvenation of their valleys is due to incision into the sub-Miocene surface and the grading of their courses to the end-Tertiary peneplain. The Thowa is the principal river in the east and with its tributaries drains nearly the whole of the eastern portion of the area. It flows parallel to the Mutito escarpment in the Kitui area and as far south as Voo in the present area, where it then flows eastwards, meandering across the end-Tertiary peneplain with little regard to the trend of the underlying rocks. The tributaries of this river rise in the main central hills and in the north form a trellised drainage system. The central ridges are highly dissected and the rivers, like those to the west, have the irregular gradients

characteristic of a youthful stage. Active erosion has been responsible for river capture in the Mbitini area. Once the end-Tertiary peneplain is reached the rivers flowing from the hills become more mature and develop into sand-rivers, where down-cutting is at a minimum.

Throughout the dry season the rivers rarely contain flowing water, although water can be obtained by digging in their beds, often near the surface, though in certain streams it may be necessary to dig to depths of up to fifteen feet. During the wetter periods the rivers often become raging torrents, whilst in excessive rains the water may rise to as much as twenty feet above river-bed level, as it did in 1951.

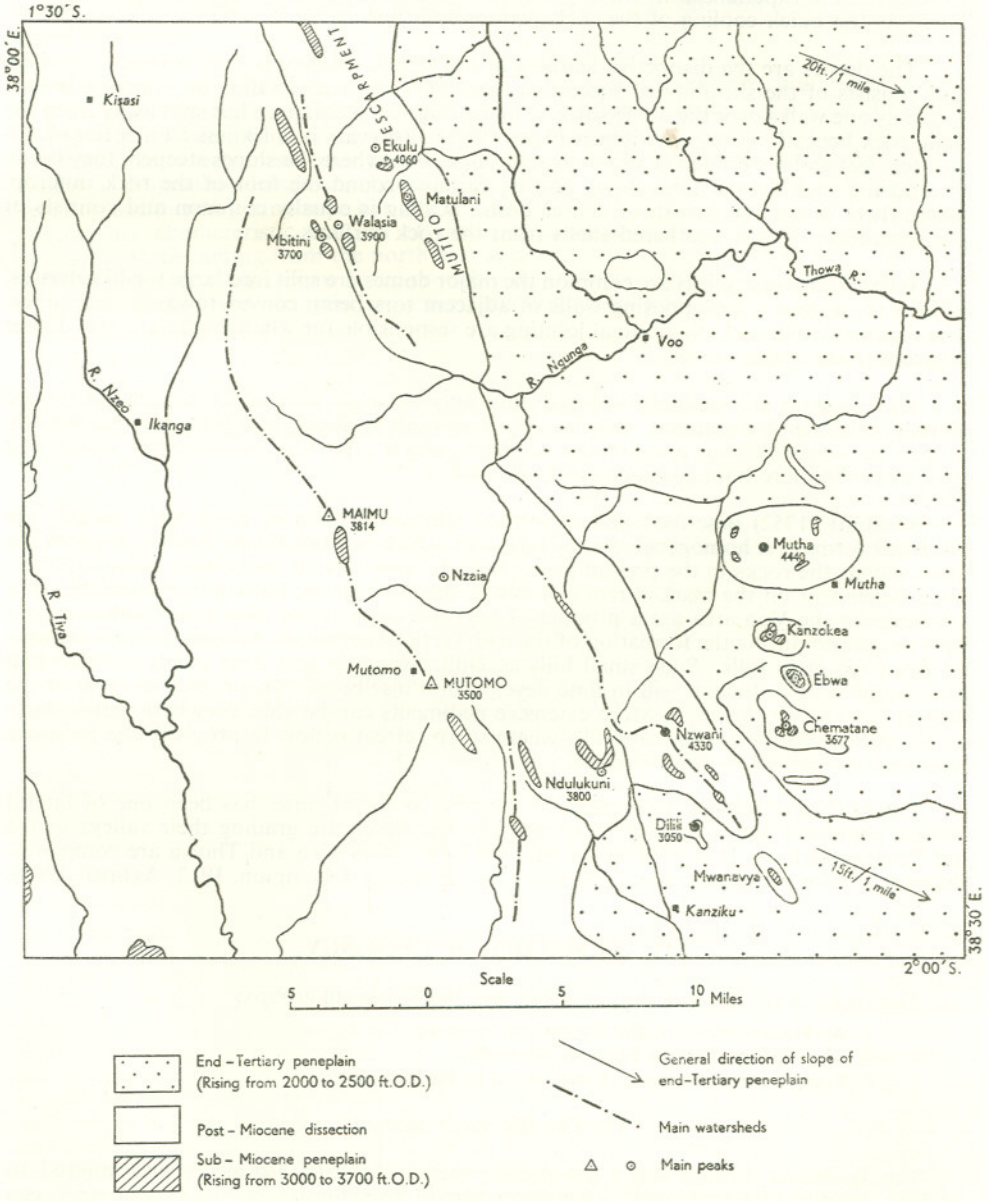


Fig. 1—Physiographical map of the South Kitui area.

Inselbergs, tors, crags, domes and whalebacks formed of granitoid and migmatitic rocks are widely developed particularly between Kisasi, Mutomo and Nzaia (Plate 2(*a*)). There are few good examples of inselbergs but they can be seen as isolated hills near Voo. Other upstanding residuals are best seen in the ridges adjoining the Ikanga-Mutomo-Kanziku road, where their major axes are parallel to the regional strike and where tors and domes alternate on the same feature. The often strongly-jointed nature of the rocks that form the residuals and their inherent structures account for many of the features. Ex-foliation weathering, including *plating* and *scaling*, is very common and is greatly assisted by extremes of temperature experienced in the dry seasons when, during the night, loud cracks can be heard as the quick cooling of the rocks causes splitting.

The domes are the distinctive features of the ridges. Plating is very common on them and consists of the shedding of successive thick plates of rock. Often one hears a hollow sound as one walks over the dome surface, indicating that a carapace has split away from the main rock beneath. These curvilinear plates (Plate 3,(*b*)) vary in thickness from a few inches to a few feet and are eroded *in situ* on gentle slopes but, where the slopes steepen, they break up and the rock debris slides down and is scattered round the foot of the rock outcrop, where there is often a growth of denser bush. Scaling is equally common and consists of the separation of thin weathered shells from the rock surfaces.

Where transverse joints are common the major domes are split into large tor-like masses, as seen at Mutomo, the opposing walls of adjacent tors being convex towards each other. The regional strike and longitudinal jointing are responsible for whale-backs and flat domes adjacent to the major domes.

Such features are gradually reduced until only flat rock pavements, completely devoid of rock debris and vegetation, remain. Their smooth surfaces, however, are occasionally broken by weathered-out amphibolite schlieren which offer less resistance to weathering than does the more homogeneous granitoid rock.

Mabbutt (1952) described and illustrated similar features in south-west Africa. He discussed forms in a homogeneous rock (granite), which is moulded by erosion in much the same way as the rocks in the present area where, however, there are certain essential differences dependent on the marked regional strike, the dip and the lack of homogeneity. The inselbergs in the Voo area are a product of lateral erosion under semi-arid conditions and have developed during the formation of the end-Tertiary peneplain, though they never occur far from the main hills. Such small hills as Dilili, which is now only partly isolated and surrounded by a pediment, will in time develop into inselbergs. This is true of most of the hills of this part of the area. More extensive pediments can be seen elsewhere, particularly on the eastern flanks of the main hills where scarp retreat is now in progress due to active headward erosion of youthful streams.

The physiographical development of the area in recent times has been one of lateral erosion combined with *extension* of stream-courses, which are grading their valleys to the end-Tertiary surface. It is to be noted that the large rivers Tiva and Thowa are completely dispersed on this peneplain, about 100 miles east of Mutha (Champion, 1912; Aylmer, 1908).

IV—SUMMARY OF GEOLOGY

The rocks of the south Kitui area fall into the following groups:

1. Archaean rocks of the Basement System.
2. The Tertiary Yatta Plateau phonolite.
3. Superficial deposits of Pleistocene to Recent age.

(1) *The Basement System*

The Basement System rocks are mainly metamorphosed sediments now altered to marbles, gneisses and granulites. They form part of an extensive belt of similar Archaean rocks which have an approximate north-west to south-east trend from Maralal to the south Kenya border, and through Tanganyika to Mozambique.

Pelitic sediments are represented by sillimanite and graphitic gneisses, but associated garnetiferous biotite gneisses may belong to the same group, representing a transition from the more widespread semi-pelitic types. The latter are predominant throughout the area, forming part of an interbanded psammitic and semi-pelitic series of biotite-hornblende gneisses and more granitoid varieties. Interstratified with all these are calcareous rocks, crystalline limestones and calc-silicate granulites, which form marked mappable horizons in the central part of the area and are probably a calcareous zone repeated by folding. In the south-east of the area are leucocratic felspathized psammitic rocks which have been thrown into a number of folds and grade northwards into a semi-pelitic series. The lack of widespread sillimanite gneisses as seen in the Kitui area (Sanders, 1954) is an indication of lateral variation, pelitic sediments of the north grading to the semi-pelitic series of the area under discussion.

Orogenic folding of the Basement System rocks was accompanied by granitization which had a marked effect on them, there being a general increase in alkali metasomatism from east to west. Granitoid gneisses were formed and mainly occur at the culmination of the anticlinal axis which forms the principal tectonic feature in the west, between Kitui and Kanziku. Migmatitic bands are characteristic of the folded area to the east of this axis and here the sedimentary structure has often been obliterated. Tensional cross and diagonal jointing are characteristic features of the migmatitic zone and can be related to compressional forces acting from the north-east and south-west which have severely folded the rocks of the area. An ancient fault, probably of pre-metamorphism age, parallels the axes of the main folds, and recurrent movement has undoubtedly taken place along it throughout geological history.

(2) *Tertiary Phonolite*

Patches of Tertiary phonolite outcrop in the south-west corner of the area and represent small tongues of the main Yatta Plateau lava which, according to Dodson (1953, p. 5), poured out in the area to the west along fissures aligned north–west to south–east. Other signs of Tertiary volcanic activity were not seen in the area, where this period of geological history was largely one of peneplanation leading to the formation of the sub-Miocene peneplain and its subsequent destruction, culminating in the formation of the end-Tertiar peneplain.

(3) *Pleistocene and Recent Deposits*

Superficial sands, gravels and soils are extensive over the whole area and almost conceal the underlying rocks on the end-Tertiary peneplain. Black cotton soil is present west of the main north-south road, whilst superficial kunkar limestone deposits are scattered and rare. River gravels are exposed in the river Thowa and certain of its tributaries, and are probably of Pleistocene age.

V—DETAILS OF GEOLOGY

1. The Basement System

The rocks of the Basement System are considered to be the metamorphosed equivalents of originally sedimentary rocks, the sedimentary pattern being retained. The repetition of certain beds, e.g. the meta-calcareous horizons mentioned by Sanders (1954, p. 10) in the Kitui area, the presence of originally carbonaceous limestones, and preserved current-bedding and stratiform succession are considered proof of sedimentary origin.

Evidence of lateral variation is thought to exist in this area. The pelitic gneisses mapped by Sanders in the area to the north of the present one, grade into rocks in this area which do not contain the higher-grade index mineral, sillimanite. West of Matulani sillimanite and graphite gneisses grade rapidly into rocks of semi-pelitic origin. Another example of lateral variation is seen south of Mutomo where the more northerly biotite gneisses grade imperceptibly into biotite-hornblende gneisses to the south, as is shown on the map.

The rocks of the Basement System in the south Kitui area may be classified into the following groups:

Calcareous	Crystalline limestones Calc-silicate granulites and gneisses
Pelitic	Biotite-sillimanite para-gneisses Graphitic gneisses
Semi-pelitic	Biotite gneisses Banded biotite gneisses Biotite-hornblende gneisses Hornblende gneisses and granulites Felspathised gneisses Felspar porphyroblast gneisses Biotite-garnet gneisses
Psammitic	Quartz-felspar-biotite granulites Quartz-felspar gneisses
Migmatitic	Microcline-oligoclase-biotite-hornblende gneisses with amphibolite schlieren
Anatectic or palingenetic	Granitoid gneisses Pegmatites
Meta-intrusive	Amphibolites Hornblende-pyroxene gneisses Pyroxenites
Intrusive	Dunites and associated basic rocks

The stratigraphical succession in the Basement System as seen in the area is as follows:

	Thickness (approximate) *Ft.*
Quartz-felspar-biotite granulites Garnet and hornblende-biotite gneisses	7,000
Felspar porphyroblast biotite gneisses Biotite-garnet gneisses Graphitic marbles Sillimanite and graphitic gneisses (in the north) Garnet and hornblende-biotite gneisses	9,000
Migmatitized semi-pelitic gneisses Biotite gneisses Migmatitized semi-pelitic gneisses Biotite-hornblende gneisses Marbles and calc-silicate gneisses Biotite and hornblende-biotite gneisses Alternating semi-pelitic and psammitic gneisses	28,000

(1) *Metamorphosed Calcareous Sediments*

The metamorphosed calcareous sediments are (*a*) crystalline limestones, and (*b*) calc-silicate granulites and gneisses.

(*a*) *Crystalline limestones*

The limestones form frequent outcrops in the area and the major bands are continuous over considerable distances. The thicker marbles form heavily bush-covered hills which are conspicuous in areas of less dense scrub, whilst the thinner bands are only made noticeable by occasional rocky outcrops. Junctions are rarely exposed and only visible where streams have cut down deeply. The major bands are found in the Kitui–Kanziku hills and have

probably been repeated by folding and faulting, although there is undoubtedly more than one horizon present. One horizon in the area six miles west of Kanziku is probably continuous as far north as Musa, north of Ikanga, although it could not be traced continuously throughout on account of the thick soil cover.

Graphitic gneisses frequently occur with the marbles which invariably contain scattered flakes of graphite. In the Maralal area Shackleton (1946, p. 7) noticed graphitic bands overlying and underlying the marbles. In the Kanziku graphite area extensive trenching has shown that whilst the greater proportion of the graphite bands are found near the base of the marble, many bands occur within and throughout the marble horizon. Quartz-felspar bands, calc-silicate lenses and garnetiferous granulites are also commonly associated with the limestones.

The marbles where seen in outcrops consist principally of calcite, and recrystallisation of the limestone is evident where extremely coarse calcite crystals occur, as at Ndulukuni. They vary in colour from white to bluish-grey and when iron-stained are a dirty brown. Fine banding in them is emphasized by the graphite and calc-silicates. The strike of the limestones often varies considerably within a few feet and is an indication of their extreme mobility during folding. The presence of graphite in them has undoubtedly aided movement, the graphite acting as a lubricant between more competent beds. Many of the bands are modified near their junctions by the formation of redeposited fine-grained limestone (kunkar), which is also found overlying the marble in certain instances. The portions in which secondary limestone is being deposited are pinkish and contain coarser patches, presumably the original marble. Where the marble is exposed in trenches six miles west of Kanziku the modification of the marble where it is in contact with the soil is seen *in situ*.

In thin sections the marbles are found to consist mainly of calcite associated with subordinate silicates, which include fibrous antigorite and iddingsite, pseudomorphosing olivine, and diopside, phlogopite, scapolite and mica. Apatite, felspar, and rounded quartz pools are not uncommon. The calc-silicate lenses are locally rich in certain minerals, for example specimen 53/759* from Jasio is composed of light brown phlogopite in shreddy flakes associated with diopside, a little apatite, iron ore and what appears to be talc. The Kanziku marble (IX. 18) contains large crystals of a pale brown hornblende, large intergrown crystals of phlogopite (pleochroic from colourless to fresh orange-brown) and rounded crystals of colourless diopside. There are large patches of scapolite and occasional grains of oligoclase, whilst white mica forms crystals and aggregates among the scapolite. In addition large and small aggregates of zoisite and occasional, colourless, optically positive crystals referred to enstatite are also present. A diopside marble collected from the eastern margin of the band contains large crystals of tremolite, broken by carbonate stringers. Other minerals present include quartz, microcline, diopside and green hornblende. Crushing of the marbles has taken place near the contacts and slides show dynamic straining of the calcite and severe brecciation, accompanied in certain cases by the introduction of chalcedonic silica.

(*b*) *Calc-silicate granulites and gneisses*

These melanocratic rocks are not widespread in this area and in only three cases was it possible to map them. In general they are lenticular segregations either associated with marbles or occur in the strike continuation of marbles where the limestone is no longer present. The remainder are associated with biotite gneisses, forming small prominent bands, and probably represent the result of complete alteration of limestone or calcareous bands by granitising fluids (cf., Shackleton, 1946, p. 8). A mappable calc-silicate gneiss with definite banding, east of Maimu, when traced along the strike is seen to interdigitate and disappear into biotite gneiss which has been partly migmatitized. The same band, but more granulitic, was found farther north at the Ikanga-Voo road and traced for a considerable distance parallel to a marble horizon. This rock is black, mottled white by felspar, and weathers into black rounded boulders in stream sections. Like many similar rocks mapped

*Numbers 53/759, etc., and numbers prefixed by IX refer to specimens in the regional collections of the Mines and Geological Department, Nairobi.

in other parts of the Colony it contains plagioclase, scapolite, hornblende, diopside, hypersthene, garnet, epidote, quartz, iron ores and accessories (53/728–53/735 from near Maimu). At least three or more of the main minerals are present in these rocks except in certain lenses where diopside comprises up to 99 per cent of the volume (53/704, Maungu). Shackleton (1946, p. 8) draws attention to the fact that the calc-silicate rocks are in some cases associated with hornblende gneisses and that the hornblendic rocks may represent a different stage in the migmatitization of calcareous sediments. Similar associations were seen in the present area, particularly in the Ngunga valley.

The plagioclase felspar was found to be andesine (An_{46}) in 26 slides examined, whilst in specimen 53/910 from Kangwa it is labradorite (An_{63}). The plagioclases usually show good albite twinning but untwinned crystals were noted in one case (53/732*a*) where they are also highly strained. Intergrowths of plagioclase with diopside, garnet, quartz and calcite were observed.

Pale green diopside is the common pyroxene and invariably exhibits sieve structure and alteration to green hornblende, internally or round the crystal margins. Sometimes the diopsides are a deep green variety unlike the more normal, colourless to pale green varieties seen in most slides (53/730–53/731). Hypersthene, pleochroic from pink to pale green, is associated with the diopside in many rocks (e.g. 53/728) in subhedral aggregates.

Blade-like hornblende, which frequently replaces pyroxene, is another common mafic mineral in the calc-silicate rocks and varies in colour, from brown through brownish-green to green. In slides such as that of specimen 53/711 from the river Masaa pyroxene is subordinate to the common hornblendes. Epidote was not commonly seen with the amphibole but does occur in some specimens.

Pink garnets in the calc-silicate gneisses vary in size up to 3 mm. and usually contain chadacrysts of plagioclase, biotite and pyroxene. They occur as scattered often irregular crystals or rarely as granular euhedral aggregates, and magnetite granules are often associated with them. In specimen 53/728 from two miles east of Maimu the garnet is occasionally surrounded by felspar, while in specimen 53/683 from the same locality garnets measuring up to 2 mm. in diameter are surrounded by zones are of plagioclase crystals, which in turn surrounded by shells of green pyroxene altering to dark hornblende. This is an excellent example of the concretion principle in metamorphism, when growing porphyroblasts have formed iron-free zones around themselves.

Scapolite is seen to replace the plagioclase or to occur as anhedral, irregular grains, frequently associated with the felspar. Other accessory minerals in these rocks include apatite (which in 53/772 from four miles north of the Bewick Moreing graphite camp contains rod-like inclusions orientated parallel to their vertical axes), calcite both anhedral and needle-like sheaves when it is secondary after scapolite (53/817, S.E. slopes of Nzwani), biotite flakes pleochroic from dark green or dark brown to light brown (53/914, south of Nzwani), iron ore, and sphene. Sphene and iron ore most commonly occur as numerous scattered crystals, except in specimen 53/659 from the river Ngunguni where the sphene is in granular aggregates up to 2 mm. in width. A highly weathered iron-stained band outcrops north of Mbitini and thin sections of the rock (53/620) show large irregular crystals of tremolite with crowded small pink garnets, these two minerals constituting a large proportion of the entire rock.

The wide variations in mineral composition of the calc-silicate rocks in general is illustrated by the estimated modes* of eleven examples quoted in Table II. Specimens 53/874 and 53/912 represent more normal types, the others being characterised by unusual proportions of one mineral or by the presence of some particular mineral. In come cases specimens showing variations were taken from the same calc-silicate band (e.g., 53/730 and 53/732*a*).

*All modes given in this report are volumetric.

TABLE II

ESTIMATED MODES OF CALC-SILICATE GNEISSES AND GRANULITES

	53/659 %	53/735 %	53/730 %	53/817 %	53/874 %	53/912 %	53/662 %	53/732*a* %	53/711*a* %	53/711 %	53/620 %
Andesine	84	78	59	56	51	50*	49	37	10	10	5
Biotite	—	—	+	+	1	—	—	—	8	—	—
Hornblende	1	1	5	5	15	2	3	60	2	60	—
Diopside	10	+	8	35	5	37	40	2	80	27	—
Hypersthene	—	15	7	—	—	5	—	—	—	3	—
Garnet	—	1	20	—	25	—	—	—	—	—	40
Scapolite	3	+	—	1	2	2	—	—	—	—	—
Tremolite	—	—	—	—	—	—	—	—	—	—	50
Epidote	—	—	—	—	—	—	—	+	—	—	—
Sphene	2	—	+	1	+	+	—	—	—	—	—
Iron Ore	+	5	1	+	1	4	8	1	+	+	5
Calcite	—	—	—	2	—	—	—	—	—	—	—
Other accessories (incl. quartz)	+	+	+	+	+	+	+	+	+	+	+

*The plagioclase in 53/912 is labradorite.

53/659 River Ngunguni, two miles of E. of Mutomo.
53/735 Two miles E. of Maimu.
53/730 Two miles E. of Maimu.
53/817 S.E. slopes of Nzwani.
53/874 River Ngunga, five miles W.S.W. of Voo.
53/912 Kanotui, seven miles E. of Ikanga.
53/662 Two miles E, of Mutomo.
53/732*a* Two miles E. of Maimu.
53/711*a* Mwamba, E. of Maimu.
53/711 Mwamba, E. of Maimu.
53/620 One mile N. of Mbitini.

(2) *Metamorphosed Pelitic Sediments*

Rocks of argillaceous origin occur in the north and central parts of the area between the western migmatite zone and the more calcareous rocks near the Mutito scarp further east. The wide distribution of sillimanite seen in the area to the north (Sanders, 1954) was not noticed, though the mineral does occur in uniform biotite gneisses between the Walasia and Matulani ranges. Unfortunately many of the rivers in this area are sandy and outcrops poor and hence possibly the full extent of sillimanite development was not recognized. It would seem that the sillimanite content decreases southwards through the area and that the mineral is not found farther south than the river Kakengele. The majority of the rocks mapped by Sanders in the Kitui area as metamorphosed argillaceous sediments are therefore considered to pass into semi-pelitic rocks in this area, where only sillimanite and graphitic gneisses are recognised as true pelitic gneisses.

(*a*) *Biotite-sillimanite para-gneisses*

The biotite-sillimanite flaggy gneisses are chiefly exposed between Walasia and Matulani. The gneisses contain thin folia rich in blue-grey lustrous sillimanite sheaves, the folia forming inconspicuous thin bands in pale brown biotite granulites. The folia vary in thickness from 0·5 mm. to 5 mm. and are lenticular in shape, thinning to near-white streaks. The sillimanite sheaves and needles are mostly orientated parallel to the principal foliation of the surrounding rocks, but occasional needles lie at angles of as much as 55° to this direction. In the river Munyune a sillimanite gneiss is associated with graphitic gneisses and here the sillimanite forms rare small ovoid faserkiesel. Sanders (1954, Kitui area) has described typical faserkiesel in biotite gneisses, the ovoids being, "virtually felspar-free nodules, in which interlacing fibrous sheafs of sillimanite are enclosed in a quartz mosaic".

Thin sections of these rocks (53/899, 53/901), from the Marieti river area west of Matulani, show dark brown biotite flakes with needle aggregates and scattered prisms of sillimanite in a granoblastic mosaic of quartz, untwinned plagioclase, twinned plagioclase recognised as oligoclase, and a little microcline. The felspars are invariably cracked and the replacement of oligoclase by untwinned potash felspar is seen round their borders. Iron ore, rounded apatite prisms, and rare zircon and epidote are accessory.

(b) Graphitic gneisses

Only three occurrences of lustrous grey graphitic gneisses not interbedded with limestone were found outcropping in the area, one being seen in the river Kataka, another near the junction of the Munyune and Kakengele rivers south of the Ikanga–Voo road, and a third in the upper reaches of the river Ngunga south of the same road. In the last two cases they are associated with biotite-sillimanite gneisses and are near to but not directlyu nderlying a limestone band. They occur near the top of the semi-pelitic series where it grades into semi-calcareous gneisses, a thin limestone being the first indication of the change. In the Kataka occurrence the graphitic band outcrops in the bed of the river and is approximately nine feet wide, and on a vertical surface the graphite flakes are seen to be orientated, the lineation plunging northwards. In the rivers Munyune and Ngunga the graphite occurs in one- to two-foot wide bands in a zone approximately fifteen yards broad.

Microscopically the gneisses are medium-grained rocks in which quartz, microcline and oligoclase occur as interlocking grains with thin graphite flakes, biotite, and in specimens 53/883 and 53/908 variably altered pyroxene and epidote. Sphene, apatite, iron ore and rare small garnets are also present.

The graphitic rock (53/915–53/942) associated with the marble west of Kanziku is essentially a graphite-quartz-felspar-apatite gneiss, silver grey when fresh but on weathering often highly stained black, green, or brown. The gneiss is a medium-grained xenoblastic rock containing albite and oligoclase felspar with subordinate orthoclase and pyroxene. Biotite is rare. Late orthoclase occurs in intergranular spaces, being elongated in the direction of foliation. Apatite is abundant in prisms with sub-rounded outline, measuring up to 0·5 mm. in length. Graphite flakes vary in size up to 3 mm. in length and are usually ragged and thin. They are rarely included inside the quartz and felspar but are more usually intergranular. The gneissose texture is emphasized by the quartz and felspar grains which have a tendency to be elongated in the direction of the graphite flakes, which are themselves subparallel to the strike of the rocks. Similar rocks are described by Bastin (1912) from Adirondack graphite deposits in America.

Estimated modes of the metamorphosed pelitic rocks are shown in Table III.

TABLE III

ESTIMATED MODES OF METAMORPHOSED PELITIC ROCKS

	53/901	53/908	53/883
	%	%	%
Quartz	30	5	3
Microcline	—	52	—
Plagioclase	54	15	72
Sillimanite	5	—	—
Graphite	—	20	5
Biotite	10	—	10
Diopside	—	—	8
Accessories	1	8	2

53/901 Biotite-sillimanite gneiss, river Maveti, one mile N.N.W. of Chango.
53/908 Graphitic gneiss, river Kataka, one mile S.W. of Matulani.
53/883 Graphitic biotite-pyroxene gneiss, river Munyune, six miles N.E. of Maimu.

(3) *Metamorphosed semi-pelitic sediments*

The large plain west of the Ikanga-Kanziku road is underlain by a rock series of semi-pelitic origin, consisting of alternating melanocratic and leucocratic bands, which vary in width up to a mile. The bands grade rapidly into one another so that it is difficult to define a true boundary between them, and it is obvious that the rocks represent original alternating semi-pelitic and psammitic bands which were often lenticular and exhibited wide lateral variations. West of the Tiva river the bands are overlain by a thickly bush-covered black cotton soil cover and the infrequent outcrops consist of granitoid gneisses only. Banding similar to that seen farther east is found, however, on examination of aerial photographs of that part of the area, when the boundaries of broad bands can be recognised where they underlie thin soil cover.

Rocks of the same type have also been mapped west of Voo, but again exposures are few on account of the sand cover which overlies much of the succession. River sections such as the Ngunga expose the rapidly alternating series, but only the more resistant metamorphosed semi-psammitic bands outcrop as hills. Aerial photographs of the eastern part of the area reveal the sinuous strike of these rocks which could be mapped in part only, due to the thick sand cover.

Between the two areas described lie the Kitui–Kanziku ranges of hills, the rocks of which are considered to be of semi-pelitic origin but grading to true metamorphosed pelitic sediments north of the present area. The most prominent of the rocks are the characteristically flaggy gneisses which form the *arête*-like ridges of Chango, Matulani and other hills. The gneisses occur as upstanding weathered blocks resembling unmetamorphosed sedimentary flags. Westwards there is an increase in the microcline content as the migmatitic zone near Mbitini is reached and the rocks grade imperceptibly through augen gneisses into banded migmatitic gneisses with more rounded outcrops, as exemplified by Walasia and Mbitini. Biotite and hornblende are the common mafic minerals and impart a flaggy nature to the rocks, which are variably gneissic and granulitic. For descriptive purposes the rocks may be classified into the following groups:

(*a*) Biotite gneisses
(*b*) Banded biotite gneisses
(*c*) Biotite-hornblende gneisses
(*d*) Hornblende gneisses and granulites
(*e*) Felspathized gneisses
(*f*) Oligoclase porphyroblast gneisses
(*g*) Biotite-garnet gneisses

(*a*) *Biotite gneisses*

Hornblende-free biotite gneisses are developed in the Voo area, particularly near the Kemwa hills south of the Voo dispensary. They are pale brown in colour, often strongly foliated, and flecked with small brown biotite flakes which are occasionally concentrated into dark bands. They grade into leucocratic granulitic varieties relatively poor in biotite. In thin sections (53/860 from Kemwa and 53/889 from the river Ngunga west of Voo), dark brown biotite flakes are associated with quartz and plagioclase, forming a medium-grained heteroblastic texture. Microcline is present in various granulitic bands and in specimen 53/889 is the most common felspar. Here the microcline has replaced oligoclase and quartz, forming deep lobe-like embayments into these minerals, whilst it also contains quartz as small droplets. Iron ores, rounded apatites, sphene and rare zircon are necessary.

Estimated modes of two specimens are shown in Table IV.

TABLE IV

ESTIMATED MODES OF BIOTITE GNEISSES

	53/860	53/889
	%	%
Quartz	5	10
Microcline	40	4
Plagioclase	46	80
Biotite	8	5
Accessories	1	1

53/860 Kemwa, two miles S.E. of Voo.
53/889 River Ngunga, two miles W. of Voo.

(*b*) *Banded biotite gneisses*

Sillimanite gneisses mapped in the western part of the pelitic series in the Kitui area by Sanders grade into strongly banded biotite gneisses in this area. They form softer bands in a semi-migmatitic series near Mbitini east of Ikanga and Mutomo and west of Chango, near the Ikanga–Voo road. These dark banded rocks are usually found in the valleys, the larger rivers such as the Kilui have their entire courses in rocks of this type. *Lit-par-lit* injection, and ptygmatic and pegmatitic veining are common, whilst contortions and sinuous

foliations are indications of plastic flow. Occasional prominent-weathering calc-silicate granulite bands, as seen near the road one mile west of Chango, are associated with the gneisses.

In thin sections orientated brown biotite and blades of green hornblende are seen, set in a heteroblastic or granoblastic matrix of quartz and felspar. Porphyroblastic development of oligoclase occurs in specimen 53/632 from the river Kaluluni, whilst subhedral oligoclase and anhedral microcline are seen in the groundmass. Myrmekite and both microcline and quartz replace the oligoclase in part, but there is no porphyroblastic development of the microcline as is characteristic of the neighbouring migmatites of Mbitini. Comminuted borders of the larger felspars and fine granoblastic aggregates in certain slides indicate the resistance of the rocks to crushing. Sphene is a common accessory and is a result of the decomposition of ilmenite and biotite; the other accessories include, apatite, zircon, iron ore and sericite.

Table V shows some estimated volumetric compositions of the banded biotite gneisses.

TABLE V

ESTIMATED MODES OF BANDED BIOTITE GNEISSES

	53/666	53/613	53/911	53/695	53/621	53/632
	%	%	%	%	%	%
Quartz	15	10	5	5	10	15
Microcline	—	—	—	—	5	—
Plagioclase	81	72	86	83	68	51
Biotite	3	7	8	10	15	30
Hornblende	—	8	—	—	1	3
Accessories	1	3	1	2	1	1

53/666 Chome, E. of Mutomo.
53/613 River Kisio, Mbitini.
53/911 River Ngungu, E. of Nguani.
53/695 Three miles E. of Mutomo.
53/621 One mile N.E. of Mbitini.
53/632 River Kaluluni, Mbitini.

(c) Biotite-hornblende gneisses

The best exposures of the biotite-hornblende gneisses are found in the rivers Tiva and Nzeo and their tributaries, with minor developments in the river Ngunga, near Voo. They form an interbanded series with biotite and psammitic gneisses and their field relationships suggest a semi-pelitic sedimentary origin rather than an intrusive origin. Other rocks of this type were mapped east of the Mutomo-Kanziku road where they form lower ground between migmatite ridges. They outcrop chiefly towards Ndulukuni, grading into banded biotite gneisses northwards, east of Mutomo and towards the Ikanga-Voo road.

The biotite-hornblende gneisses are melanocratic or mesotype rocks generally exposed in river courses only, and are often found to be extremely friable due to the ease with which they weather. Sometimes they grade into black granulitic varieties, when they form resistant bands in which there is little biotite to be seen.

Similar rocks have been described by Schoeman (1948, p. 14) and Bear (1952, p. 13). In some cases such as in the river Ngulungu (53/639) and at Unthunguni (53/863) the gneisses are xenoblastic with a weak gneissose structure, the mafic minerals being roughly segregated. Many slides indicate that shearing has taken place, imparting a stronger foliation to certain rocks (53/635*a* from the river Tiva, 53/637*b* from the River Tiva, 53/643 from the River Ngulungu). Large poikiloblastic hornblende blades (pleochroic from yellow-green to green to dark brownish green) are intimately associated with pale or dark brown biotite flakes, and in specimens such as 53/671 from Uwenee, 53/703 from two miles N.E. of Mutini and 53/794 from the river Kathini both minerals show crude preferred orientation. The biotite flakes, which are infrequently interleaved with muscovite, are occasionally seen to wrap

round the plagioclase crystals. In sheared specimens the mafic minerals are ragged and broken and often wisp-like near the edges of the more euhedral felspar crystals. The felspar, ranging in composition from An_{20} to An_{45}, is polysynthetically twinned plagioclase. The crystals occasionally show pericline twinning and are usually altered along the twin planes, sericite being the common alteration product. Myrmekite and replacement of quartz by interlobing oligoclase are common. Iron ore, including blood-red hematite (in 53/635*a*), prismatic apatite, zircon, sericite, calcite and sphene are minor constituents. Crushed specimens (53/803, from the River Kucha) have a typical mortar texture, the comminuted borders of the felspars being surrounded by granules of the same mineral.

The biotite-hornblende gneisses grade into hornblende-diopside or biotite-diopside gneisses and granulites, whilst in one specimen, 53/798 from Nzungululuni ridge, hypersthene is present, often as large crystals up to 3 mm. in length. In a diopside-biotite gneiss (53/642 from the River Ngulungu) the biotite is a reddish-brown variety and is associated with the pyroxene.

A number of estimated modes of these rocks are shown in Table VI.

TABLE VI

ESTIMATED MODES OF BIOTITE-HORNBLENDE GNEISSES

	53/635*a*	53/747	53/794	53/877*a*	53/703	53/593	53/737	53/639	53·642	53/798
	%	%	%	%	%	%	%	%	%	%
Quartz	5	8	4	3	5	3	5	3	3	4
Plagioclase	52	69	63	82	54	80	67	59	63	60
Myrmekite	—	2	1	—	—	—	+	—	—	1
Biotite	15	10	10	7	5	2	2	15	10	1
Hornblende	25	10	20	7	35	13	25	20	—	20
Diopside	—	—	—	—	—	—	—	1	20	—
Hypersthene	—	—	—	—	—	—	—	—	2	10
Accessories	3	1	2	1	1	2	1	2	2	4

Biotite-hornblende gneisses:
- 53/635*a* River Tiva, one mile N. of river Ngulungu junction.
- 53/747 Chambusia, six miles S.W. of Mutomo.
- 53/794 River Kathini, one mile below Mutomo road.
- 53/877*a* River Ngunga, six miles W.S.W. of Voo.
- 53/703 Two miles N.E. of Maimu.
- 53/593 River Nzeo, nine miles W.N.W. of Mutomo.
- 53/737 Maungu, five miles S.E. of Mutomo.

Biotite-hornblende-pyroxene gneisses:
- 53/639 River Ngulungu at Veterinary track junction.
- 53/642 River Ngulungu, two miles below Veterinary track junction.
- 53/798 River Kithusi, seven miles W.S.W. of Kanziku.

(d) Hornblende gneisses and granulites

Biotite-free hornblende gneisses and granulites are found within the semi-pelitic series and form melanocratic bands. The former are fine- to medium-grained granular rocks with little gneissose structure except when this feature is emphasized by leucocratic material. Slides show that they are granoblastic aggregates of plagioclase and hornblende with subordinate quartz. Strongly pleochroic green hornblende in specimen 53/888, from three miles west of Voo, is associated with grains of magnetite and a little ilmenite. The plagioclase in this same specimen is mainly oligoclase, often untwinned, and shows myrmekitic growths and replacement of quartz round the edges. Specimen 53/647 from the river Ngulungu is characterised by the presence of green diopside and hypersthene. Although the diopside occurs as large irregular crystals, it is mainly found as loose granular aggregates associated with hypersthene surrounding the hornblende. The hornblende is also partly replaced by biotite. Iron ore, apatite (measuring up to 0·75 mm.), zircon and granular sphene are accessory minerals in these rocks. With an increase in hornblende content the hornblende gneisses and granulites would grade into plagioclase amphibolites.

Table VII shows estimated volumetric compositions of two examples.

TABLE VII

ESTIMATED MODE OF HORNBLENDE GNEISSES

	53/647	53/888
	%	%
Quartz	7	5
Plagioclase	65	45
Hornblende	15	45
Pyroxene	10	—
Apatite	2	—
Accessories	1	5

53/647 River Ngulungu.
53/888 River Ngungu, three miles west of Voo.

(*e*) *Felspathized gneisses*

Massive reddish-pink granitoid outcrops are interbanded with the biotite-hornblende gneisses in the area of the Tiva and Nzeo rivers. They are considered to be impure psammitic bands within the semi-pelitic series and are characterized by the nature of their outcrop, their striking colour and by gradations to the darker interbanded rocks. Near the biotite-hornblende gneisses the felspathized gneisses are an alternating series of dark and light bands occasionally showing graded bedding as in the river Tiva, where exposures are good. Porphyroblastic felspars occur in the mafic bands and as they increase in number the rocks becomes more coarse-grained and enclose impersistent and lenticular folia of biotite-hornblende gneiss. Towards their centres the lighter bands are more homogeneous, leucocratic, often coarse-grained, granitoid gneisses with fewer mafic lenses or minerals. These rocks form rapids and waterfalls characteristic of the middle reaches of the Tiva and Nzeo rivers and indicate stages in the grading of these river valleys from the sub-Miocene to the end-Tertiary peneplain. Schoeman (1948, p. 21) describes similar rocks in the area west of Kitui and considers that they were formed by quiet replacement *in situ*. This is borne out in the present area where sedimentary structures have been preserved and few indications of migmatization are seen. To the north–west the felspathized gneisses grade into migmatites and granitoid gneisses, where evidence of mobilization is more apparent.

Specimens from nearer the edges of the bands, Nos. 53/585, 53/588, 53/592 (whose localities are quoted in the table below), are medium-grained and have a crystalloblastic texture and there is little or no development of microcline, though myrmekite is relatively common is some. Perthite is present in two of them. Small pale green hornblende crystals are sometimes associated with the biotite, both being irregular and the former showing alteration and iron-staining. One specimen, 53/638, contains in addition small diopside crystals slightly replaced by magnetite. Apatite, zircon, sericite and iron ore are common accessories.

Estimated modes of the rocks mentioned are as shown in Table VIII.

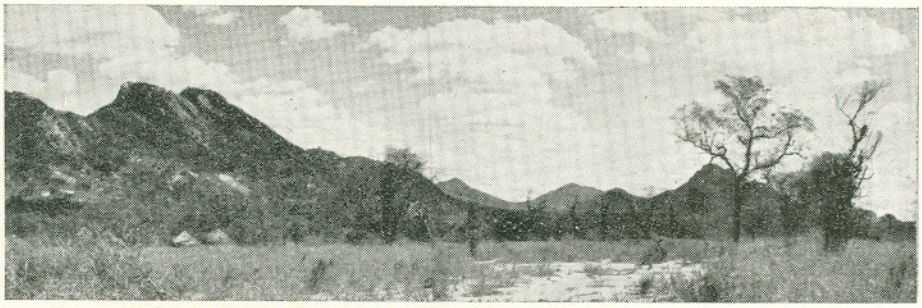
TABLE VIII

ESTIMATED MODE OF FELSPATHIZED GNEISSES

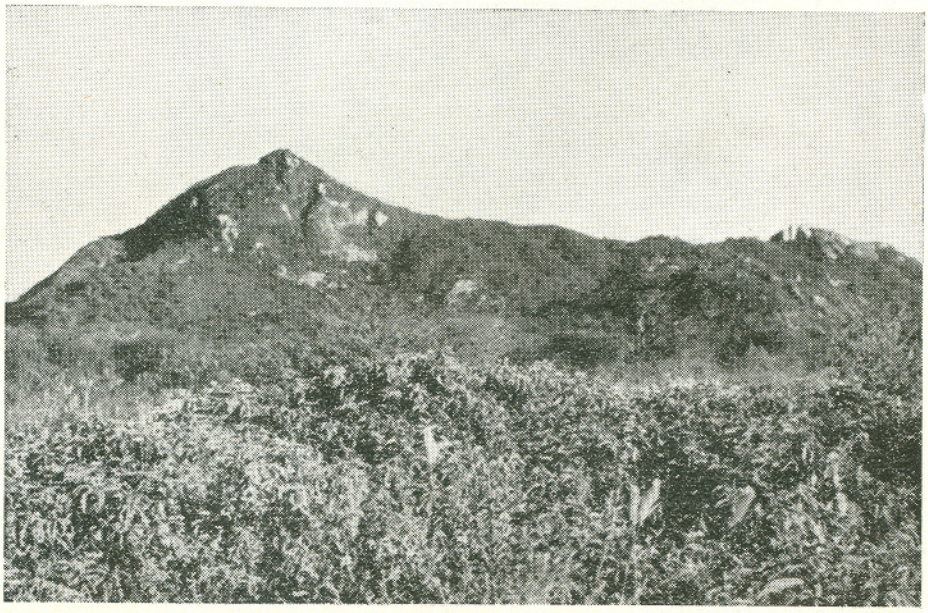
	53/592	53/588	53/585	53/638
	%	%	%	%
Quartz	15	5	5	5
Microcline ..	—	—	+	—
Perthite ..	—	50	10	—
Plagioclase ..	67	34	75	80
Myrmekite ..	1	3	2	—
Biotite ..	5	1	1	1
Hornblende ..	10	5	4	4
Diopside ..	—	—	—	6
Accessories ..	2	2	3	4

53/592 Leucocratic hornblende-biotite gneiss, river Tiva, nine miles W. of Mutomo.
53/588 Leucocratic hornblende gneiss, river Nzeo, four miles S. of Ikanga.
53/585 Leucocratic hornblende gneiss, river Nzeo, 3½ miles S.S.E. of Ikanga.
53/638 Leucocratic hornblende-diopside gneiss, nine miles S.W. of Mutomo.

Plate 1.—Views in the central ranges of hills in the South Kitui area.

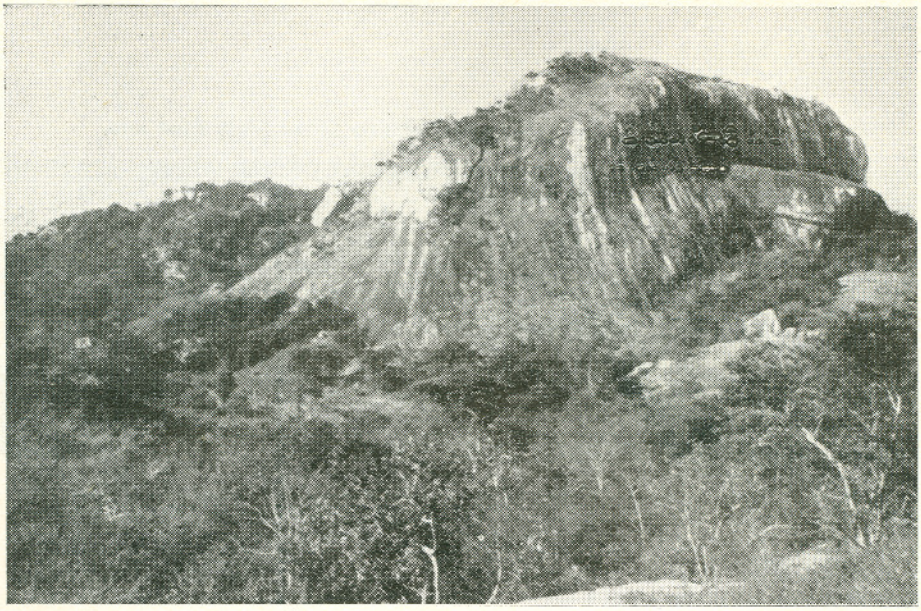


(a) Walasia (left), Matulani (middle distance right) and Ekulu (background). The low ground in the centre consists of sandy soil overlying garnetiferous and sillimanite-biotite gneiss. The hills are composed of oligoclase porphyroblast gneisses, those on the left being migmatitized.



(b) Ndulukuni: the main hill, composed of biotite-garnet gneiss, forming the southern extremity of the Ndulukuni anticline.

Plate 2.—Migmatites in the South Kitui area.



(a) Microcline-biotite-hornblende migmatites forming Mbitini hill. Large microcline pegmatite lenses are prominent.



(b) Contorted migmatite of Uwenee, showing plastic deformation.

(*f*) *Oligoclase porphyroblast gneisses*

These flaggy gneisses form prominent ranges of hills from the central northern border to Nzuli and Mathima a few miles north of Ndulukuni (Plate 1 (*a*)). They are meso-type rocks with alternating dark and light bands with conspicuous orientated pink felspar porphyroblasts in a dark base. The bands vary in width from a few inches to three feet but are rarely sharply defined. Biotite and hornblende are the common mafic minerals whilst garnet is developed in thin bands, and indicates a gradation between the non-calcareous and semi-calcareous beds. Sillimanite is absent. The rocks are strongly foliated, the planes of foliation being parallel to those in the other pelitic gneisses. Locally migmatitic sheets are developed, as is seen on the Ikanga–Voo road and in the river Ngunga. In such cases the foliation is often strongly contorted, and the development of microcline in the Mbitini area has produced a noticeably more homogeneous rock. Occasional amphibolite banding and schlieren were seen in porphyroblastic gneisses in the river Kataka.

In thin sections oligoclase and microcline porphyroblasts are seen, set in a granoblastic matrix of quartz, microcline and plagioclase, variably associated with muscovite, biotite, or biotite and hornblende. The albite-twinned plagioclase porphyroblasts have subhedral habit and are more altered than the potash felspar, for example in specimen 53/752 from Nzuli the crystals are crowded with thin wisp-like flakes of sericite. Larger sericite crystals are also sometimes included, together with rounded quartz crystals. Occasionally myrmekite is developed round the borders or associated with microcline as a replacement product. The matrix is often medium-grained but bands of more fine-grained material are sometimes present as in specimen 53/904 from the river Kataka.

In specimen 53/882 from the river Kakengele small, sometimes ragged, brown flakes of orientated biotite are common, scattered throughout the rock. A coarser-grained variety is typified by specimen 53/898 from Mangai, and in this large crystals of green hornblende, 2 mm. in length, contain large ovoid pools of quartz or partly enclose biotite flakes. Iron ore, sericite, and apatite are accessary in all the porphyroblast gneisses, the prismatic apatite being parallel to the foliation as expressed by the biotite.

An estimated volumetric composition of one of these rocks, specimen 53/882 from the river Kakenkele is:

Quartz	Microcline	Plagioclase	Biotite	Hornblende	Accessories
15	15	59	9	1	1

(*g*) *Biotite-garnet gneisses*

Occurrences of the biotite-garnet gneisses are limited. Between Walasia and Matulani and in the river Ngunga section are bands of granulitic biotite gneisses sprinkled with deep red garnets. They are dark-grey mesotype rocks, often well foliated, the foliation being emphasized by melanocratic bands rich in biotite. They outcrop mainly in stream sections and are interbedded with, or grade into, flaggy biotite gneisses and hornblende granulites and gneisses. Another horizon occurs in the Ndulukuni syncline (Plate 1, (*b*)) where the gneisses show good foliation, but the garnets are larger and generally confined to the darker bands.

Specimen 53/909, from the Walasia area, contains small euhedral pale pink garnets, up to 0·5 mm., associated with variably orientated dark brown and greenish-brown biotite flakes in a fresh granoblastic mosaic of plagioclase and quartz. The plagioclase which encloses small rounded blobs of quartz is mostly oligoclase, finely albite-twinned and in one case pericline-twinned. Thin sections of the Ndulukuni band are generally similar to that described above, but the biotite is concentrated in thin folia and has more tendency to a preferred orientation. It is reddish-brown, dichroic to light greenish brown or greenish-brown, and wraps round the large garnets (53/769). The latter measure up to 3·0 mm. in diameter and are cracked and contain numerous inclusions, unlike the Walasia garnets. The garnets

in the river Ngunga specimens also exhibit sieve structure. Large twinned oligoclase and untwinned plagioclase porphyroblasts have developed parallel to the biotite folia in the Ndulukuni rocks. Iron ore, apatite, zircon and muscovite are present.

Some estimated modes of various biotite-garnet gneisses are shown in Table IX.

TABLE IX

ESTIMATED MODE OF BIOTITE–GARNET GNEISSES

	53/723	53/830	53/876*a*	53/909	53/770	53/769
	%	%	%	%	%	%
Quartz	10	10	5	10	5	15
Plagioclase	63	69	80	69	73	34
Hornblende	—	—	1	—	—	—
Biotite	25	15	10	15	15	35
Muscovite	—	1	—	—	—	—
Garnet	1	3	4	5	5	15
Accessories	1	2	+	1	2	1

53/723 Kenze, five miles N.N.W. of Ndulukuni.

53/830 River Muliluni, Ndulukuni.

53/876*a* River Ngunga, six miles W.S.W. of Voo.

53/909 One mile E.S.E. of Walasia, Mbitini.

53/770 S.W. slopes of Ndulukuni.

53/769 Ndulukuni.

Garnet-rich rocks

A deep red massive garnet-rich rock with a distinct gneissose texture forms Magongo hill, on the north side of one of the dunite pipes at Ndulukuni. The proximity of the rock to a dunite pipe led the writer to consider the rock to be of igneous origin, but microscope examination suggests that it has been reconstituted from the garnetiferous biotite gneisses in which the dunite was emplaced. Massive garnet-rich rocks occur elsewhere in Kenya and are not connected with igneous intrusions.

Four slides of the rock (53/846) were examined and found to be characterised by pink garnet and a colourless or pale green pyroxene. This pyroxene, which is probably hypersthene with almost no sign of lamellar structure, has weak pleochroism and is biaxial negative with an axial angle of approximately 85°. In specimen 53/846 (4) the garnet occurs as massive crystals associated with quartz and hypersthene while a second specimen, 53/864 (3), is similar but contains a greater proportion of pyroxene and magnetite with a little apatite and a mineral resembling an amphibole. Specimen 53/846 (2) is a quartz-garnet rock containing partly oxodized iron ore while a fourth specimen, 53/846 (1), consists of small subhedral crystals of garnet and massive garnet, hypersthene, quartz and in part a pyritic mineral and abundant magnetite.

(4) *Metamorphosed psammitic sediments*

Metamorphosed psammitic sediments are preponderant over a wide area in the eastern portion of the district, forming resistant ridges and hills, and are typically leucocratic rocks with subordinate mafic minerals, though thin streaks and lenses of mafic material are to be seen throughout the series. In many parts, such as the hills between Kanziku and Voo (Mutha, Chematane, Kanzokea, Ebwa, etc.), they are difficult to separate from granitoid and leucocratic banded gneisses. True migmatitic varieties were rarely seen and it seems likely that they are metamorphosed derivatives of sandstones and associated rocks which have been quietly permeated *in situ* by granitic material.

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

Fine-grained leucocratic pale brown to pink quartz-felspar-biotite granulites are best exposed in the Voo area and form resistant bands and lenses associated with biotite-hornblende gneisses. Similar rocks have been described by Sanders from the Kitui area. In thin sections they are found to be composed of mosaics of quartz, plagioclase, microcline, perthite, and unorientated flakes of brown biotite. The plagioclase is largely finely twinned oliogclase and shows the greatest alteration, being heavily clouded; the potassic felspars are comparatively clear. Albite rims have formed along the oligoclase margins when in contact with microcline. Quartz, a common constituent, forms irregular clear grains or is included within the felspars as small rounded pools. Sparse garnet is seen in one band in the river Ngunga (53/877). Iron ore is the most common accessory constituent and can be readily mistaken for dark biotite in a hurried field examination of the rocks.

The quartz-felspar-biotite granulites grade into biotite free quartz-felspar granulites. Estimated modes of both types are shown in Table X.

TABLE X

ESTIMATED MODES OF QUARTZ-FELSPAR-BIOTITE GRANULITES

	53/865	53/895	53/867	53/877	53/885	53/868	53/871	53/896
	%	%	%	%	%	%	%	%
Quartz	20	25	18	50	20	8	15	30
Microcline and perthite ..	57	15	50	20	20	10	74	10
Plagioclase ..	20	53	30	28	59	80	10	59
Biotite	2	5	+	1	+	—	—	—
Accessories ..	1	2	2	1	1	2	1	1

Quartz-felspar-biotite granulites
- 53/865 Three miles S.W. of Voo.
- 53/895 Seven miles N.W. of Voo.

Quartz-felspar granulites
- 53/867 Five miles S.W. of Voo.
- 53/877 River Ngunga, seven miles W.S.E. of Voo.
- 53/885 River Ngunga, three miles W.S.W. of Voo.
- 53/868 Five miles S.W. of Voo.
- 53/871 Seven miles S.W. of Voo.
- 53/896 Seven miles N.W. of Voo.

(*b*) *Quartz-felspar gneisses*

Leucocratic quartz-felspar gneisses form the hills between Voo and Kanziku, Nzwani and Mutha being the highest (Plate 3 (*a*)). They are mostly homogeneous, white or buff, coarse- to medium-grained rocks containing hornblende and/or biotite, which have a random orientation. Melanocratic streaks and lenses band the rocks and near Dilili on the Kanziku-Mutha road they have a decided banded appearance. The rocks are considered to be metamorphosed psammitic sediments which had original interbanded semi-pelitic material, and pass into the semi-pelitic series in the Voo area.

The quartz-felspar gneisses are heteroblastic rocks in which microcline is often common and is seen to replace plagioclase. Quartz forms irregular, re-crystallised grains but is rarely contained as droplets within the felspar and occasionally forms a graphic intergrowth with biotite flakes (specimen 53/861, from Kemwa). Among the felspars oligoclase shows the greatest alteration, being clouded by sericite flakes, and is associated with myrmekitic growths.

Rare muscovite flakes were seen in some specimens. Like the quartz-felspar granulites these rocks contain perthite. Near the darker bands there is a greater proportion of hornblende and biotite which occur as unorientated blades and flakes. The hornblende which is a dark olive green variety is commonly altered to chlorite, whilst the biotite has a pale pinkish brown to greenish brown colour.

Table XI shows a number of estimated modes.

TABLE XI

ESTIMATED MODES OF QUARTZ-FELSPAR GNEISSES

	53/856	53/810	53/811	53/861	53/807	53/814
	%	%	%	%	%	%
Quartz	5	5	10	15	10	10
Microcline	43	27	5	15	2	5
Perthite	—	—	—	2	—	—
Oligoclase	50	65	81	63	81	69
Muscovite	1	—	—	—	+	—
Biotite	—	2	3	1	3	7
Hornblende	—	—	+	3	3	8
Accessories	1	1	1	1	1	1

Quartz-felspar gneisses { 53/856 Mutha. 53/810 Skwata. 53/811 Ndakani.

Quartz-felspar-hornblende gneiss 53/861 Kemwa.

Quartz-felspar-hornblende-biotite gneisses { 53/807 Ndakani. 53/814 Ndakani.

(5) *Migmatites*

The rocks in the north-western part of the area and on the ridges immediately adjacent to the Ikanga–Mutomo–Kanziku road are considered to be true migmatites. They are highly granitized gneisses derived partly from semi-pelitic rocks in which veins, lenses and laminae of granitic material either exhibit crude parallelism concordant with the original sedimentary pattern or occur as ptygmatic veins which bear no relationship to the regional tectonic scheme. Unorientated felspar porphyroblasts indicate the intital stages of granitization and the rocks grade into augen gneisses (near the locus of greatest granitization, viz. Mutomo ridge) in which oligoclase and microcline porphyroblasts are more frequent and orientated. On the feature running along the Ikanga–Kanziku road strongly banded migmatitic gneisses grade into homogeneous leucocratic rocks in which a faint wavy foliation is visible. The wavy foliation can be attributed to slight movement when the rock was plastic (Plate 2 (*b*)) Ptygmatic veins are considered by Wilson (1952, p. 2) to be of *primary* or *secondary* origin, and he also classifies the veins into three structural groups (*op. cit.*, p. 19). In the present area examples of veins in which the contortions have resulted from primary buckling during injection into static country-rock were seen. Other veins, however, are considered to have some tectonic significance and to be the product of combined primary injection and country-rock movement. In these cases the direction of injection was at right angles to the strike, whilst the traces of the axial planes of the ptygma parallel the strike of the migmatites and the axes of the major folds.

The migmatites are the southerly extension of the migmatitic zone west of the Kitui area, and have the same granitic or granodioritic composition. They grade into the semi-pelitic series to the south-west and into a large homogeneous granitoid mass west of the upper reaches of the Nzeo river. Granitoid sheets are present elsewhere but are not common. There is a westward increase in the microcline content of the migmatites and the development of microcline migmatites from the sodic oligoclase porphyroblast gneisses of the eastern ridges can be traced. The large tor and dome structures seen on the Mbitini and Mutomo ridges can be attributed to the relatively larger proportions of microcline in the rocks constituting them.

In the upper Tiva, Koma and Mewee rivers excellent examples of *lit-par-lit* injection are to be seen. Here the hornblende-biotite bands are separated by introduced leucocratic quartzo-felspathic material, the parallel banding being well preserved. The individual bands, which usually have sharp contacts, are never more than a few inches in thickness and some are contorted.

In thin section the mafic bands are seen to consist of aligned ragged biotite, pleochroic from yellow to greenish-brown, and green hornblende in a quartz-plagioclase mosaic. The leucocratic bands are a granoblastic aggregate of felspar and quartz with subordinate hornblende and biotite. The felspar is microcline and oligoclase and in specimen 53/601, from the river Mewee, occasionally has granulated borders indicative of the beginning of mortar structure. Epidote, calcite, muscovite and iron ore are accessories and are commonly confined to the crushed margins of the felspar.

In more homogeneous types local banding is still present and hornblendic granitoid folia widen and pinch between thinner parallel melanocratic bands, which contain varying proportions of biotite and hornblende. Certain of them have a preponderance of biotite towards their edges whilst their centres are composed of meso-type rock. Typical specimens are 53/652–655 from Mutomo hill. In one of these rocks (53/655) faintly twinned oligoclase, hornblende and biotite are associated with ragged pale-green diopside partly altered to hornblende. Magnetite, ilmenite, sphene, epidote and large prismatic apatites are accessory.

Xenomorphic-granular and crystalloblastic textures, as seen in the migmatites of the area south-east of Embu (Bear, 1952, p. 20), are found in similar rocks of this area and a high microcline content associated with shearing was also noted. Replacement structures such as myrmekite are common. Biotite and hornblende are the ferromagnesian minerals and are found in the granitoid portions as well as in the dark-coloured bands already described. The microcline-microperthite porphyroblasts are set in a microcline-oligoclase-quartz matrix, mortar texture being developed to varying degrees. Microcline and microcline-microperthite do not show the same degree of alteration as the plagioclase nor do they contain the numerous inclusions of the latter mineral.

Granitic sheets invade the main gneissic host-rocks, particularly in the Mbitini area. Here the sheets are slightly discordant, unlike the smaller concordant granitic lenses. The sheets are faintly sinuously banded but the banding does not conform to that in the host-rock, whose foliation wraps round the intrusions. These sheets exhibit a more typical granitic hypidiomorphic-granular texture than the host rocks which commonly have xenomorphic-granular textures.

Amphibolite schlieren are common in the migmatitic rocks and weather into elongated holes on flat rock surfaces. The schlieren are ovoid and elongated parallel to the lineation, and are rich in biotite. They contain small amounts of felspar, though many of the melanocratic varieties contain little visible felspar. Locally the schlieren are drawn out into hornblende-rich bands which pass into hornblende ortho-gneisses, the bands disappearing into pink granitic material firstly as small clots and finally as scattered crystals. In certain cases the bands end abruptly at the edges of large inlands of granitic rock but reappear on the farther sides of the islands, indicating a possible intrusive origin for such granitic bodies.

(6) *Anatectic or Palingenetic rocks*

(*a*) *Granitoid gneisses*

Granitoid gneisses are frequently found in the main migmatite zone and are coarse-grained pink rocks that often give rise to conspicuous massive outcrops. They contain amphibolite bands and schlieren like the migmatites, into which they grade. The close similarity of the granitoid gneisses to the granitic lenses and sheets in the main migmatite zone, and the fact that they occur within this zone, suggests that they may have had a degree of mobility and that they suffered intense granitic soaking during migmatitization. The granitoid gneisses are, in fact, considered to be granitized semi-pelitic sediments which have suffered greater alteration than the neighbouring migmatites. Some of the granitic sheets described above can also be included under this heading. Near the mapped contacts the granitoid rocks are foliated, but are more homogeneous within the masses themselves where biotite and rarer hornblende are usually unorientated, though occasionally they are arranged in a linear pattern.

The granitoid gneisses in thin sections reveal xenomorphic-granular textures, grading to more granitic textures (53/594, Nzui–Mewee junction). Microcline, quartz, oligoclase and biotite form the major constituents. Microcline and microcline-microperthite are very common but antiperthites were also noticed. Twinned oligoclase containing numerous quartz inclusions is of frequent occurrence and is the most altered of the felspars. Quartz occurs in allotriomorphic and rounded grains, large lobed crystals, small rounded pools in the felspars and as an essential constituent of myrmekite. Biotite and hornblende are not common, although the rock in an outcrop three miles south-east of Kisasi may be termed hornblende granitoid gneiss, as it contains a notable amount of porphyroblastic hornblende. The biotite, which is pleochroic from straw yellow to brown, occurs as large plates and is chloritized in some cases; muscovite is occasionally interleaved with it. Hornblende is sporadic in its presence and none was seen in slides of the more normal gneisses from the homogeneous portions of the granitoid masses. Iron ore, sphene and zircon are accessory.

The replacive nature of some of the minerals of the rock is shown by small allotriomorphic islands of microcline in finely twinned oligoclase, relic plagioclase within microcline, and lobe-like myrmekitic growths. The oligoclase is often cloudy and marginally altered, probably to an albitic composition. An indication of magmatic conditions is shown by the idiomorphic tendency of the plagioclase, round which quartz and microcline have grown.

(*b*) *Pegmatites*

Pegmatitic intrusion accompanied granitization in the migmatitic parts of the area and in the quartzo-felspathic gneisses in the east. The larger bodies are sheets and veins averaging two to three feet in thickness, although the sheets are anything up to twenty feet in thickness. Though some of the pegmatites may have been formed by replacement, in general their intrusive character is shown by the cross-cutting nature of the veins which often branch from the concordant sheets. These intrusions have clear-cut margins and invade all rock types within the migmatites. Fine-grained quartzo-felspathic aplites are frequently seen as narrow anastomosing veinlets and are found in areas where pegmatites are numerous.

At least three stages of pegmatitisation are recognised. Pegmatites of the first stage, which cut and are thus later than the conformable granitoid gneisses, are assumed to have been emplaced during the main phase of granitization. A second, late stage occurred after the migmatites had resumed some rigidity, as shown by the veins that have been emplaced in fault-planes, the faults being small strike-slip movements associated with drag-folding. Still later pegmatites veining other fault fractures are seen in the Ngunga valley, where the Mutito fault is exposed. These pegmatites are considered to represent the latest stage, being

associated with structures of younger age than the period of granitization. It is likely that the first two stages were not separated by any great length of time and, may have been concomitant.

The pegmatites are white, pink or brown in colour and are either uniform or variable in texture. In the coarser varieties large six-inch flesh-coloured felspars occur within a coarse quartz-felspar matrix with few or no mafic minerals. No muscovite was seen in the pegmatite, but small books of biotite were noted in some. Ilmenite and magnetite are associated with pegmatites in the Voo area, whilst magnetite-bearing quartz segregations form small isolated hills at the southern foot of Mutha and south of Mwanavya, south-east of Kanziku. These occur within an area of metamorphosed psammitic sediments.

Schoeman (1948, p. 29) draws attention to mafic aureoles surrounding segregation pegmatites, suggesting that the enrichment in mafic minerals is due to subtraction of felsic material required to form the segregations. Such aureoles were commonly seen in the present area, as at Nguani near Ikanga, the mafic constituents being biotite and hornblende.

(7) *Metamorphosed intrusive rocks*

Dykes and sills that were intrusive into the Basement System rocks before metamor phism are not numerous in the area. The outcrops vary from a few inches to over forty feet in width and in one instance a number of thin intrusions over a width of six feet were seen.

The metamorphosed intrusive rocks include amphibolites, plagioclase and pyroxene amphibolites, hornblende-pyroxene gneisses and a pyroxenite. The majority are concordant sills usually associated with hornblende-biotite gneisses, but the pyroxenite and a hornblende-pyroxene gneiss (53/584) are discordant dykes.

(*a*) *Amphibolites*

The rocks under this head grade from plagioclase and pyroxene-bearing amphibolites to amphibolites with increase in hornblende content. A lenticular coarse-grained greenish-black amphibolite occurs in the quartz-felspar gneisses south of Nzwani, whilst the remaining types were seen in the semi-pelitic series. In thin sections the rocks are found to be even-grained, consisting of green hornblende in some slides and brown in others, the hornblende forming a mosaic with twinned plagioclase felspar ranging in composition in different slides from An_{29} to An_{60}. There is little alteration except for slight cloudiness of the felspar. Specimen 53/677 from Chome contains scattered granular hypersthene whilst in 53/755*a* from Etulu pink euhedral garnets and colourless to pale green diopside are present. In the coarser variety from Nzwani (53/914*a*) green hornblende and pale green diopside occur in approximately equal quantities, the hornblende replacing the diopside. Iron ore is an extremely common accessory and is often present as a result of the alteration of the ferromagnesian minerals.

(*b*) *Pyroxene-hornblende gneisses*

These rocks are similar in appearance to the amphibolites but thin sections show decided differences, the principal being their gneissose texture. In specimen 53/573*c* from the river Tiva diopside is the predominant mafic mineral and is wholly or partly pseudomorphosed by olive-green hornblende, which often occurs as a broad margin to the pyroxene. A brownish-green hornblende is associated with thin biotite crystals in 53/584, from the river Nzeo, whilst the pyroxene in this case is hypersthene. Other specimens, 53/893 from the river Thowa and 53/907 from the river Kataka, contain a greater proportion of hornblende and the felspar is labradorite of composition An_{70} in 53/893.

(*c*) *Pyroxenite*

The only pyroxenite discovered in the area outcrops in the river Kathini below the graphite workings. It is a discordant intrusion, green in colour, occurring as irregular patches in a granitoid gneiss. It is a nearly monomineralic rock (specimen 53/799) and is composed of pale green diopside partly replaced by pale green hornblende, and calcite.

(8) *Basic and ultra-basic intrusive rocks of post-Basement System Age*

Four ultra-basic intrusives and associated rocks were located on, or near, the axis of the Ndulukuni anticline. Three of these—Kapoponi, Magongo and Mukono—outcrop as small knolls one and a quarter to two miles north of the Ndulukuni peak whilst the fourth, Kenze, is five miles north of that hill. The intrusions are dunite pipes which are rarely seen outcropping at the surface, but in most places are covered by large black boulders of basic rocks, the boulders often being so massive as to suggest that they are *in situ*. At Kapoponi and Kenze, however, pitting and trenching has shown that they are everywhere underlain by soft yellowish-green serpentinized dunite and have been isolated by weathering of the dunite. Where exposed in the trenches the dunite is cut in every direction by magnesite veins varying in width from a fraction of an inch to six feet. Asbestos, talc and vermiculite are also associated with the basic intrusions but good exposures of the vermiculite were only seen associated with, or near to, the magnesite veins. In certain trenches on the southern side of Kapoponi and on Mukono large patches of nearly pure pyroxene (enstatite) rock were seen and probably represent a differentiation product of the original intrusion. At Magongo hill the dunite adjoins a reddish rock which forms the higher part of the hill, dunite occupying the lower southern slopes. The principal rock of the intrusions is dunite in which olivine altered to serpentine and antigorite forms about 95 per cent, the remainder consisting of clinopyroxene, pyrrhotite and iron ore.

The most interesting rocks associated with these intrusions are the boulders that overlie them. They are all typically melanocratic, heavy rocks usually medium-grained but occasionally fine-grained, and vary considerably in mineral composition. Similar rocks have been described by Pulfrey (1946) from the Meru district and reference is made to his classification (*op. cit.* p. 69) in describing the rocks here. The rock types include: gabbros, melagabbros, bojites, pyroxenites and saxonite.

(*a*) *Gabbros*

The gabbros range from fine-grained rocks to more coarse-grained types generally exhibiting a hypautomorphic granular texture in which the felspars are rarely idiomorphic. Pale to emerald green pyroxene is associated with a pale pink augitic type and is little altered to hornblende. Primary green hornblende, strongly pleochroic in shades of green, is tabular in habit but usually sub-idiomorphic. The ferromagnesian minerals are associated with granular iron ore which in some cases is enclosed entirely within the hornblende, though occasionally as in specimen 53/727F from Kenze none is present. The plagioclase in the specimens collected is mostly labradorite to bytownite (range found An_{60} to An_{80}). It occurs in polysynthetically twinned crystals, approximately equidimensional, and exhibiting little alteration. Pericline-twinned individuals are present but not common. Sphene and green spinel (pleonaste) occur in certain specimens, the latter as anhedral crystals associated with iron ore (53/841 from Kapoponi).

(*b*) *Melagabbros*

The melagabbros are similar to the gabbros except that they contain less felspar, with a corresponding increase in pyroxene content. In specimens 53/784 and 53/791*c*, both from Kenze, small irregular pale flesh-coloured garnets are included in large felspars whose medium composition would, however, preclude these rocks from being named kedabeckites (Johannsen, 1949, p. 241).

A single example of melagabbro (53/844*a*) was picked up at Magongo and like the rocks previously described appears granulitic in the hand-specimen. A thin section however shows that its grain size varies from 0·5 mm. to 3 mm. Brown pleochroic hornblende is associated with fairly fresh augite, whilst pale pink euhedral garnet is accessory. The amphibole contains occasional rounded inclusions of augite and in certain cases is clearly replacing pyroxene. A little labradorite, occurring interstitially between the other minerals, is present but is not abundant. Rare iron ore is the only other accessory.

(*c*) *Bojites*

Basic intrusives in which amphibole is the predominant ferromagnesian mineral are rare. Three slides of such rocks were examined and in these the hornblende is preponderant, there being a marked reduction in the pyroxene content. The hornblende shows slight replacement by brown biotite, whilst larger tabular crystals have ragged borders unlike the amphiboles of the gabbros. The plagioclase, like that in the gabbros, is calcic with a composition about that of bytownite. Rounded apatites occur in these rocks.

Volumetric analyses of a number of the basic rocks are as follows:

	53/783	73/727F	53/842	53/784	53/791A	53/791D
	%	%	%	%	%	%
Plagioclase	60	40	15	20	50	35
Pyroxene	20	60	74	77	—	15
Hornblende	18	—	5	+	50	50
Garnet	—	—	—	3	—	—
Spinel	—	—	2	—	—	—
Iron Ore	2	+	4	+	+	+
Others (including sphene, apatite, biotite and chorite)	+	—	+	+	+	—

53/783 Gabbro, Kenze.

53/727F Gabbro, Kenze.

53/842 Melagabbro, Kapoponi.

53/784 Garnetiferous melagabbro, Kenze.

53/791A Bojite, Kenze.

53/791D Bojite, Kenze.

(*d*) *Pyroxenites*

Other granulitic rocks among the boulders are pyroxenites in which the felspar content is small and in which a pale pinkish-brown pyroxene is the dominant mineral, associated with hornblende which pseudomorphoses it in part, and pale green chlorite. Specimen 53/845 from Magongo contains abundant green spinel in addition. Brown oxidised ilmenite is scattered throughout the rock.

(*f*) *Saxonite*

The saxonite (53/840, Kapoponi) is a more coarse-grained rock in which little alteration was observed. Abundant and fairly fresh olivine, hypersthene, and green spinel (pleonaste) are the common minerals and iron ore is present more rarely. Slight serpentinisation of the olivine occurs along fine cracks, whilst granular iron ore is scattered throughout the crystals. Characteristically the pleochroic hypersthene occurs as subhedral crystals up to 2·5 mm. in length. The spinel, in grains up to 3 mm., is a late replacive growth and is intimately associated with fibrous chlorite.

2. Tertiary–Yatta Plateau Phonolite

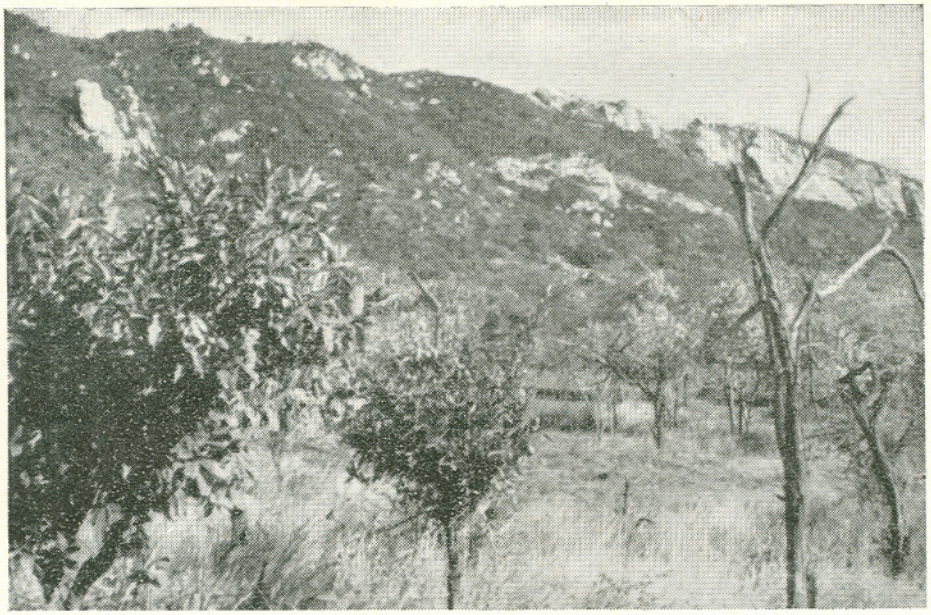
Kapiti-type phonolite of the Yatta plateau occurs in two places in the south-west corner of the area, where it forms small tongues from the main outcrop in south-east Machakos. The flow is considered to be of Tertiary age (e.g. Dodson, 1953, p. 5).

Megascopically the phonolite is a fine-grained rock with medium-sized to large phenocrysts, the texture of the groundmass varying according to the position in the flow. The phenocrysts consist almost entirely of large anorthoclase crystals and of invariably smaller nepheline crystals, both of which show some zeolitization. Olivine phenocrysts are rare and small, and partly replaced by carbonates. Anorthoclase and nepheline occur in the groundmass together with aegerine, aegerine-augite, augite, kataphorite and cossyrite, whilst patches of analcime are occasionally seen. Rare amygdales contain calcite, zeolites and kaolinite.

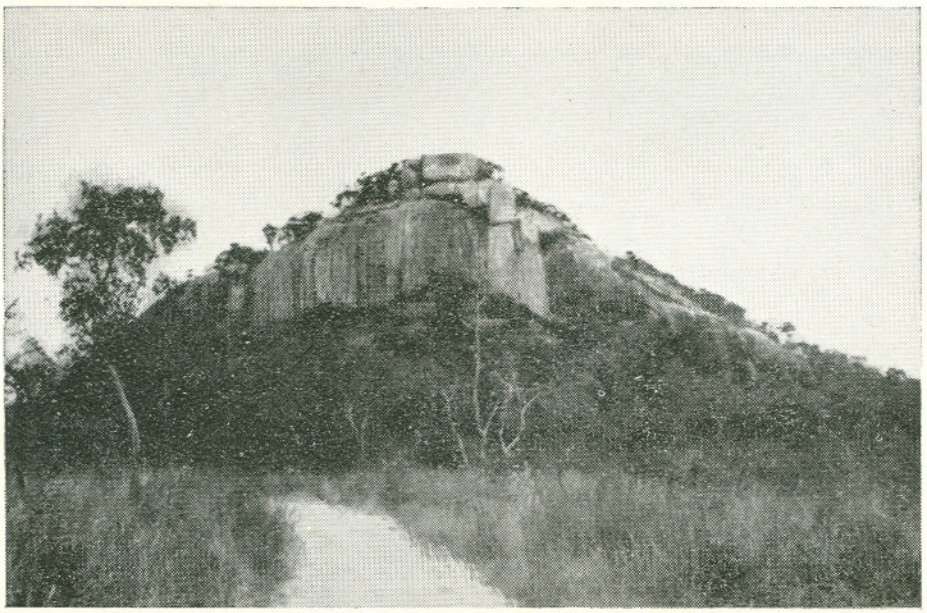
3. Superficial Deposits of Pleistocene to Recent Age

Bright red and red-brown sandy soils cover the greater proportion of the area and locally kunkar limestones and lateritic ironstones can be seen. The soils are the products of weathering under semi-arid conditions and are particularly developed in the eastern half of the area, though the soil mantle there is never thick. The Thowa river has cut through about twenty feet of superficial deposits to expose Basement System rocks in its bed. Good 20-foot sections are also exposed in the Kataka valley, N.W. of Voo, where a *piedmont* fringe of coarse gravels formed by combined sheet-flow and stream action has accumulated at the base of the Mutito scarp. The soils are principally quartz-felspar sands with biotite and magnetite, their colours varying according to the nature of the underlying rock. Areas of black cotton soil are found in the west on the gently sloping plain between the sub-Miocene and end-Tertiary peneplains. Many of the streams are bordered by similar soils, whose development is due to poor drainage and bears no relation to the underlying formations. To the north where streams are more numerous and rainfall heavier the red soils are replaced by black soils which are more amenable to cultivation and produce good crops. The seasonal nature of the flow of the large rivers such as the Tiva and Thowa together with the decrease in their gradient gives rise to bedded sands and gravels in their lower reaches where the carrying capacity of the rivers is small. The alternation of beds of gravels and sands is interpreted as a result of seasonal flooding, the coarse materials being brought down the river during periods of spate, whilst the sands are deposited when flood waters have subsided. Extreme rains will cause the removal of such deposits and this is seen in the Tiva valley south-west of Mutomo where the heavy rains of 1951 caused extensive erosion of the river deposits bordering the river course. Locally the river beds contain superficial limestone deposits which have been deposited on rock surfaces from lime-rich waters.

Plate 3.



(a) Quartz-felspar gneisses of Nzwani. Curvilinear joints are responsible for the shape of the large rocky outcrop on the right.

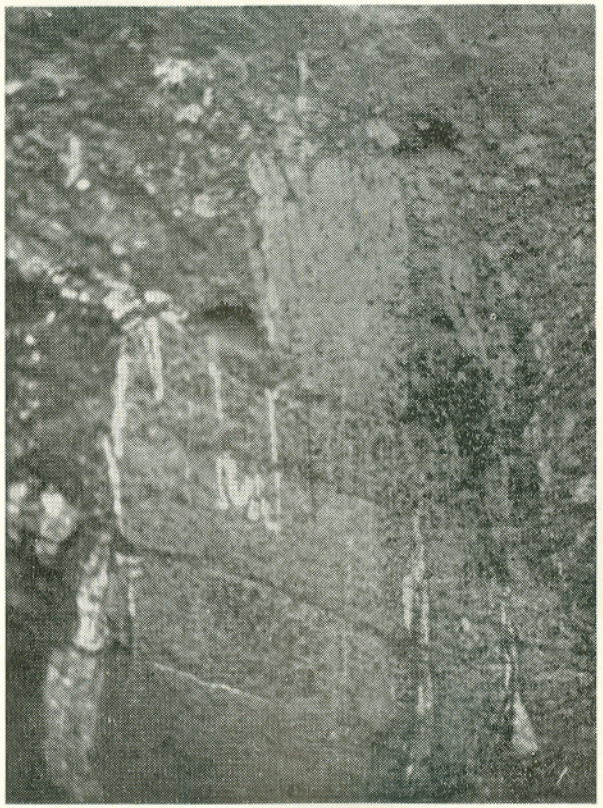


(b) Hill composed of migmatites, south of Mutomo hill. Curvilinear joints are visible, being sub-parallel to the surface of the hill.

Plate 4.



(a) Looking south at one of the faults in the Mutito fault-zone where it crosses the river Ngunga. The fault plane has been "injected" by a quartzo-felspathic pegmatite.



(b) Graphite band in the marble of the Bewick Moreing Prospect. Small aplitic ptygma are clearly visible in the dark graphite band, which shows the effect of soil creep near the surface.

VI—METAMORPHISM AND GRANITIZATION

The nature, continuity and homogeneity of the rocks of the Basement System and the presence of sedimentary structures in them have led writers to the conclusion that the rocks were originally mainly sediments which have been subjected to regional metamorphism. The metamorphism has been considered to be of Archaean age, the rocks having suffered alteration over prolonged periods and probably on several occasions.

In the Kitui area granitization accompanied regional compression and downwarping to low levels in the earth's crust, where it is presumed hot viscous magma contributed to raise the temperature to high levels, whilst magmatic fluids permeating the rocks accelerated chemical reaction. Although no intrusive bodies of batholithic dimensions were seen and recrystallisation *in situ* was predominant, magmatic intrusions did take place along the axis of the Kitui anticline resulting in migmatitisation and pegmatitic injection. An increase in metamorphic grade is apparent from east to west (cf., Schoeman, 1948, p. 19) towards the Kitui anticlinal axis, where granitoid sheets and migmatites occur and where granitizing fluids have been most effective. Alkali metasomatism has played an essential part in the alteration of the original sediments through the following stages: biotite-hornblende gneiss—plagioclase porphyroblast gneiss—augen gneiss—migmatitic and banded gneiss accompanied by permeation and *lit-par-lit* injection—granitoid gneiss. A comparable example is seen in the Stavanger area of Norway where there has been a progressive enrichment in albite and potash felspar in rocks of pelitic origin (Goldschmidt, 1921). The progressive development of microcline westwards in the South Kitui area and the high proportion of this mineral in the rocks to the west implies a high degree of metasomatic exchange of alkalis, and contrasts with the effects produced by metamorphism of psammitic rocks to the east away from the anticlinal axis and where microcline is rare. The final stages of granitization are represented by the injected granitic sheets and pegmatitic veins. The pegmatites and aplites invariably cross-cut all the other rocks and form a reticulate pattern throughout the migmatite zone.

The limestones have been little effected by granitization; recrystallization and the development of forsterite being the only response. During compression they adjusted themselves to tangential forces by flowage rather than by fracturing, which perhaps accounts for their relative impermeability to granitizing fluids. Fracturing later intervened, however, as is proved by the fact that the graphitic bands in the marbles exposed in the Kanziku area are veined at right-angles to and parallel to the foliation by aplites. Lenses of calc-silicate rock within the marbles may have been protected from the effects of granitization, but fracturing and aplitic veining in the marbles would tend to disprove this. Calc-silicate gneisses and granulites which are found associated with the biotite gneisses and the marbles on the other hand represent rocks that were highly susceptible to mineralogical changes and characteristic mineral assemblages have resulted. Green diopside, hypersthene, hornblende, garnet and plagioclase are characteristic of these rocks although all are not necessarily present together, and mineralogical disequilibrium is indicated in those rocks in which they are. Although such assemblages would usually be considered as indicative of the pyroxene hornfels facies or the granulite facies, it is undesirable in the present case to include them in either of those facies as the area is one of intense granitization.

Sillimanite, a high-grade index mineral of regional metamorphism, is present in the area in biotite gneisses and garnetiferous biotite gneisses. The sillimanite has developed in an originally pelitic sediment in a restricted zone of probably high alumina content. The assemblages formed indicate the high-grade sillimanite-almandine sub-facies of the amphibolite facies of metamorphic rocks and may be compared with assemblages found in rocks in the Kitui and Embu areas. Lower grades of metamorphism are probably represented by the biotite gneisses of the Voo area.

It is concluded that the controlling factor in metamorphism here was recrystallisation *in situ* without the addition of material from external sources, except locally as indicated above.

VII—STRUCTURE

Folding.—The western half of the area is dominated by the N.W.–S.E. trend of the axes of numerous folds (Fig. 2) though north of Ikanga the trend becomes N.–S., a direction

that is continued in the Kitui area. The folds are delineated by the topography, every range being approximately parallel to the fold axes. West of Ikanga the highly folded gneisses generally dip westwards forming the westerly limb of the Kitui anticline, which is the major structural feature of the area. East of the anticlinal axis rocks representing a thickness of approximately 37,000 to 44,000 feet of sediments have been thrown into a number of overturned folds as far east as the Mutito fault, forming the flank of an anticlinorium some 30 miles broad. Near the Mutito fault the folds are tighter but their axial trends remain parallel to the main regional trend. The most complicated folding is that seen at Ndulukuni where a single marble band has been thrown into a number of overturned folds.

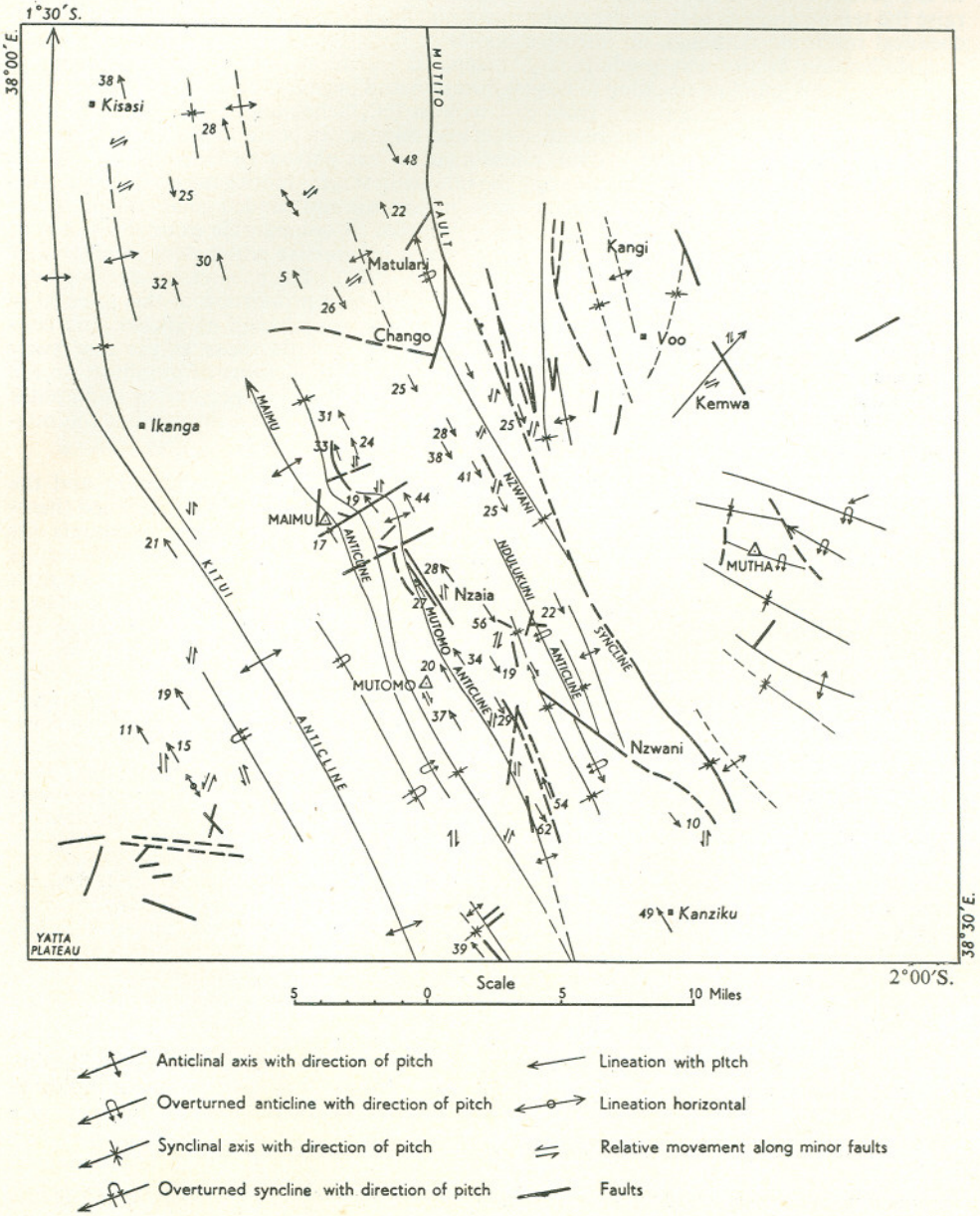


Fig. 2—Structural map of the South Kitui area.

East of the Mutito fault overfolding of the rocks is most apparent but of a more complicated nature than that farther west. The axial trend of the folds has shifted slightly and is more north-westerly in the Mutha area, whilst north of Voo the trends continue to follow the main N.N.W.–S.S.E. trend. The Kemwa anticline is the best exposed and is beautifully illustrated on aerial photographs, on which the faulted and northerly displaced nose of the fold can be seen. Other folds are equally well shown on the photographs and suggest that the Kemwa fold is a drag fold on the generally N.W.–S.E. trending folds of the region. At Mutha village an overturned anticline with S.W.-dipping limbs is well exposed along the roadside from the dispensary northwards towards Voo.

Minor Structures.—The linear arrangement of such minerals of the gneisses as hornblende and biotite is parallel to the original bedding planes at a large angle to the dip of the rocks, and is presumed to be a b-lineation. Most lineation observations were taken in the western and central parts of the area and are shown on Fig. 2. The pitch varies from as much as 62° to nil but is usually about 25° either to the N.W. or S.E. West of a line through Mbitini, Wenduku, Jasio, one mile west of Ndulukuni, and Kanziku, i.e. to the west of the east flank of the Mutomo anticline, all but one of the lineations measured pitch north-eastwards whilst east of that line, with two exceptions, one of which can be accounted for by faulting, the lineation pitches south-eastwards. Pitch culminations are normally expected at right-angles to the regional strike but in this area the "culmination" is parallel to the axial trend of the folds. Unfortunately the culmination passes across badly exposed country and in the time available for the present survey no evidence could be obtained of the reason for this abnormality. It is suggested, however, that the line of culmination may represent a bedding slide possibly associated with movement along the southern extension of the Mutito fault, where thrusting has probably taken place. The presence of graphitic marbles along the line also suggests that it was here that movement was easiest, producing the two directions of lineation along the regional strike.

Throughout the area minor faulting of the order of a few inches to about three feet was seen. These minor faults (*see* Fig. 2) displace folded beds, which probably represent drag folding associated with the major folds of the area. In every case examined the more disturbed beds are thin bands or schlieren of hornblende-biotite gneiss between granitoid material. Boudinage structures also appear to parallel the axes of folding but they are of infrequent occurrence. Both these features, boudinage and small scale folding, were observed on horizontal surfaces which makes their use in a tectonic synthesis of the area difficult.

Faulting.—Faulting perpendicular to the axial trend of the folds is particularly developed in the Maimu area, but is also present near the Yatta Plateau. Mylonite veins are exposed over a width of six feet in the valley south of Maimu trigonometrical beacon, while rare slickensided blocks occur as float here. Similar mylonites with slickensiding and shearing were seen in the Ngunga valley south of Chango where, however, little or no lateral shift has taken place. Diagonal faulting has caused displacement along the Ndulukuni anticline where beds have been downthrown to the south–west. On the east flank of this anticline a folded marble band was mapped but its southerly extent is masked by a heavy alluvial cover, whilst the northerly extent of what is probably the same folded marble band near Kanziku is similarly hidden. It seems that thinning and displacement of the band has occurred near the diagonal fault which passes south-eastwards along the western foot of Nzwani.

Other faults parallel the axes of the folds, and occur near their axes. Three strong faults can be mapped west of Nzaia in the Mutomo anticline and it is not unlikely that they continue farther south where, however, mapping is difficult on account of a thick alluvial cover. These faults occur where maximum folding of the rocks has taken place and together with the strong jointing seen in these rocks, as at Nzaia, are a measure of the amount of relief to compressional forces which occurred during folding.

The Mutito and associated faults comprise a marked feature on the eastern margin of the Kitui hills. There is a pronounced drop in the north on to the end-Tertiary peneplain and isolated hills of fault breccia, just east of the scarp, are indicative of westward fault-scarp retreat through erosion. What is called for convenience the Mutito fault is in fact a fault-zone nearly two miles wide, and is well exposed in the valley of the river Ngunga, W.S.W. of Voo (Plate 4 (*a*)). Numerous faults separate blocks of hornblende-biotite gneisses

which have been thrown into folds of small amplitude whilst shearing, fault breccias, gouge, pegmatites and veining by chalcedonic silica are all associated with the faulting. South of the river Ngunga no topographic or other field evidence of the fault was seen, but from structural evidence displayed on Mutha and adjacent hills it is thought that the fault passes into a high-angle thrust fault which is entirely covered by alluvium. The extension of the fault is considered to pass into the longitudinal fault which cuts the Nzwani syncline. In the north the Mutito fault has several branches, movement along which has been responsible for the displacement of small blocks near the northerly pitching Matulani syncline which was overturned during the folding.

Jointing.—Jointing is particularly well developed in the granitoid and migmatitic rocks of the area and comprises longitudinal joints, cross-joints, diagonal joints and foliation joints. The foliation joints are rough and are not so clear-cut as the other kinds of joints. The cross-joints are particularly noticeable in the Maimu–Mutomo ridge where eroded clefts are flanked by dome-like hills with opposing convex faces. Cross-joints are similarly developed in the ridges of porphyroblastic felspar gneisses in the north–east and have isolated large flags of these rocks, the flags being particularly noticeable on the crests of certain ridges such as Matulani. The diagonal joints are near-vertical cracks at an angle to the remaining joints and are less frequent, but have aided weathering processes to isolate many of the hills in the Kitui–Kanziku ranges. During the period of compression stretching took place along the crests of the anticlines producing longitudinal tension joints parallel to the axes of the folds. With the intrusion of granitic magma, flow lines parallel to the axial trends of the folds were produced, hence introducing a linear weakness in this direction. It is possible, therefore, that during cooling after impregnation by migmatizing fluids various joints would also be produced through contraction.

In some cases shearing has taken place up or down the foliation planes, as is well exposed in some of the graphite trenches at the Bewick Moreing Prospect. In the trenches, sheared junctions between various beds are common and thin sections show the degree of granulation along such contacts especially those of the granitoid gneiss bands.

The marble bands show rapid changes in strike which have been produced by relief at right-angles to the direction of pressure. The Maimu faults and the major joints across the Mutomo hills and neighbouring ranges are probably due to tensional relief.

The rarer diagonal joints seen may represent shear planes and are probably later in origin than either the longitudinal joints or cross-joints, some evidence for this being seen where pegmatites follow these directions cutting the other joint directions. During the early stage of migmatization the longitudinal joints were probably injected by granite material, pegmatites and aplites, as the western part of the area is characteristically invaded by such veins in the direction of greatest elongation of the rocks. Later pegmatitic and aplitic veining is represented by the diagonal veins which are seen particularly among the migmatitic rocks and probably represent the final intrusions from a nearly cooled centre.

Although the dominant N.W.–S.E. trend in the area could have been produced by shearing deformation under the influence of E.–W. forces, the structures are best interpreted as the result of compressional forces acting from the N.E. or S.W. This differs from the Machakos area a few miles farther west where Baker (1954, p. 22) postulates E.–W. compression aided by rotation around centres of granitization to account for concentric structures around granitoid domes. The N.–S. trends in the northern part of the present area are, however, indicative of E.–W. compression. The folding was followed by intense migmatization when much of the sedimentary fabric was destroyed in the north and the intrusion of granitic sheets elongated perpendicular to the direction of pressure took place.

VIII—ECONOMIC GEOLOGY

Few minerals of economic importance have been discovered within the South Kitui area, which is composed nearly entirely of Basement System rocks. Graphite deposits west of Kanziku have proved, however, to be of considerable extent and despite their distance from rail, their exploitation in the future may be of value to the Colony. A small export has already been made from one deposit. Deposits of other minerals are mainly associated with the Ndulukuni basic intrusions but are limited in extent and their development at the moment is considered to be uneconomic.

1. General

(1) *Graphite*

In 1941 a certain amount of work was carried out in a search for workable graphite beds by B. A. Brannstrom (Government prospector) on a marble band which crosses the Ikutha–Kanziku road approximately four miles west of Kanziku. Later, in 1942, E. R. Wright pegged five graphite claims on the marble band, the most southerly claims crossing the road. In early 1943 he pegged four new claims north of this, transferring the claims, after re-pegging the earlier location, to Mr. G. J. Laing in 1944, who re-transferred them the same year to Raw Material Development Ltd., which, however, abandoned the claims in late 1944. C. R. Stokes-Fair, another private prospector, pegged a single graphite claim in the same area in 1945, the claim expiring in 1948. All the claims mentioned were eventually allowed to lapse without any work being carried out on the deposits apart from prospecting and initial testing of the ore.

No further interest was taken in the area until R. O. Johnston erected a protection notice on what is now called the Bewick Moreing Prospect in 1950.

(a) Bewick Moreing Prospect

Though Johnston erected a Prospecting Notice on his prospect he carried out little systematic work and did not renew the notice. Later, in 1951, D. K. Hamilton (E.C.A. geologist) and D. Hobden (Government prospector) carried out more extensive field work in the area and their results, together with laboratory tests carried out in the Mines and Geological Department, showed that possibly economic deposits existed and that it was desirable they should be further examined and developed by a private company.

An Exclusive Prospecting Licence, covering an area of nominally 422 square miles (found on survey to be 330 square miles) was granted, therefore, to Bewick Moreing and Co. Ltd., with effect from 2nd November, 1951, in order that the graphite deposits could be examined more fully and with a view to selling Kenya graphite on the world market. Work on the main deposit was begun in 1951 and is being carried out at the time of writing.*

The deposit lies six miles west of Kanziku, fifty miles from Kitui and approximately forty miles from Kibwezi, the nearest point on rail to the south. At present access to the deposit is possible by means of a motorable track from the Mutomo–Kanziku road. The area is low-lying, being only 2,500 feet above sea-level, and is thickly covered by bush and thorn scrub. The prospect is crossed by the river Kathini in the north where no graphite exposures can be seen, the only natural exposure of graphite being in a small stream in the southern third of the prospect. Water supplies are poor and can only be obtained by digging in the river Kathini although bore-holes would probably yield sufficient for domestic purposes, and limited supplies for special purposes are available from the bore-hole at Kanziku. The men of the Akamba tribe are the only local labour available, and being so far away from centres of European and Indian population thay have had little contact with modern working methods, resulting in acute labour difficulties and shortages, with subsequent delay in work on the prospect. The thorn scrub and low bush in the district provides little timber for use in mining, the thorn trees available being stunted and bent and it is with the utmost difficulty that straight trunks six feet in length can be found. A large area around the deposit has already been searched for suitable trees to line the one shaft, six feet square and 120 feet deep, which has now been sunk. As mining operations proceed the timber and water shortages will present urgent problems to the mining company involved.

The graphite deposit (*see* Figs. 7, 8 and 9 at end) is contained in and overlain by limestone approximately 240 feet in thickness, which itself is part of a semi-pelitic series of biotite-hornblende gneisses and banded granitoid gneisses, striking forty degrees west of north (320°) and dipping steeply east, usually at about 70°. The graphite deposit is in the east limb of a small anticlinal flexure, the axis of which passes between the deposit and a neighbouring more westerly deposit which is described below (p. 42). Minor faults that displace the deposit are considered to be adjustments resulting from the folding.

Descriptions of the rocks of the succession were given in an earlier chapter, but it should be added here that examination of thin sections of the graphite rocks from the prospect

*The Exclusive Prospecting Licence was allowed to lapse in November, 1953, claims being subsequently pegged over the deposits that the company had found of most interest. All the claims were relinquished by February, 1955.

shows that they are nearly biotite-free and that the graphite is mainly intergranular, so that difficulty should not be experienced in extracting it. Extraction tests carried out in England, however, have shown that the flakes are broken in some cases during extraction, presumably by quartz grains in the ore.

Trenches dug at right-angles to the strike have revealed a graphitic zone over 5500 feet in length, characterized by a swarm of graphitic lenses near the base of the limestone, where it is in contact with a massive granitoid gneiss to the west. This granitoid gneiss interfingers with marble and graphite bands, while similar occurrences are seen at the top of the marble at its junction with a biotite-hornblende gneiss. Trench G510S exposes a typical cross-section of the graphite zone and shows the following succession from east to west:

	ft.	*ins.*	
Siliceous marble	15	0	
Marble with graphitic schist bands	4	0	
Marble with disseminated graphite flakes	108	6	
Graphitic schist	4	6	
Marble (hidden by soil cover)	6	0	
Graphitic schist	5	0	
Marble with disseminated graphite flakes	2	0	
Graphitic schist	4	0	
Marble with disseminated graphite flakes	4	6	
Graphitic schist	2	0	
Dark red garnetiferous granulite	3	0	(approx.)
Marble with disseminated graphite flakes	3	0	
Graphitic schist	1	0	
Marble with disseminated graphite flakes	3	0	
Graphitic schist	1	0	
Brecciated marble with thin marble bands	8	6	
Siliceous marble with a thin graphite band	6	6	
Marble with disseminated graphite flakes	41	0	
Siliceous marble with a thin graphite band	6	0	
Granitoid gneiss	Base not seen		

Throughout the marble zone, granitoid gneisses, biotite-hornblende gneisses, calc-silicate granulites and other similar rocks are found as small lenticles. In the southern part of the deposit a dark brown garnetiferous granulite averaging five feet in thickness, forms a good "marker" horizon a few feet above the base of the limestone, little good-grade graphite rock being seen below it. The general strike of all the lenses and bands of graphitic gneisses coincides with that of the surrounding rocks whilst trench sections in the graphite and marble indicate great variations in the dip of the lenses, ranging from 25° to vertical. Although more than one main horizon of graphite occurs within the marble that, lying near the base of the limestone appears to be of most economic importance.

Almost all the graphite bands bend over to the west near the surface. In depth, however, they dip continuously eastwards though generally steepening towards the vertical. In the one shaft already sunk the persistent eastwards dip has been followed to a depth of 120 feet. The westerly turn-over of the graphitic bands near surface seems to be of relatively recent origin and due to soil creep.

As one shaft only has been sunk, and that near the main graphite band, the nature of the bands in depth cannot be stated with certainty. Although it is likely that they are lenticular in the plane of the dip there is no reason to believe that the tailing out of a lens will not be followed by the appearance of other lenses at greater depths.

Many of the graphite bands exposed in the trenches are veined by thin white quartz-felspar aplites devoid of graphite flakes. In trench G346N such veining occurs in two directions, one parallel to the foliation, the other horizontal. Thicker (two inches) veins follow the former direction whilst thinner veins (half inch) are horizontal. Many other trenches show similar veining but not so well exposed. Other veining is of ptygmatic type and was seen in trench G475S (*see* Fig. 3 and Plate 4 (*b*)) and at the top of the shaft. The axes of the folds parallel the strike of the foliation. It is presumed that these aplite veins were injected during a late stage in the metamorphism of the area and after the period of intense folding which was responsible for minor folds within the graphite bands (*see* Fig. 4).

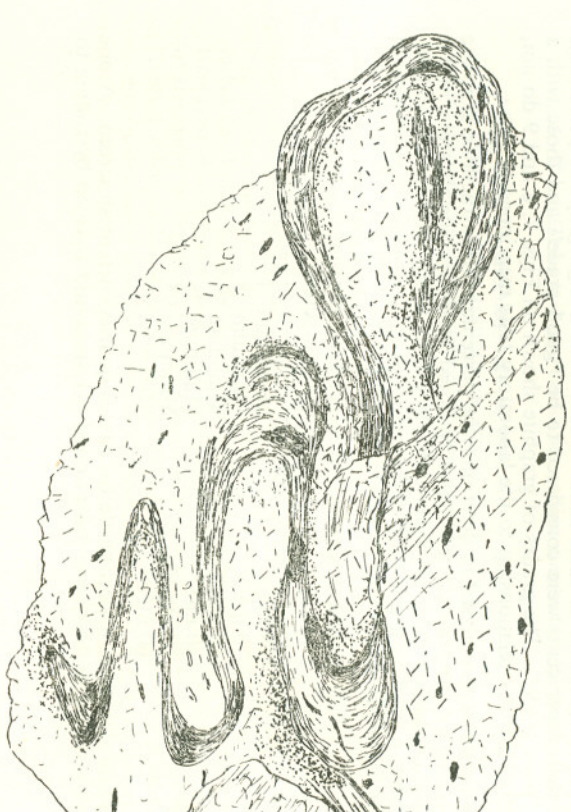


Fig. 4—Minor folding of a thin graphite band in the marble at the Bewick Moreing Graphite Prospect.

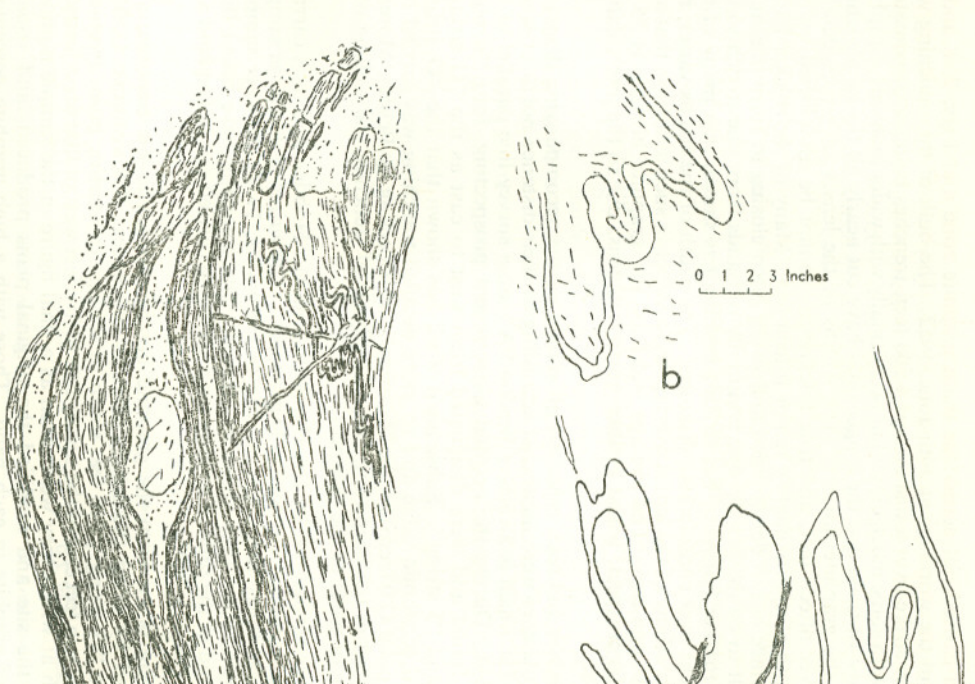


Fig. 3.—Quartzo-felspathic veining in graphite bands. The two diagrams in the right are enlargements of aplitic ptygma seen in two of the graphite lenses.

Trenching has been carried out across the main graphite zone and Figs. 7, 8 and 9 (at end), show the plan of the workings at 30th June, 1952. The bulk of the trenching was carried out normal to the strike over a distance of 4,500 feet, trenches being approximately one hundred feet apart, with some much closer but occasionally with wider intervals. Graphite bands are exposed in most of them and the longer ones have cut nearly all the bands which are considered to form the graphite horizon. The widths of the lenses vary considerably from a few inches to over fifteen feet, and true thicknesses cannot be established until a band is exposed to a depth of approximately ten or fifteen feet. Many of the thicker bands are composite at the surface but in depth pinch and swell, often closing to form one main band. It is often difficult to establish a definite continuity of bands from one trench to the next because of lack of marker horizons, but strike trenching has shown that many of the bands are in fact persistent over considerable distances. The width of the bands varies, but averages about eight feet. Many of the lenses overlap one another in such a fashion that any cross-trench cuts at least one lens. The average width of the graphite horizon is 75 ft. in the southern part of the prospect, whilst farther north it widens, due to the intercalation of quartz-felspar lenticles.

The location of trenches and rock types are all shown on the accompanying diagrams (Figs. 7, 8 and 9). The trenches were numbered according to their distance north or south of the survey starting point which is a cement beacon "A", on a survey line parallel to the strike of the marble band. During the original Government prospecting, four "strings" of graphite lenses were found and were designated from west to east as the "G string", "H string", "I string" and "J string". Subsequent work has shown that the "G string" has the greatest potential economic value and so more detailed trenching was carried out across it, Beacon "A" is point G 0 (zero) on the "G string". Prospecting by Bewick Moreing and Co. Ltd., has consisted in the deepening and multiplying of trenches, the sinking of a shaft and strike stripping of parts of the prospect.

Original sampling was carried out by Dr. Hamilton and Mr. Hobden and tests carried out on the samples in the Mines and Geological Department. The writer took a large sample from the shaft when it was thirty feet deep, but (up to December, 1952) no other samples had been tested in Nairobi other than those mentioned. The company have taken their own samples, however, and at the time of writing tests are being carried out in England and America, but results are not available.

Channel samples were taken from the graphite bodies exposed in the trenches, and sample numbers assigned by using the survey lines as references. Thus sample G501S/2E–5W was taken in the "G string", 510 feet south of the survey starting point from the seven foot band extending two feet east of the survey line to five feet west of that line. Samples from pits have the depth at which they were taken as a final figure in the sample number. The writer re-surveyed the site and modified the original plans produced, and *visually* estimated the quantity of graphite in each band. Those with a high graphite percentage (estimated greater than 5 per cent) were considered to be "good grade" and those with a lower percentage, "poor grade". The grades of graphite shown on Figs. 7, 8 and 9 do not, therefore, necessarily bear any relationship to the laboratory tests mentioned below.

The original samples were analysed to determine the percentage of extractable graphite of crucible flake size in the ore, the United States National Stockpile Specification of 1st December, 1947, for crystalline flake graphite, crucible grade, being used as a standard. This standard requires a minimum graphitic carbon content in a moisture-free sample of 85 per cent and the following screen distribution:

U.S. Standard Screen	Requirement, per cent retained on screen
8 mesh	Maximum 1
20 mesh	Minimum 8
30 mesh	Minimum 34
40 mesh	Minimum 75
50 mesh	Minimum 95
60 mesh	Minimum 97

The samples were hand dollied in a steel pestle to pass a quarter-inch mesh screen. A one pound fraction of the passed material was taken out for testing and crushed by rolling to

about 16 mesh (B.S.S.). The product was put through a disc crusher and screened on 20 mesh (Tyler)* the retained fraction being put through the disc crusher and similarly screened. By repetition of this process (usually three times) a clean graphite concentrate was eventually retained and was assumed (in spite of the necessary over-crushing) to represent the available + 20 mesh (Tyler) graphite.

The minus 20 mesh (Tyler) was then screened on 30 mesh (B.S.S.) and 60 mesh (B.S.S.) and the products retained weighed. These products were separately treated in potassium mercuric iodide solution of specific gravity 2·4. The heavy and light fractions were separated dried and weighed.

By this means, the + 20 mesh (Tyler), the — 20 mesh (Tyler), + 30 (B.S.S.), and — 30 (B.S.S.) + 60 (B.S.S.) fractions extracted from the ore were determined, representing the percentage of extractable graphite of crucible flake size in the ore. These percentages of extractable graphite were then plotted graphically, according to size distribution, against a comparative curve representing the U.S. specification. To plot analysed results, the test screen apertures were considered equivalent to U.S. standard screen sizes. Fig. 5 illustrates graphically, the best, poorest and average grade of graphite tested in this manner.

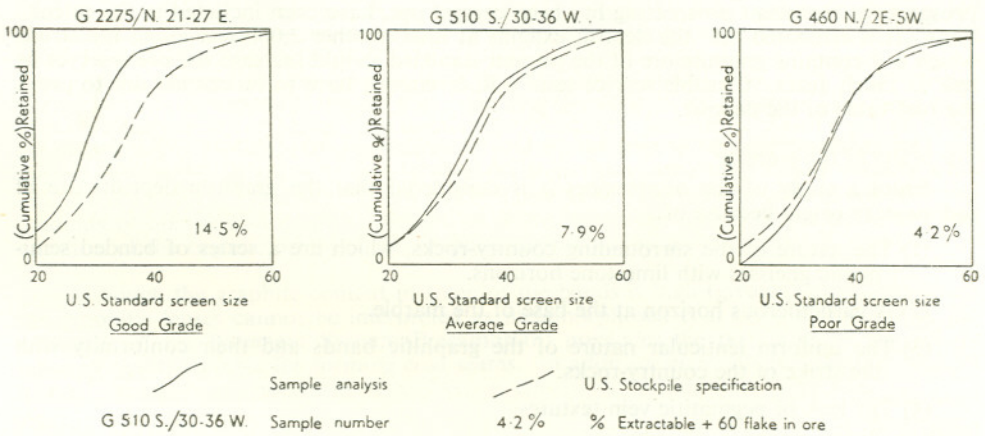


Fig. 5—Graphical result of tests carried out on three samples from the Bewick Moreing Graphite Prospect.

Altogether 27 samples were so tested and graphs drawn, from which it was seen that the best crucible-grade graphite occurs in the northern and southern sections, nearly every sample from these parts meeting the specification. In the central section, however, the grade is poor and any graphite there has been ignored in calculating ore reserves. From visual inspection the grade of graphite does not appear to decrease with depth and a test on the sample from a depth of 30 feet in the shaft confirmed this view, the graphite being much better than the specification.

In estimating ore reserves calculations were made separately for the northern and southern sections. The lengths of the sections were taken to be the distance in which the maximum number of lenses occurred. The average width of graphitic rock was then computed by dividing the total width of graphitic rock seen in all trenches by the number of trenches. Reserves were calculated to a depth of 10 feet at first as this was the average depth of the bands as seen in the trenches. These figures gave the volume of graphite ore which, when divided by the factor 15 to convert to weight in short tons, is the total tonnage of ore down to that depth. From the laboratory tests, an average crucible-grade graphite per-

*As U.S. Standard Screens were not available, it was necessary to use both Tyler and British Standard Screens to duplicate as nearly as possible the sizes required by the U.S. specification.

centage was known for particular bands and from these an average percentage of graphite was computed for the north and south sections. The results were as follows:

	Proven Ore down to 10 feet depth	Estimated Ore down to 50 feet depth
Northern Section ..	13,500 tons at 10% grade	67,500 tons
Southern Section ..	8,000 tons at 12% grade	40,000 tons

The total crucible-grade graphite available down to ten feet depth in the graphite ore is, therefore, about 2,300 tons. Assuming the ore persists to a depth of fifty feet at these grades, for which there is some reason—the shaft sunk reached a depth of about 120 feet in the centre of the main lenses—the estimated reserves of crucible grade graphite will be approximately 11,500 tons, which at a market price of £50 per ton would realise £575,000.

To give a more reliable and accurate estimation of ore reserves more closely spaced shafts and trenches are recommended. Although the extra trenching is desirable, especially to the north, shaft sinking is preferable as mining of ore on this prospect would be in depth rather than by open-cast working. Ore reserves also exist in the remaining graphite lenses to the east, but as suitable trenching across them has not been carried out, neither the "J string" lenses shown on the figures nor lenses found in new trenches north and south of the main prospect, where recent prospecting has been carried out, have been included in the calculations. It is estimated that the deposit extends at least another 2,000 feet along the strike, which if it contains graphite ore of the present standard should increase the ore reserves by half as much again. Crucible service tests will, of course, have to be carried out to prove the real value of the deposit.

The origin of the graphite

From a study of the occurrences it is considered that the graphite deposits are of sedimentary origin because of:

(1) The nature of the surrounding country-rocks, which are a series of banded semi-pelitic gneisses with limestone horizons.

(2) A garnetiferous horizon at the base of the marble.

(3) The uniform lenticular nature of the graphitic bands and their conformity with the strike of the country-rocks.

(4) The lack of pegmatitic vein textures.

The marbles in the South Kitui area all contain disseminated, crystalline graphite, however, and it must be borne in mind that the graphite could have formed by the reduction of calcium carbonate. This concept of inorganic origin, in the case of the larger graphite deposits, would necessitate the movement of the formerly distributed carbon into concentrations (cf. Bateman, p. 247). Although the area as a whole has been highly altered by granitizing fluids accompanied by pegmatitic injection, no major intrusive bodies similar to those seen farther north were recognised near the prospect. The small pegmatite veins that are present do not appear to be of the type or on the necessary scale to have been accompanied by great hydrothermal activity, and nowhere in the southern part of the area was graphite seen unless in, or associated with, a marble band. Had the carbon been introduced with pegmatite material or by hydrothermal acitivity it is likely that occurrences other than those associated with limestones would have been found. The lenses do not display the mineral suites of metasomatic deposits, whilst efforts to find stringers connecting the individual lenses have been unsuccessful. This fact, plus the lack of large-scale shears (except in the plane of the dip) tend to confirm the writer's view that the lenses essentially represent lenticular deposition with subsequent shaping by movement, rather than by the break up of more continuous bodies into lenses. Differential movement during folding would cause upper beds to move towards the tops of structures. This movement would be parallel to the direction of dip and would produce maximum distortion in that direction. It can be assumed that the neighbouring rocks slipped easily past the graphitic beds, thus accentuating their initial lenticular form. Shearing of the bands is seen in thin sections and the marble-granitoid gneiss contact is also highly sheared within a few feet of the contact.

Winchell (1911), in describing graphite occurrences in Montana, critically discusses the chemical conditions surrounding the origin of the graphite, making reference to various types of deposits. One of these deposits is granite pegmatite and a second occurs filling veins or fault fissures, not parallel to, nor having any relation to the bedding, and also as irregular bunches, pockets and stringers. None of these features were observed in the present deposit which conforms to deposits described by Bastin (1910), who attributed a sedimentary origin to them. A number of micrometric analyses were carried out on the graphitic rocks of the Bewick Moreing prospect the results of which are shown below:

	53/928	G1065S 11-17W	G510S 30-36W	G430S	J	H43	G2275N 21-27E	G415S	G760S 5-17E	G965S 3-6E	G510S 8-11E	G810S 7-11W
	%	%	%	%	%	%	%	%	%	%	%	%
Quartz and felspar ..	75·5	88·0	84·0	78·6	76·5	77·9	76·2	64·8	55·5	49·6	52·6	47·2
Graphite ..	2·3	8·4	13·3	15·4	16·9	17·5	22·3	22·4	41·8	41·9	42·9	49·3
Apatite ..	5·5	3·4	2·8	0·8	6·6	4·6	1·5	4·9	2·5	5·5	4·5	3·5
Pyroxene ..	14·2	—	—	4·4	—	—	—	2·7	—	—	—	—
Biotite ..	2·5	—	—	0·9	—	—	—	—	—	—	—	—
Other minerals (incl. calcite)	—	0·2	—	—	—	—	—	5·1	1·5	3·0		—
	100·0	100·0	100·1	100·1	100·0	100·0	100·0	99·9	101·3	100·0	100·0	100·0

These rocks contain an abnormally high apatite content and it has been suggested by Hamilton in a departmental report that "the graphite zone is the metamorphic equivalent of sedimentary facies of higher than usual organic content. Sedimentary and environmental conditions led to lens-like accumulations of organic remains within the limestone and the immediate associated rocks". It was thought that the apatite might have formed from organisms having a chitinous (?) covering. There is in fact no relationship between the amounts of apatite and graphite present, as is shown by the figures in the table, and the question of the organic origin of the graphite cannot yet be settled.

Although the graphite content in some of the bands is high (greater than 20 per cent) the graphitic lenses cannot be interpreted as metamorphosed coal beds, as the age of the sediments of the Basement System (Precambrian) precludes the possibility of the occurrence of plants suitable for forming coal seams. In addition many of the graphite deposits formed through metamorphism of coal seams consist of "amorphous" graphite.

Winchell (1911, p. 229) has shown that the development of graphite can result from "the oxidation of the carbon of bituminous shales by water (aqueous gas) at high temperatures", being precipitated when the solutions cool. In the presence of sufficient water the carbon in bituminous and carbonaceous shales will be oxidised if the temperature is greater than 600° C., but on cooling below 600° C. under pressure graphite may be expected to crystallise out. The following reversible reaction will hold good in these two cases (cf., Winchell, 1911):

$$C + 2H_2O \rightleftharpoons CO_2 + 2H_2$$
$$C + H_2O \rightleftharpoons CO + H_2$$

It is possible that the present deposits represent carbonaceous sandstone or shale lenticles near the base of an original locally impure limestone, all of which on metamorphism were transformed to their present state. Winchell (*op. cit.*, p. 228) shows that graphite can form at all temperatures between 1,000° C. and 450° C., but that more than half of the graphite studied formed between 750° C. and 600° C. Increased pressures would modify equilibrium during the first reaction, and probably raise the temperature required for the formation of a given amount of carbon dioxide and graphite. In all the slides examined no wollastonite was found and the absence of this mineral, together with the presence of the mineral assemblage calcite-forsterite-diopside, is indicative that the temperature of formation of the graphite did not exceed that at which wollastonite would appear (cf., Turner, 1948, pp. 64–65). The reaction of calcite, forsterite and diopside to form monticellite can take place at a temperature of approximately 560° C. but the presence of abundant silica would preclude the formation of that mineral, whilst wollastonite would normally form between 500° C.

and 700° C. depending upon pressure. Although temperatures below about 650° C. have prevailed the formation of graphite from hydrocarbons produced during metamorphism is unlikely as has been shown by Winchell (*loc. cit.*, 1911, p. 223).

The original limestones may have contained magnesia-rich portions in the form of dolomite or magnesium limestones, which could have been reduced at temperatures below 600° C. at normal pressures, giving off abundant carbon dioxide. Assuming that the rise in temperature was brought about by thermal metamorphism due to the proximity of a magma containing abundant free hydrogen then the reactions cited above would lead to the production of graphite, providing a temperature of more than 600° C. was reached. The amount of hydrogen in magmas is, however, too small to produce any great quantity of graphite and it appears unlikely that a mode of origin for graphite by the reduction of magnesia-rich limestones can be substantiated.

(b) Shah Vershi Devshi Prospect

Messrs. Shah Vershi Devshi pegged ten graphite claims in 1951, along the same marble band as that prospected in the early 1940's. but three quarters of a mile north of the Kanziku road. Like the Bewick Moreing property the prospect is in low-lying, heavily bushed country with no water-supplies. A bore-hole that was sunk to over 500 feet did strike water, but not in sufficient quantities for milling purposes. In addition the provision of timber and labour are difficult, as in the case of the Bewick Moreing prospect.

The graphite schist is contained in a westerly dipping marble band which is considered to be the same horizon as that in the Bewick Moreing Prospect. The band is contained in the same semi-pelitic series, which here forms the westerly limb of a southerly pitching anticline, the axis of which passes between the two prospects. Dips are variable, ranging from 38° to vertical. A number of cross-faults, mainly located near the camp site, have disturbed the beds and at least one large strike fault was observed but, through lack of suitable exposures, the full extent of its displacement could not be mapped (*see* Fig. 10, at end). West of this fault, a number of easterly dips were recorded and are indications of the eastern limb of another anticline, the fault occurring along the axis of a minor synclinal flexure. Near the northern boundary of the prospect deep trenching and pitting has shown that the rocks there are highly folded and the nose of a small overturned, faulted, north-westerly pitching anticline with steep limbs is exposed in the pit in trench "H". In the centre of this trench the beds are sharply folded as is indicated on the plan (Fig. 10), although bad exposures and the few pits do not permit of a true interpretation of the structure here. The beds in this central block are mostly alternating quartz-felspar gneisses and graphitic gneisses, and small sharp folds with amplitudes of one or two feet were observed. Here again the graphite has acted as a lubricant and aided the movement of one bed against another. Movement along fault-planes is shown by the smearing of the graphite to nearly "amorphous" masses such as are not seen in other places, where flake graphite is characteristic. Lenses of calc-silicate rocks, granitoid gneisses and hornblende-biotite gneisses are exposed in all trenches and where exposed on the surface enable the structures to be more readily interpreted.

Trenching was carried out across the marble band at approximately two hundred feet intervals over a distance of 2,000 feet, the longest trench measuring over 550 feet in length. A single strike trench and numerous pits have revealed the presence of at least one large graphite lens but, otherwise, the graphite bands are so thin and the trenches so far apart that it is impossible to establish with certainty the continuity of bands from one trench to another. Unfortunately at the time of the survey trenches had not been deepened beyond an average of five feet, which has been found to be unreliable for the estimation of ore reserves.

In September and October, 1951, geophysical surveys of the prospect were carried out by Geophysical Surveys (Pty) Ltd., and resistivity and self-potential values recorded. For the resistivity survey, depth-probing down to fifty feet was employed, and the constant separation traverses were observed with the electrodes at right-angles to the strike of the formation. The results of this survey are contained in an iso-resistivity contour plan with a contour interval of 10,000 ohm/cms. but, within the important low resistivity areas, the contour lines for 5,000 ohm/cms. have been inserted (*see* Fig. 11, at end). The main feature of the iso-resistivity plan is a well-developed zone of low resistivity values which commences in the north, having its maximum extent near the camp and splitting into two

portions at the southerly end of the area shown on the plan. These low resistivity zones include the greater part of the graphite occurrences as seen in the trenches. Eastwards the survey indicated no low resistivity anomalies.

Observations on the variation of the natural earth potential were also made at 50 feet intervals along the traverse lines and the results presented as an equi-potential plan (Fig. 12, at end). These results not only confirm the general trend of the resistivity survey but are, in addition, more specific. The major self-potential anomalies which exist in the northern and central portions of the area represented on the plan are, in general, the area where graphite has already been exposed.

The self-potential survey, being more specific, was taken as the basis for the interpretation of the results by the geophysical company while the resistivity survey was used as confirmatory evidence whenever possible. There is no doubt that a certain proportion of the anomalies in the natural earth potential can be attributed to changes of rock type and to geological structure. On the other hand the presence of graphite ore is probably responsible for the greater part of the observed anomalies and is confirmed by the resistivity survey. These anomalies are distributed over a wide area as are the bands, which if they continue in depth, would give some difficulty in mining on account of their small width.

Until more trenching and deepening of all trenches is completed it is impossible to take suitable samples or make any estimation of ore-reserves in this deposit. The main band appears to be of good grade, whilst others in trench H are thin bands in quartz-felspar gneisses which will present mining problems on account of the tightly folded nature of the rocks. Local tests, by the company concerned, on samples taken from exposed bands have shown that suitable flake-graphite can be extracted by a dry process, but a normal wet flotation is in fact being used.

The company began production in 1952 and the output has been as follows according to records in the Mines and Geological Department*.

Date	Production	Size analysis of production (in bags of 224 lb.)			Percentage recovery	Tons ore treated
		−4+24	−25+44	−44+100		
	lb.					
1952	69,440	75	75	160	7·75	400
1953:						
January ..	17,589	20	20	38	7·347	106
February ..	27,444	30	30	63	6·287	191
March	23,228	21	21	42*	6·36	163
April	12,371	3	13	24†	7	78¾
May	28,519	4	20	15‡	6·90	184
June	27,412	7	20	24§	6·08	201

*20 bags of −100 material in addition.
†3 bags of −100 material in addition.
‡28 bags of −100 material in addition and 60 bags of −44 material.
§20 bags of −100 material in addition and 54 bags of −44 material.

(c) *Other occurrences of graphite*

Graphitic gneisses near the Ikanga–Voo road and west of Matulani occur in relatively thin bands rich in biotite, whilst graphite is also present as disseminated flakes or small graphitic lenses up to a few inches in length, in nearly every marble band. In all cases except those described in the proceeding sections the graphite content is low and has no economic value.

(2) *Vermiculite*

Deposits of vermiculite associated with the Kapoponi and Kenze basic intrusives were known to exist in 1940 when the late Sir Charles Markham, as agent for the Kenya Magnesite Company, pegged claims at Kapoponi, Kenze (3½ miles north of Kapoponi) and Magongo

*The production reported for the months July–December, 1953, was approximately 66½ tons of graphite, valued at a little over £3,000, and derived from the treatment of 946 tons of graphitic rock. There was no production in 1954. In 1955, 172 tons valued at nearly £7,000 were produced and, in 1956, 462 tons with an estimated value of more than £18,000.

(1 mile north of Kapoponi). The claims were abandoned in 1940 and the area re-pegged by E. R. Wright in 1942, who transferred his claims to Raw Materials Development Ltd., the claims again being abandoned in 1944. C. S. Hitchen of the Mines and Geological Department visited the mine in 1940 and 1942 and reported on the occurrences. Later, in 1945, C. R. Stokes-Fair re-pegged the claims but there is no record that he mined vermiculite and the claims expired in 1947.

The vermiculite occurs as numerous small lenses between pegmatites which have invaded the dunite pipes of Kapoponi and Kenze. The extent of the deposits is not known and no further pitting was carried out during the present field-period. An examination of the abandoned pits indicates, however, that the deposits are limited. Varley (1952) in a monograph on vermiculite has recently described a number of occurrences of this mineral in Kenya, reference being made to Kapoponi. Requests have been made for Kapoponi vermiculite from X-ray workers in soil science and clay mineralogists, who have found that this particular vermiculite is one of the purest known. The vermiculite, which has a hardness of approximately 1·5, occurs in uncemented aggregates and weighs in bulk between 65 and 70 lb. per cubic foot. Tests on two specimens indicate that their true specific gravities are 2·18 and 2·21. Expansion tests on sized, but unwinnowed, material gave a silvery-buff product weighing approximately 13 lb. per cubic foot, a figure which could be improved under better conditions of exfoliation. An analysis made by the Imperial Institute in London of a sample of the Kapoponi material, which is believed to be a true vermiculite allied to jefferisite, is shown below and compared with jeffersite from the U.S.A. and with an average of the analyses of seven vermiculites from the U.S.A.

	1	2	3
	%	%	%
SiO_2	35·66	37·10	35·04
Al_2O_3	12·48	17·57	14·55
Fe_2O_3	7·47	10·45	5·13
FeO	0·48	1·26	0·59
MgO	21·51	19·65	21·71
CaO	not detected	0·56	0·46
Na_2O	1·24	—	—
K_2O	0·42	0·43	—
H_2O-	9·15	—	19·99
H_2O+	9·49	13·76	
TiO_2	1·80	—	—
P_2O_5	0·28	—	—
MnO	0·01	—	—
NiO	—	—	2·44
Total ..	99·99	100·78	99·91

1. Vermiculite, Kapoponi, Kenya. Analyst, H. J. Broughton, A.R.I.C.
2. Jefferisite, Pennsylvania. G. J. Brush, *Amer. Journ. Sc.*, 1861, 31, p. 369.
3. Average analysis of seven vermiculites from U.S.A. E. R. Varley, 1952, p. 5 (after Gruner).

(3) *Asbestos*

The Kapoponi, Magongo and Kenze basic intrusives were all prospected for asbestos by various people between 1937 and 1944. E.V. Kinloch was first interested in the possibilities of mining talc and asbestos and in 1937 received permission to remove two tons of material for testing. Kenya Magnesite Ltd., Raw Materials Development Ltd., E. R. Wright and C. R. Stokes-Fair all pegged claims in the area (*see* above) but little of value was found. In the half-year ending 1944, asbestos to the value of £51 was extracted by Raw Materials Development Ltd., other records of production during the period 1940–1944 are incomplete but include three tons or ore mined by C. R. Stokes-Fair in 1945.

The asbestos is a compact anthophyllite associated with garnet and glassy crystals of tremolite. Although occasional fibres are long the majority are short and matted, the tensile strength being rather poor according to the Government Metallurgist who visually examined some hand-specimens of the ore. Reserves are unknown but, like these of the vermiculite, appear to be limited.

(4) *Talc*

Talc is also associated with the Kapoponi mineral occurrences and was prospected concurrently with them. The deposits are poor.

(5) *Magnesite*

Another mineral associated with the asbestos, talc and vermiculite, is magnesite and all claim-holders have been aware of its occurrence and the possibility of extracting it at the same time as the remaining minerals. C. S. Hitchen examined the area in 1940, sampled the magnesite, and prepared a departmental report. During the present survey, exposed carbonate veins were found to be of poor quality and composed mainly of calcium, not magnesium carbonate. The description of the deposit given below is, therefore, based on Hitchen's work. The magnesite occurs in veins up to four feet in width, forming a reticulate pattern in the dunite. In most trenches on Kapoponi the magnesite although white, was soft and friable, a circumstance no doubt attributable to weathering processes. In parts, especially to the north of the main knoll, the magnesite has been intensely silicified, and in some cases completely replaced by opaline silica. Rough calculations by Hitchen indicated that, neglecting possible inclusions of pyroxene granulite, the quantity of dunite plus magnesite in the hill from its summit to its base amounts to about 4,000,000 long tons. If only 1 per cent of this proved to be extractable magnesite of good quality, some 40,000 tons would be available.

A number of samples were taken from various trenches and analysed for insoluble residues (and in some cases for SiO_2 also) and for calcium content. Details of the results are shown below and the sampling localities are marked on Fig. 6.

Laboratory Number	Description	Insoluble	SiO_2 (Insolubles)	CaO	Equivalent $CaCO_3$	Presumed $MgCO_3$
		%	%	%	%	%
15275	2 ft. 6 in. below surface ..	5·96	5·38	0·66	1·18	92·86
15276	6 ft. 9 in. below surface ..	10·21	10·07	0·87	1·55	88·24
15277	Small veinlets approx. 6 ft. below surface	2·40	—	0·63	1·13	96·47
15278	Fragments visible in trench	3·29	—	1·56	2·79	93·92
15279	Good vein 1 ft. 6 in. in width	0·56	—	0·56	1·00	98·44
15280	Good vein 10 in. in width ..	0·71	—	0·59	1·05	98·24
15281	Good vein in trench sampled over 12–15 ft.	0·26	—	1·28	2·29	97·45
15282	Small veins under soil cover..	0·75	—	1·72	3·07	96·18
15283	Veins 1½ in.–2 in. at 5 ft. below surface	7·44	—	0·59	1·05	92·51
15289	Composite sample of 1–8 above	3·10	2·64	1·05	1·88	95·02
15267	From Trench Y	2·69	—	1·11	1·98	95·33
15262	From Trench Z	9·03	—	0·77	1·38	89·59
15260	Pit at Survey point H ..	11·74	—	1·26	2·25	96·01
15259	Pit on N.E. knoll	24·67	—	6·10	10·89	64·44

Dashes indicate no determination was made.

From these tests it appears that with the exception of a limited area in the north, the Kapoponi magnesite is generally of good quality and that by selective mining a quantity of material of the required standard could be obtained. Although the northern part of the deposit shows high silicification the western half of the hill is of exceptional purity and a good deal of fairly pure material could also be obtained from the south and south-east, where magnesite is particularly abundant.

As in other deposits the bulk of the silica occurs in the form of veinlets and coatings of crystalline and chalcedonic silica. Surface decomposition, which has softened both the dunite and the magnesite, has also reduced this silica to a white friable condition so that it cannot be easiiy distinguished from the magnesite.

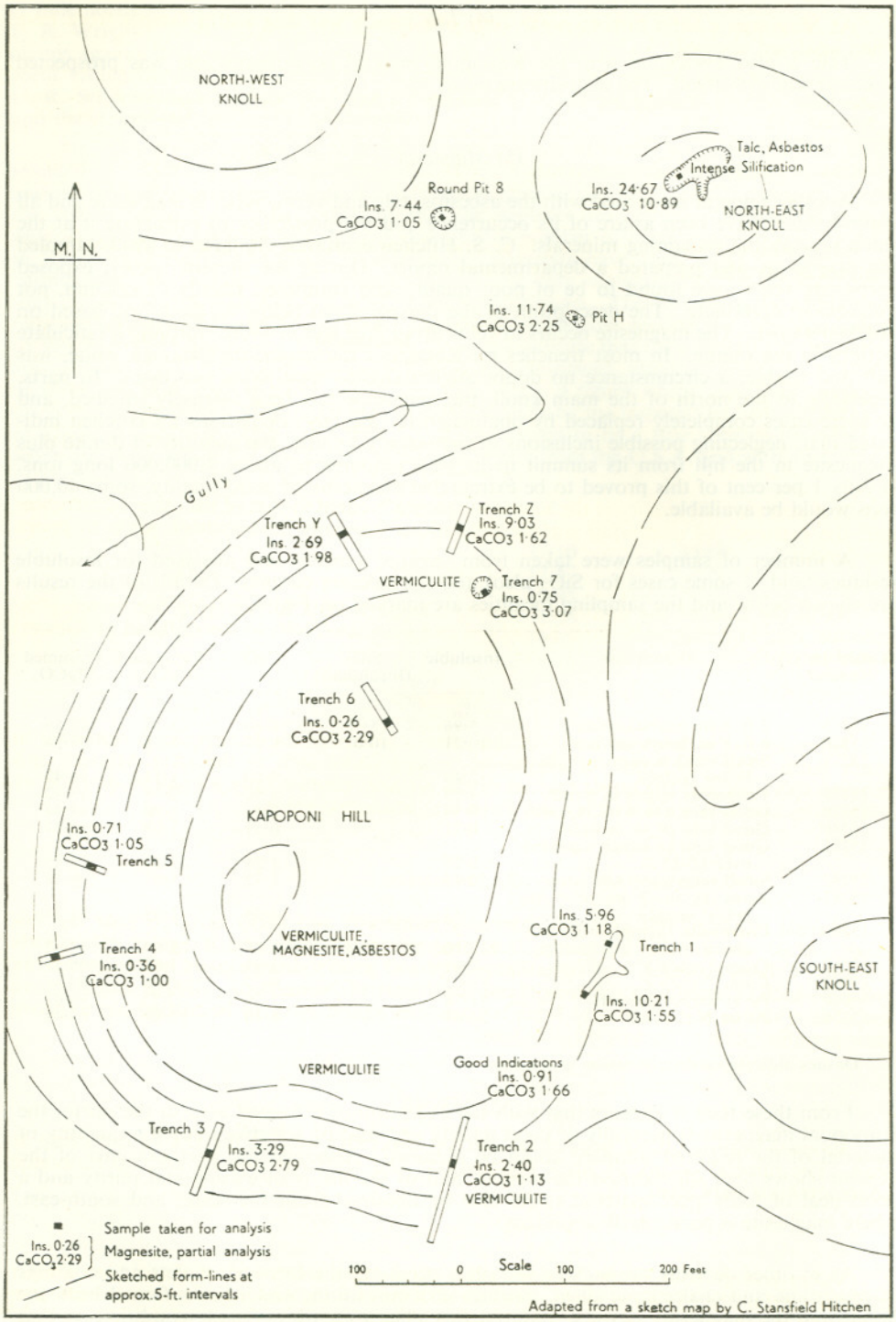


Fig. 6—Sketch map of the Kapoponi magnesite deposit showing the location of samples taken for analysis.

At Magongo a little further north only one trench was dug and a sample from here when analysed showed:

Laboratory Number	Description	Insoluble	SiO_2 (Insolubles)	CaO	Equivalent $CaCO_3$	Presumed $MgCO_3$
		%	%	%	%	%
15284	Magongo trench grab sample	2·54	—	2·55	4·55	92·91

Magnesite was seen outcropping in several places on Kenze, 3½ miles to the north, and analyses of samples taken there are as follows:

Laboratory Number	Description	Insoluble	SiO_2 Insolubles))	CaO	Equivalent $CaCO_3$	Presumed $MgCO_3$
		%	%	%	%	%
15285	Surface, northern slope ..	1·17	—	2·41	4·30	94·53
15286	Surface, northern slope ..	2·00	—	0·73	1·30	96·70
15287	Surface, eastern slope ..	4·38	0·51	2·35	4·19	91·43
15288	Surface, near summit ..	0·97	—	3·68	6·57	92·46

It is seen that the quality of the Kenze magnesite is equal to that of the other occurrences and the existence of promising surface indications warrants development work to prove the deposit.

As in the case of the graphite deposits, transport costs for carrying the vermiculite, asbestos, talc, and magnesite from Kapoponi and associated hills to the railhead at Kibwezi would be costly.

(6) *Sillimanite*

Sillimanite is widespread north of the present area, but its occurrence is restricted in south Kitui. The few bands of sillimanite-bearing rocks seen in the river Marieti, and between this river and the upper reaches of the Kataka, contain only a small proportion of sillimanite, and it is unlikely they will have any economic value.

(7) *Limestones*

Marble bands in this area are extremely numerous and many outcrop near the few roads. Most are impure, containing scattered graphite flakes and irregular calc-silicate lenticles. Others, however, look remarkably pure and good tonnages could be expected from outcrops such as those seen north-west and south-east of Ndulukuni. These might prove useful as a source of agricultural lime, but analyses would have to be carried out to prove their possible value in cement manufacture.

(8) *Ilmenite*

Ilmenite-bearing quartz pegmatites outcrop two miles west of the D.C.'s rest camp at Voo. The mineral occurs as small segregations and scattered crystals and no economic concentrations were seen.

(9) *Brick-earths*

Valley-bottom soils in the Mewee valley, three miles south-east of Kisasi, are similar to those used in the Mulango location (south of Kitui) for the making of bricks, which have been used in the building of the A.I.M. mission. The high mica content of the Mewee soils would, however, probably cause rapid expansion and cracking of the bricks during firing.

2. Water-supplies

During the wetter months the rivers carry running water and so provide ample water supplies for the native population and their cattle. In the middle of the dry season, however, no running water is available and water-holes must be sunk in the sand of the main rivers such as the Tiva, Nzeo, Ngunga and Thowa. Water was seen at the surface, however, in the river Ngunga, north of the Ikanga–Voo road during July, a pond of water being dammed by a granitoid gneiss band.

The district administrative officers are now helping the local population to construct earth dams across minor streams or near springs, which frequently occur at the base of the migmatite ridges. These dams conserve water from a small area but provide sufficient supplies for the neighbouring natives and their livestock. During recent years, however, rainfall has been inadequate and the water-table is dropping rapidly so that frequently such earth dams contain no water, the women of the tribe having to walk many miles, daily, to the water-holes in the larger rivers to fill their few water pots.

Water bore-holes have been constructed by the Public Works Department at Mutomo, Kanziku and Mutha and these form an excellent source of supply during the dry periods, unfortunately the Mutomo water is extremely brackish, whilst at Mutha the water is only a little less saline. The presence of the bore-holes has caused a migration of people to these centres with the result that there has been a severe drop in the level of the water-table, so that water has now to be rationed in the drier periods.

The larger rivers, if dammed with concrete dams could provide excellent water-supplies for this area and in addition, provide means of irrigation. The Tiva river particularly lends itself to such a project but any scheme would be expensive and would have to form part of a long-term policy. Another good dam site is at the point where water was seen in the river Ngunga, where the construction of a concrete weir would increase water-supplies considerably. The dams would obviously hold up a large quantities of sand but these in turn would act as a reservoir, if suitable means were provided for draw-off.

The need for water-supplies in such areas as this is becoming more critical as each year passes. Construction of dams would certainly help, especially as lack of water will start migrations of the Wakamba and so aggravate conditions elsewhere and cause trouble within the tribe when there is insufficient land for adequate grazing where water is available. A Government scheme is in hand to provide bore-holes in the country east of Mutha so that the the land there can be used for cattle grazing. This would off-set any migration from this already sparsely populated area and would also attract Africans from neighbouring locations to settle here. Encouragement is also being given to the Africans to grow crops that will help to retain the already thin soil cover. Over-grazing on such ground would otherwise lead to soil erosion and rapid run-off of valuable rain water.

Water bore-hole details supplied by the Public Works Department are:

Locality	P.W.D. No.	Depth in feet	Water struck (feet)	Water rose to (feet)	Yield per 24 hours (gallons)
Mutomo No. 1 1946	C 452	289	Abandoned		—
Mutomo No. 2 ..	C 464	272	137 and 165–175	114	26,400 (now saline)
Kanziku	C 496	431	87 and 289	38	5,040
Mutha	C 538	500	326 and 470	213	7,608 (now saline)

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